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FOREWORD

The *42nd International ICT Convention MIPRO 2019* was held from 20th to 24th of May 2019 in Opatija, Croatia. The Convention consisted of twelve conferences under the titles: *Microelectronics, Electronics and Electronic Technology (MEET), Distributed Computing in Data Science and Biomedical Engineering (DC), Telecommunications & Information (CTI), Computers in Education (CE), Computers in Technical Systems (CTS), Intelligent Systems (CIS), Information Systems Security (ISS), Business Intelligence Systems (miproBIS), Digital Economy and Digital Society (DE/DS), Engineering Education (EE), Software and Systems Engineering (SSE)* and *Composability, Comprehensibility and Correctness of Working Software (4COWS)*. An additional conference was dedicated to the works of students: *MIPRO Junior-Student Papers (SP)*.

This comprehensive Book of Proceedings includes all positively reviewed and presented papers from each of these conferences. All the papers were reviewed by an international review board and the list of reviewers is contained in the Book of Proceedings. These papers were written by the authors from scientific institutions, educational institutions, industry and state and local administration.

The convention was organized by the Croatian ICT Society MIPRO with the help of numerous patrons and sponsors to whom we owe our sincere thanks. We especially single out our golden sponsors HEP-Croatian Electricity Company, Ericsson Nikola Tesla, Končar-Electrical Industries and T-Croatian Telecom along with our silver sponsor InfoDom. Our bronze sponsor is Storm Computers.

To all who helped organizing the 42nd International ICT Convention *MIPRO 2019* as well as editing of this Book of Proceedings we extend our heartfelt thanks.

Prof. Karolj Skala, PhD
International Program Committee
General Chair

M E E T

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PAPERS

Fabrication of GePb-Alloys by Means of Pulsed Laser Induced Epitaxy

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***Abstract* – Theoretical simulations predict that direct band transitions are favored in Germanium-Lead (GePb) alloys with Pb concentrations of $c_{Pb} \approx 3.4\%$. This could enable the creation of semiconductor lasers that are directly structured on Ge substrates. However, the formation of alloys with these properties is hindered by the low equilibrium solubility of Pb in Ge. Therefore, the usage of out-of-equilibrium growth methods, such as pulsed laser induced epitaxy (PLIE), is necessary. The contribution focusses on the formation of GePb alloys with varying Pb concentrations.**

To cover a wide range of Pb concentrations, pulsed laser deposition (PLD) was utilized to deposit thin and smooth Pb films of varying thicknesses on Ge samples. After deposition, PLIE was used for alloying. For both processes, an Argon-fluoride (ArF) excimer laser emitting radiation at a wavelength of $\lambda = 193$ nm was used. The quality of the resulting alloys is evaluated by using Raman spectroscopy and the impact of different process parameters of PLIE is discussed.

Keywords – pulsed laser deposition; pulsed laser induced epitaxy; GePb; PLD; PLIE

I. INTRODUCTION

Because unconditional recombination of excited charge carriers is a requirement for stimulated emission, direct band gap semiconductors are necessary for the fabrication of semiconductor lasers. As both Si and Ge are indirect band gap semiconductors, recombination in these materials is unlikely. However, numerous applications could emerge from a laser source directly integrated on Si, e.g. optical interconnects for highly integrated logic circuits [1] or optoelectronic circuits with integrated logics and error correction [2].

Group III-V compound semiconductors typically feature direct band transitions and are commonly used for the fabrication of semiconductor lasers. However, their integration into the Si platform is hindered by numerous problems, like lattice mismatch, diverging expansion coefficients, highly stressed films, and more [3]. Alternatively, simulations indicate that by introducing substitutional Pb into the Ge crystal, a direct band gap semiconductor can be obtained. In case of relaxed GePb, the transition is predicted to occur at a Pb concentration of $c_{Pb} \approx 3.4\%$ [4].

In this work, GePb alloys have been created in two processing steps: First, a thin layer of Pb was deposited on a Ge wafer by means of pulsed laser deposition (PLD). PLD utilizes pulsed laser radiation to excite the surface of a target to a plasma state. The expanding plasma plume reaches the opposing sample surface and covers the sample with a thin layer of the target material. In contrast to thermal evaporation used in a previous work [5], PLD is a sputtering process, which facilitates the growth of very thin and uniform layers. Therefore, very smooth surfaces can be obtained [6]. Furthermore, in contrast to the continuous growth of thermal evaporation, growth in the PLD process occurs pulse by pulse, which enhances the controllability of the resulting Pb layer thickness.

After the Pb layer deposition, pulsed laser induced epitaxy (PLIE) was utilized for alloying. The main issue for GePb formation is the low equilibrium solubility of Pb in Ge [7]. Therefore, out of equilibrium growth methods, such as PLIE, are necessary and particularly PLIE has recently been applied for the creation of GePb alloys [5]. During the PLIE process, the sample surface gets molten through laser radiation. Because of the higher diffusivity in the molten state, the Pb layer intermixes with the Ge substrate underneath and almost immediately after the laser exposure, the liquid resolidifies from bottom to top, using the substrate as a heat sink and recrystallization seed (see Fig. 1). As both the deposition and the epitaxy process rely on an ArF excimer laser beam as primary energy source, this work flow opens up the possibility of an all 193 nm laser-assisted process with PLD and PLIE within one single HV-UHV chamber, thus avoiding Pb oxidation.

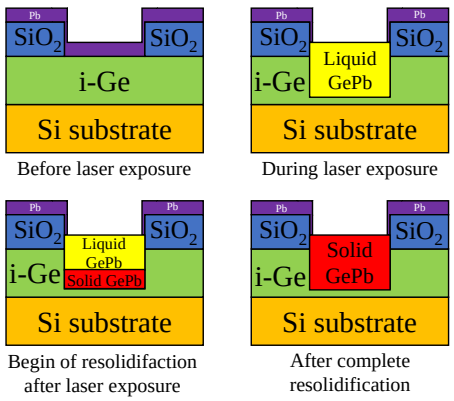

Figure 1. Schematic of the working principle of PLIE.

II. SETUP

To optimize the PLD process, 200 mm Si (100) wafers have been used. The cleaning procedure involved immersing the samples in piranha solution (30% H_2SO_4:H_2O_2 in proportion 3:1) for 10 minutes, rinsing with deionized water and immersion in two stages of an ultrasonic bath of deionized water for 5 minutes each. The samples were then dried with a N_2 dispenser.

The Ge wafers were prepared with a 6" molecular beam epitaxy (MBE) system in which C, Si, Ge and Sn are used as matrix materials and B and Sb as p- and n-type dopants, respectively. Growth was performed on 4" p-doped Si (100) wafers with a sheet resistance of 10 Ωcm to 20 Ωcm. First, the native oxide was removed through thermal desorption at 900 °C [8]. To reduce the resulting surface roughness, a 50 nm thick Si buffer was grown at a substrate temperature of T_{sub} = 600 °C. A 100 nm thick i-Ge buffer layer was grown at T_{sub} = 330 °C and annealed for 5 minutes at T_{sub} = 850 °C to reduce the dislocation density [9]. A 900 nm-thick Ge layer was then grown at T_{sub} = 330 °C. The Ge-layer is much thicker than in the previous work, aiming to provide a larger Ge-matrix to solve the Pb in, thus reducing the total Pb concentration. Additionally, through the thicker Ge layer, the laser heated volume is confined to the Ge layer solely, as in the previous work, the heat gradient was deep enough to partially melt the Si substrate and create SiGe [5]. After the Ge deposition, the sample was cleaned by immersion in acetone for 8 minutes and isopropanol for 3 minutes. For half of the samples processed, a 150 nm-thick SiO_2 hard mask was deposited using an Oxford plasma-enhanced chemical vapor deposition (PECVD) system. Deposition rate and temperature were chosen as 50 nm/ min and 250 °C, respectively. An Azmir 701 positive photoresist was spun on the hard mask and structured using contact photolithography. The hard mask was then structured using a Sentech SI591 reactive ion etching (RIE) system with 100 sccm CHF_3 flow and a BHF dip was used to open the windows. The completed hard mask featured rectangular and square windows with edge lengths ranging from 0.1 µm to 100 µm. The cleaning of the completed samples included a dip in isopropanol to remove residuals, a dip in deionized water to remove the native oxide and drying with N_2 flow.

For both laser processes, a Lambda Physik LP220i excimer laser was used. The gas filling consisted of ArF with a Ne buffer, resulting in a wavelength of λ = 193 nm. Lasers of this kind see widespread use in CMOS processes like UV photolithography. For the PLD process, a beam splitter and a cylindrical converging lens were placed in between the laser exit and the process chamber. The beam splitter was used to measure the laser fluence indirectly but "in situ", while the lens was placed 12 mm in front of its focal position to modify the energy density on the target, as both an attenuator and a fly-eye homogenizer caused high losses. The resulting energy density on the target can be approximated to H ≈ 700 mJcm^{-2}. The optical setup for PLIE featured the beam splitter, the attenuator to control the energy density on the sample, the fly-eye homogenizer and the process chamber, an acrylic box with a detachable lid and a 1,000 sccm Ar intake. The acrylic box featured a chuck with a vacuum suction which was mounted on a triaxial translation table to move the sample to the focal point of the homogenizer and achieve a top-hat-shaped fluency profile. This was necessary because reliable characterization of PLIE products depends on a highly homogeneous laser spot. The laser repetition rate was set to 1 pulse/s for all experiments to ensure complete cooling of the irradiated zone between two successive laser pulses.

III. METAL DEPOSITION

The creation of high-quality GePb alloys by means of PLIE requires the deposition of thin and homogeneous layers. Unfortunately, this is a challenging task for PLD, as through the high energy density, several undesired processes can happen alongside the desired laser ablation, including melting, splashing and target exfoliation [10], which will lead to particulate generation. Furthermore, the plume shape and direction may change during processing due to target surface modification [11][12].

The PLD experiments were conducted inside a laser induced chemical vapor deposition (LCVD) chamber. The target holder could be shifted horizontally and tilted towards the incident laser. The sample holder was attached to the chamber lid. When tilting the target holder by 45°, target and sample were directly facing each other. The distance between target and sample was set to d_{TS} ≈ 8.7 cm, as while testing d_{TS} from 5.6 cm to 8.7 cm, this distance showed the largest uniform area of PLD deposited Pb. One- to two hundred laser pulses impinged on the same spot of the target surface before it was shifted to the next position. For vertical target realignment, the chamber needed to be purged with Ar (99.995%) and opened, as no automated elements for target rotation and translation were present. This way, a target was used for several 1,000 laser pulses.

Processing of the first samples started after evacuating the chamber to a pressure of p = 5×10^{-9} kPa, first. The ablation targets used were Pb slices which were cut off from a sample of c = 99.99% pure Pb, pressed to a thin slab and then polished with fine-grain polishing tools and isopropanol-soaked clean room cloths. To determine the resulting Pb layer thickness after PLD processing, dots of silver solution were placed on the wafers prior to the dep-

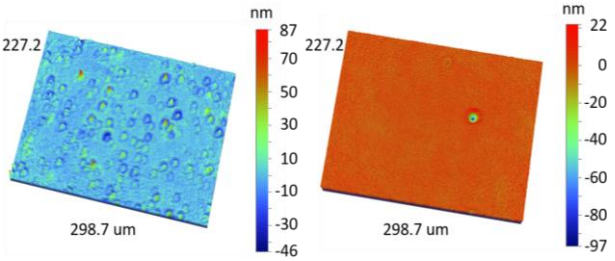

Figure 2. Phase-shifting interferometry measurement of a sample processed at HV (left) and at 1.33 kPa (right).

TABLE I. PRESSURE VARIATION

Pressure	HV	0.053 kPa	1.33 kPa
Thickness/ nm	45.44	30.54	30.50
RMS roughness/ nm	10.23	4.80	5.43
Growth rate/ (pm/pulse)	15.15	8.04	4.62
Particle generation rate/ (pulse^{-1}×mm^{-2})	447.3×10^{-3}	99.22×10^{-3}	13.19×10^{-3}

osition step. After their removal, the resulting step height was measured using tactile profilometry. The surface texture was investigated using phase-shifting interferometry. As observable in Fig. 2, both the roughness and the particulate density of the grown layer turned out to be very high. As a first improvement measure, an Ar atmosphere was introduced to the chamber after chamber evacuation. Through the higher pressure, the mean free path of the larger, undesired particulates is expected to decrease faster than the one of the small plasma species. As the collected data in Fig. 2 and Tab. 1 shows, the particulate density is reduced when choosing higher Ar pressures, suggesting that this measure is working as intended.

Furthermore, as target surface features are known to increase particulate ejection [12][13], a target with a surface as smooth as possible is preferable. For this reason, a Si wafer was cleaned with piranha solution as described above, and a dip in a solution of 40 % HF:H_2O in proportion 1:5 was used to remove the native oxide. After rinsing with deionized water, a 2.4 µm-thick Pb layer was deposited via thermal evaporation and the wafer was used as deposition target. During PLD processing, the chamber atmosphere was set to 0.053 kPa of Ar. The phase-shifting interferometry measurements of the layers grown by PLD and the corresponding data is shown in Fig. 3 and Tab. 2, respectively. With the Pb-coated Si wafer as target, the particulate count and surface roughness on the sample could be reduced further, yielding the highest quality layer so far while even retaining a favorable layer growth rate.

To investigate the reasons for this great improvement, two spot of laser exposure, one on the Pb bulk target and one on the Si wafer-based target, were compared by means of tactile profilometry. The measured data is shown in Fig. 4. The surface on the Si wafer-based target is much smoother, which probably contributes to a smaller particulate ejection. Both in the tactile profilometry measurement of the Pb bulk target in Fig. 4 and in the optical profilometry measurement of the same target in Fig. 5, pillar-like elevations can be observed, which extend above the zero level. These may form as a result of the melting and resolidification process described as hydrodynamical growth, which has been reported for pulsed laser processing of Si [14]. They cannot be observed on the Si wafer-based target, which could indicate a suppression of the molten

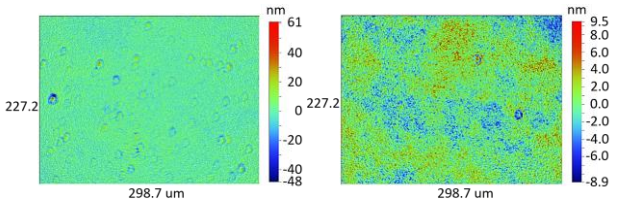

Figure 3. Phase-shifting interferometry measurements of the samples processed at 0.053 kPa with the Pb bulk target (left) and the Pb-coated Si wafer (right).

TABLE II. TARGET VARIATION

Target type	**Pb bulk**	**Pb-coated Si wafer**
Thickness/ nm	30.54	23
RMS roughness/ nm	4.8	4.75
Growth rate/ (pm/pulse)	8.04	5.39
Particle generation rate/ ($pulse^{-1}\times mm^{-2}$)	99.22×10^{-3}	12.15×10^{-3}

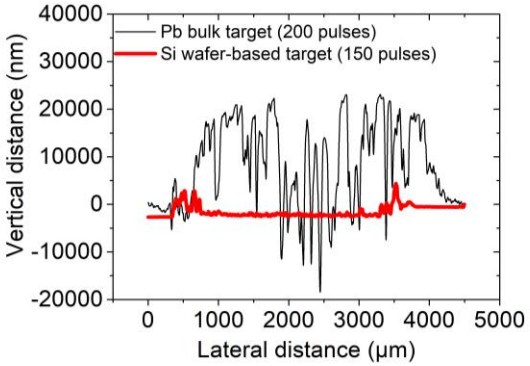

Figure 4. Comparison of the surface texture of a spot on the bulk target and on the Pb-coated Si wafer-based target.

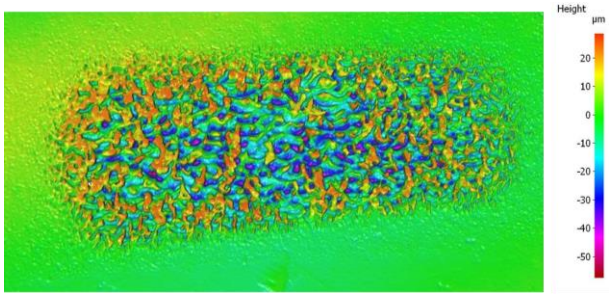

Figure 5. Optical profilometry measurement of the target surface.

phase, possibly through the higher thermal conductance of Si, $\kappa_{Si} = 124$ $Wm^{-1}K^{-1}$ compared to the one of Pb, $\kappa_{Pb} = 34.9$ $Wm^{-1}K^{-1}$ [15]. As particulate generation through splashing of a molten phase is a known issue [10], this could explain the lower particulate count. It has to be noted that the depth of the spot on the coated target roughly equals the initial Pb layer thickness before PLD processing, suggesting an ablation stop at the Pb-Si interface.

However, using wafers as the base for targets yields the possibility of wafer material being ablated. To check for undesired ablation, two wafers were prepared for the usage as deposition targets: one Si wafer and one Ge wafer. Both were coated with 1.0 µm of Pb via thermal evaporation and then used as target to deposit Pb on both a Si sample and a Ge sample simultaneously. This way, the feasibility of a Ge based target could be checked, the applicability of the process on Ge samples could be examined and undesired ablation could be reviewed: In case of Si or Ge ablation, the ablated Ge would be visible in Raman spectroscopy measurements of the Si sample and vice versa. The lower Pb layer thickness on the targets yielded even lower particulate generation rates, some as low as $0.46\times10^{-3}/mm^2$ per pulse, underlining the effectiveness of the particulate suppression through the coated target and suggesting the usage of thinner Pb layers. The properties of the grown layers were similar for both sample materials, indicating that the process can successfully be transferred to the deposition of Pb layers on Ge wafers.

As the Raman spectroscopy measurements in Fig. 6 show, neither Ge nor Si is getting ablated, underlining the assumption of self-termination at the interface and suggesting that both materials can be used for the preparation of deposition targets. The development of the plasma plume during PLD processing, shown in Fig. 7., also suggests the theory of self-termination at the Pb-Si interface.

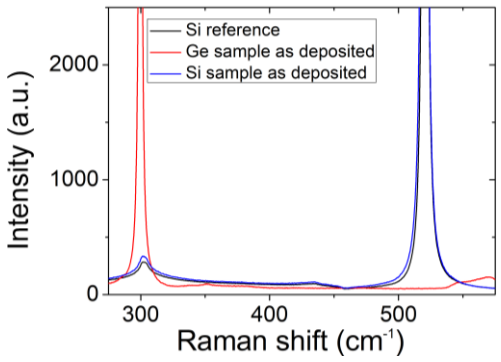

Figure 6. Raman spectra of the Si sample processed with the Ge wafer-based target, the Ge sample processed with the Si wafer-based target, and a Si reference

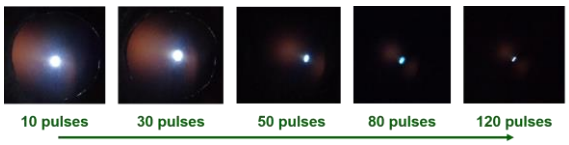

Figure 7. Intensity of the laser plume on a Si wafer-based target with a Pb layer thickness of t_{Pb} = 1.0 µm during processing.

The plume is very bright in the early stages of ablation and decreases to a slight afterglow of the laser spot after roughly 100 pulses, indicating a decrease in the amount of ablated material, and thus, the stop of the ablation process.

As the usage of the Si wafer-based target with a Pb layer thickness of 1.0 µm in an atmosphere of 0.053 kPa of Ar yielded optimized results, this process was chosen for the preparation of Ge samples for PLIE.

IV. GE/PB ALLOYING

PLIE was now used to form the desired GePb-alloys. The thicknesses of the deposited Pb layers were chosen as t_{Pb} = 5 nm, 10 nm, 20 nm and 30 nm to gather information about the scalability of the PLIE process. To evaluate the alloys grown, Raman spectroscopy was used. The Raman wavelength was chosen as λ = 633 nm. Two characteristic Raman spectroscopy measurements are shown in Fig. 8.

A. *Evaluation of the Grown Alloys*

When utilizing Raman spectroscopy, a few properties are generally shared between the samples processed. First, the main Ge peak is shifted to smaller wave numbers. This effect has already been reported in recent work [16] and is

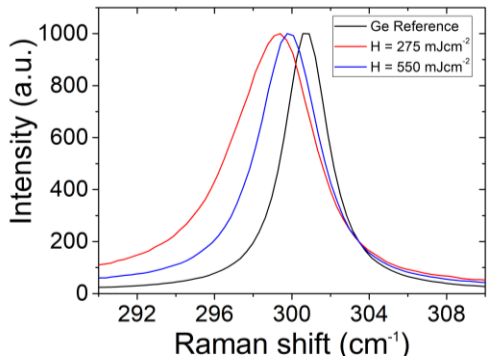

Figure 8. Two characteristic Raman spectroscopy measurements compared with a Ge reference. Both samples (red, blue) featured 10 nm of Pb prior to alloying. The PLIE pulse count was chosen as 50 pulses.

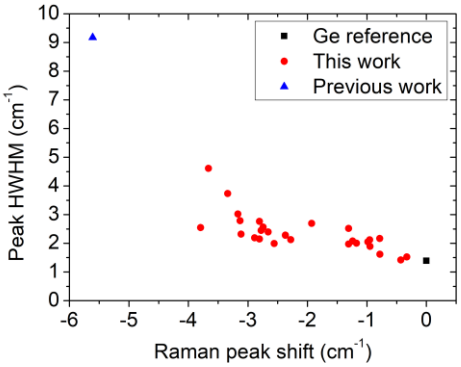

Figure 9. Raman peak shifts of samples grown in this work and a sample from the previous work for comparison [5].

a sign of tensile strain through the incorporation of Pb atoms into the Ge lattice. This behavior could be similar to the effect of the Sn percentage in GeSn alloys on the Raman spectrum, which has been investigated in more detail [17]. Additionally, the peak is broadened, which indicates a decline in crystal quality. The left side is broadened further, hinting at an inhomogeneous distribution of Pb.

The Raman spectroscopy results were evaluated as follows: The shift of the Ge-Ge mode was used as an indication of the concentration of Pb inside the Ge crystal, as a larger shift means more tensile strain, and thus, a larger Pb concentration. The asymmetry of the peaks was evaluated using a Lorentzian fit in the bounds of the top 80% of the measured peak and calculating the correlation coefficient of the measured and fitted data. A high correlation coefficient therefore means that the measured signal resembles the one of a perfectly homogeneous composition, and thus, indicates a preferable Pb distribution.

In Fig. 9, the obtained data from this work and a previous work [5], is shown. By using PLD, the Pb concentrations can be decreased significantly while the Raman peaks are much thinner, indicating preferable crystal quality and more homogeneous Pb distribution compared to [5]. It also shows that a broad range of Pb concentrations can be achieved with this method.

B. *Influence of the Pb Layer Thickness*

To examine the properties of samples with different initial Pb layer thicknesses, unmasked samples were coated with Pb layers of the thicknesses t_{Pb} = 5 nm, 10 nm, 20 nm and 30 nm. After deposition, the GePb alloy was created using two different laser fluences, 275 mJcm^{-2} and 550 mJcm^{-2}, with 50 laser pulses per sample.

The Raman peak shift- and peak half width at half maximum (HWHM) are shown in Fig. 10. The shift of the Ge-Ge mode increases with the thickness of the Pb layer prior to PLIE processing. This is an expectable result, as more Pb inside the crystal will lead to a greater degree of strain, and thus, a larger Raman peak shift. Furthermore, the broadness of the peak increases, which indicates that the crystal quality in the observed volume decreases. It has to be noted that a large difference in peak position and broadness can be observed when comparing the two energy densities: Not only is the peak shift smaller, but the peak broadness also yields much smaller values when choosing the higher fluence. This indicates that the layer

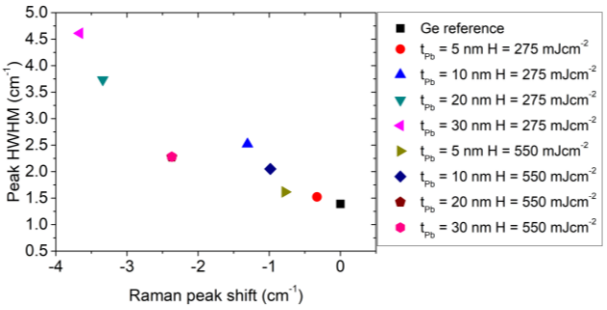

Figure 10. Raman peak shifts vs. peak HWHM from samples with different initial Pb layer thicknesses. Note that the samples with t_{Pb} = 20 nm and t_{Pb} = 30 nm at H = 550 mJcm^{-2} overlap in this plot.

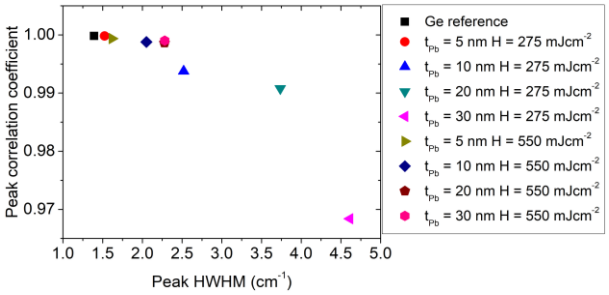

Figure 11. Raman peak correlation data vs. peak HWHM from samples with different initial Pb layer thicknesses. Note that the samples with t_{Pb} = 20 nm and t_{Pb} = 30 nm at H = 550 mJcm^{-2} overlap in this plot.

homogeneity increases massively when choosing higher pulse energies and suggests that higher laser fluences are preferable for more homogeneous Pb distributions. These results are further backed by the peak correlation coefficients shown in Fig. 11. When increasing the Pb dose, the correlation coefficient decreases, indicating a less homogeneous layer composition. For higher fluences however, a high peak correlation coefficient is retained much better.

C. Influence of the Laser Pulse Energy

To investigate the dependency of the laser fluence, a set of unmasked samples was coated with 10 nm of Pb before PLIE processing with 50 laser pulses. For each sample, a different laser fluence was chosen. Fig. 12 shows the peak shift vs. peak HWHM data. Unfortunately, the peak shifts are scattered, making interpretation difficult. This might be due to Pb layer thickness deviations, which have not been investigated. Still, the peak correlation data in Fig. 13 shows that the higher the laser fluency, the smaller the peak HWHM and the higher the peak correlation coefficient, which both hints at a preferable sample composition and crystal quality. If the number of samples under observation is extended to all samples used (see Fig. 14), a clear correspondence can be observed: The higher the pulse energy, the smaller the HWHM values for a given peak shift, which again underlines the importance of the fluence. Furthermore, the correlation coefficients in Fig. 15 show that the samples processed at elevated fluences scatter at the top for each Pb layer thickness, indicating a higher layer homogeneity. For a Pb layer thickness of t_{Pb} = 5 nm, however, the lowest energy density seems to return favorable results. This may coincide with Pb layer thickness deviations, as these two layers also yield much smaller peak shifts, suggesting that the total Pb dose in these samples is smaller than expected.

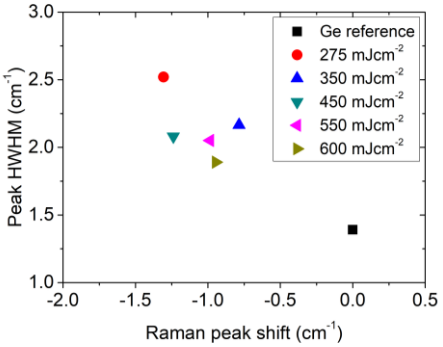

Figure 12. Raman peak shifts vs. peak HWHM from samples processed at different fluences.

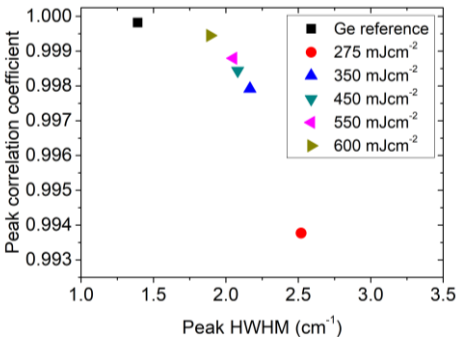

Figure 13. Raman peak correlation data vs. peak HWHM from samples processed at different fluences.

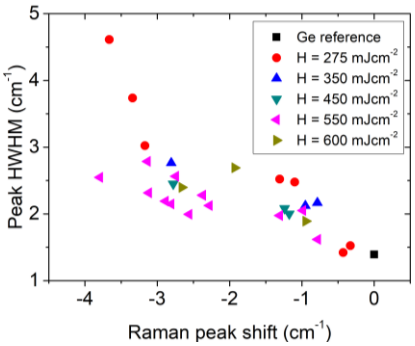

Figure 14. Raman peak shifts vs. peak HWHM of all samples processed, sorted by fluence.

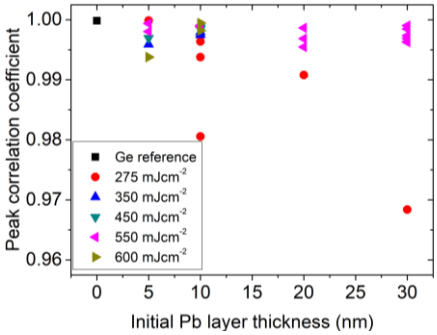

Figure 15. Peak correlation data vs. initial Pb layer thickness of all samples processed, sorted by fluence.

D. First-Order Approximation of the Pb Concentration

In the previous work, at laser fluences of H = 580 mJcm^{-2}, the generation of SiGe could be confirmed with Raman spectroscopy [5]. The Ge-Si-interface was located 250 nm below the Ge surface and PLIE led to partial melting of the Si surface, and thus, to SiGe for-

mation. When considering the lower melting temperature of Ge, $T_{M,Ge}$ = 938 °C compared to $T_{M,Si}$ = 1414 °C [15], it is reasonable to assume that in this work, the molten pool will extend to a depth of at least 300 nm below the Ge wafer surface at similar fluences. When considering a perfectly homogeneous Pb concentration in a cuboid volume while neglecting Pb ablation during the first pulses of PLIE processing as a crude first-order approximation, the Pb concentrations in Tab. 3 are obtained. The real Pb concentrations and the amount of strain inside the crystal are not known, yet especially strain is reported to have a significant impact on the Pb concentration needed for the transition towards direct band gap GePb alloys. As a broad range of Pb concentrations is suggested to yield GePb alloys with direct band transitions [4], it is likely that at least the samples with higher initial Pb layer thicknesses match the requirements.

V. Hard Mask Integrity

In the previous work, the damage threshold of the hard mask has been identified as H ≈ 300 mJcm^{-2} [5]. As higher laser fluences turned out to be favorable, the mask integrity has to be evaluated. In the optical microscope, severe damage can be observed for elevated fluences, such as 550 mJcm^{-2}, even after only 5 pulses, as shown in Fig. 16. This suggests that more durable hard mask materials should be chosen to reliably confine the GePb creation to the unmasked areas.

VI. Conclusion

PLD was introduced as a suitable approach for the deposition of Pb. The greatest challenge turned out to be the reduction of the particulate emission. This problem was solved using an Ar environment inside the process chamber and a Pb-coated Si wafer as deposition target. The later one proved to yield the largest improvement.

After the PLD optimization, the GePb alloying using PLIE was investigated. It turned out that the laser fluence is highly important, mainly because the layer homogeneity is increased, and the broadness of the Raman peaks decreased at higher fluences. Therefore, to obtain high-quality alloys, a high energy density is a necessity. Unfortunately, the SiO_2 hard masks suffered severe damage at higher fluences, which suggests the usage of more durable materials for future investigation. Furthermore, a more detailed analysis of the layer composition and strain should be undertaken in future investigation, aiming at an "All 193 nm laser assisted" process for GePb formation.

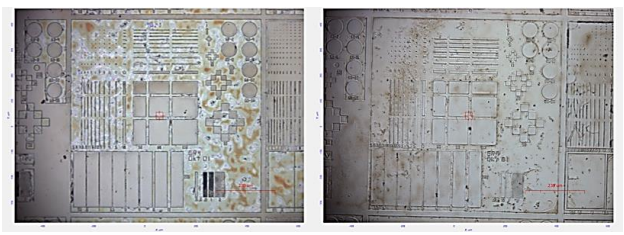

Figure 16. SiO_2 hard masks after exposure. Left: 5 pulses at H = 550 mJcm^{-2}. Right: 30 pulses at H = 550 mJcm^{-2}.

TABLE III. Approximation of the Pb Concentration

t_{Pb}	Depth of the molten pool		
	250 nm	***300 nm***	***400 nm***
5 nm	1.488 %	1.240 %	0.930 %
10 nm	2.976 %	2.480 %	1.860 %
20 nm	5.953 %	4.960 %	3.720 %
30 nm	8.929 %	7.440 %	5.581 %

Acknowledgment

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Electrical Characterization of Fabricated pin Diodes made from $Si_xGe_{1-x-y}Sn_y$ with an Embedded $Ge_{1-x}Sn_x$ Quantum Well

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***Abstract* – The interest in group-IV based optoelectronic devices has increased due to a foreseeable future demand. The main advantage is the relatively simple integration into the modern Silicon-based Complementary Metal-Oxide-Semiconductor technology platform. The ternary alloy Silicon-Germanium-Tin enables achieving a direct bandgap material made from the indirect semiconductors Silicon, Germanium and Tin. By using a virtual Germanium substrate technology these semiconductors can be integrated on a Silicon wafer. In this paper, we discuss the characterization of grown and fabricated pin-diodes made from the ternary alloy Silicon-Germanium-Tin by using Molecular Beam Epitaxy technology on a virtual Germanium substrate formed on Silicon(001) wafers. To achieve higher Tin concentrations to enable direct band transitions, a thin Germanium-Tin layer is inserted into the intrinsic region of the pin-diodes resulting in a quantum well. It is shown that these pin-diodes have electrically good characteristics and in particular a low dark current density, which suggest a high crystal-quality.**

Keywords – SiGeSn, GeSn, Quantum Well, pin diodes

I. INTRODUCTION

Optical on-chip interconnections could replace electrical connections, which became a limiting factor for scaling Complementary Metal-Oxide-Semiconductor (CMOS) based logic units. A progress towards optical on-chip communication on a Silicon (Si) platform is a difficult task, although optical modulators, waveguides and detectors have been developed and successfully integrated in Si devices. Developing an efficient laser source is still a challenging task due to the mostly indirect bandgap transitions in Si and Germanium (Ge). Direct bandgap transitions in unstrained Germanium-Tin ($Ge_{1-x}Sn_x$) alloys has been predicted for Sn concentrations $c_{Sn} > 7.3\,\%$ which would increase significantly for strained $Ge_{1-x}Sn_x$ pseudomorphical grown on Ge [1], [2]. However, growing a high quality $Ge_{1-x}Sn_x$-layer with a high c_{Sn} is difficult, because of a too high lattice mismatch between $Ge_{1-x}Sn_x$ and Ge, Sn-segregation and Sn-clustering.

Inserting Si enables growing a direct bandgap material $Si_xGe_{1-x-y}Sn_y$ epitaxial, which could be a direct bandgap material in a certain composition and a more easily adjustable lattice constant [3].

However, the ternary alloy $Si_xGe_{1-x-y}Sn_y$ is not fully known and it is still challenging to grow a high quality crystal epitaxial, because of very low solid solubilities of Sn in Si and Ge (at the melting point $s_{Sn,Ge} \leq 1\,\%$ in Ge [4] and $s_{Sn,Si} \leq 0.1\,\%$ in Si [5]). Previous research has demonstrated epitaxial grown pin-diodes with Antimony(Sb)-doped $Si_{0.46}Ge_{0.415}Sn_{0.125}$ which show an exponential forward current with a high dark current and, especially, Transmission Length Method (TLM) results show low contact resistances by using Aluminum (Al) as contact material, but still high reverse saturation currents [6].

By inserting a thin Quantum Well (QW) in the intrinsic region, it would be possible to trigger direct bandgap transitions even with a low c_{Sn} in the $Si_xGe_{1-x-y}Sn_y$-layer [7]. Growing thin layers enables the possibility of introducing $Ge_{1-x}Sn_x$ with a higher c_{Sn}, which is expected not to relax and staying strained. By replacing the intrinsic $Si_xGe_{1-x-y}Sn_y$ and introducing pure Ge as the intrinsic region (i-Ge) of the diode a Separate Confinement Heterostructure (SCH) is created with a higher possibility of direct bandgap transitions. Beneficial is the lattice matched growth between Ge and $Si_xGe_{1-x-y}Sn_y$.

However, the bandgap dependency of $Si_xGe_{1-x-y}Sn_y$ on its composition, as well as the band offsets, are not understood in total and still a subject of ongoing research. Therefore, a junction between $Si_xGe_{1-x-y}Sn_y$ and the $Ge_{1-x}Sn_x$-QW, resp. i-Ge, can form different types of heterostructures, as shown in Fig. 1, whereby the type-1-heterostructure could be used for direct band transitions.

Here, we present epitaxial grown and fabricated $\underline{\mathbf{Si_{0.37}Ge_{0.53}Sn_{0.10}}}$ pin-diodes with a thin $\underline{\mathbf{Ge_{0.84}Sn_{0.16}}}$ layer in the intrinsic region, where the intrinsic region comprises the same $Si_xGe_{1-x-y}Sn_y$ alloy or pure Ge (Fig. 2 and Fig. 3).

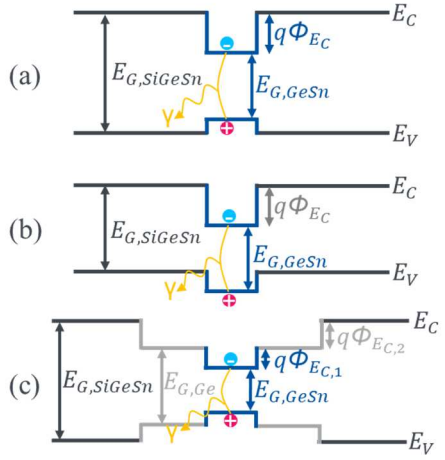

Figure 1. Possible band diagrams of a heterostructure: (a) type 1 (b) type 2 (c) SCH.

II. Preliminary Analysis

Using Molecular Beam Epitaxy (MBE) technology brings a lot of benefits, like growing high crystalline layers. If Sb is used as n-type dopant a problematic aspect is the relatively large lattice mismatch between Sb and the taking crystal matrix made from $Si_xGe_{1-x-y}Sn_y$. Especially high doping concentrations up to $N_{Sb} = 10^{20}\ cm^{-3}$ causes high stress in the grown and doped crystal. Additionally, Sb strongly tends to segregate during the epitaxial growth of n-doped layers by resulting in a doping gradient.

A preliminary research was performed on the reduction of the Sb concentration while still retaining ohmic Schottky-contacts on standard Ge-pin-diodes. These were grown on the same MBE-unit, doped with Boron (B) and Sb with $N_{B,Sb} = 10^{19}\ cm^{-3}$, fabricated in a single-mesa process and contacted with sputtered Al. Also, it was evaluated to reduce the substrate temperature T_{Sub} during

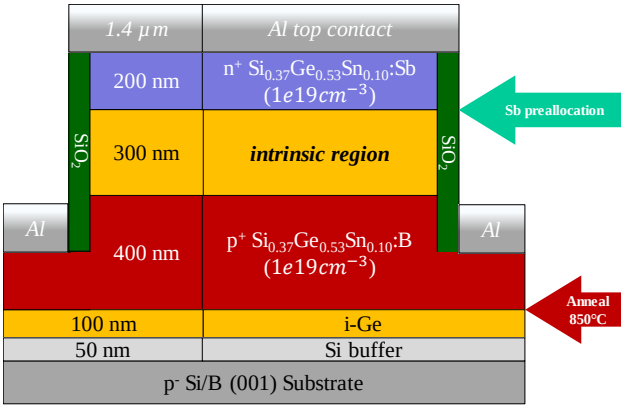

Figure 2. Layer stack of all samples. The intrinsic region varies in the layer structure and the used material.

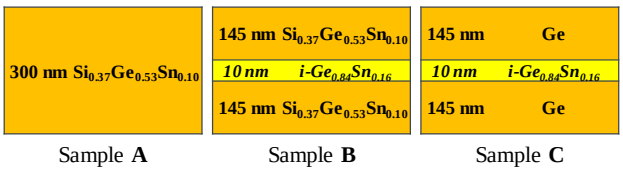

Figure 3. Layer stack of the intrinsic region.

the epitaxial growth of the Sb-doped Ge-layer to reduce the segregation of Sb. Afterwards, the so formed Ge-pin-diodes were analysed with DC-measurements. The results are shown in Fig. 4. Because the results for the samples with reduced $N_{B,Sb}$ showed no difference to the reference sample and still retained ohmic Schottky-contacts, the Sb concentrations in the $Si_xGe_{1-x-y}Sn_y$ samples were reduced, compared to our previous investigations [6].

III. Fabrication

A. Molecular Beam Epitaxy

All presented structures were grown by MBE using a solid source 6"-MBE-system with a base pressure of $P < 10^{-10}\ mbar$. As matrix elements Si, Ge and Sn were used, whereby B and Sb were used as dopants. Si is evaporated by using an electron beam evaporator, whereby Knudsen-cells were used for Ge, Sn, Sb, and B.

After an in-situ thermal cleaning step at $T_{Sub} = 900\ °C$ for $t = 5\ min$ [8], the layer stack started with a $d_{buffer} = 50\ nm$ thick intrinsic Si buffer layer in order to smoothen the surface. Afterwards, a $d_{Ge-VS} = 100\ nm$ thick intrinsic Ge buffer layer was deposited, which creates a virtual Ge substrate (Ge-VS) after an annealing-step at $T_{Sub} = 850°C$ for $t = 5\ min$ in order to reduce the threading dislocation density [9]. After this Ge-VS the lattice constant of Si merges to the lattice constant of Ge, which enables the following growth of relaxed $Si_xGe_{1-x-y}Sn_y$-layers. To prevent Sn-segregation during the growth of the $Si_xGe_{1-x-y}Sn_y$-layers T_{Sub} was lowered to $T_{Sub} = 200\ °C$. The composition of $Si_xGe_{1-x-y}Sn_y$ is chosen to fulfil lattice matched growth on Ge [3], leading to the composition shown in Fig. 2 and Fig. 3.

In order to achieve symmetrically doped n/p regions, the concentration of B and Sb is identical at $N_{B,Sb} = 10^{19}\ cm^{-3}$. The actual device layer stack starts on top of the Ge-VS with a $d_p = 400\ nm$ thick B-doped $Si_xGe_{1-x-y}Sn_y$-layer, after which a $d_i = 300\ nm$ thick intrinsic region was deposited (Fig. 2).

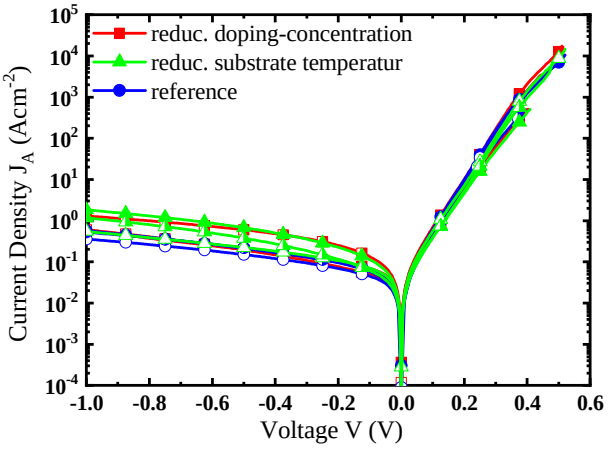

Figure 4. Averaged I(V) characteristics of cylindrical **Ge-pin**-diodes. Shown are diodes with a radius of 5 µm (■), 20 µm (□), 80 µm (◨).

Sb shows a high segregation ratio of $R_{Seg} = 20$ at $T_{Sub} = 200\,°C$ in Ge-layers [10]. In order to compensate this segregation at the n-type top layer, a Sb pre-built-up of $1/200$ Monolayers (ML) was deposited continuing with a co-evaporation of Ge and Sb.

The variation of the different samples is the structure of the intrinsic region of the pin-diodes, whereby the remaining structures are identical. Sample **A** contains the identical $Si_{0.37}Ge_{0.53}Sn_{0.10}$ in the intrinsic region as in the doped layers. In Sample **B** a $d_{QW} = 10\,nm$ thin $Ge_{0.84}Sn_{0.16}$-layer was embedded in the intrinsic $Si_{0.37}Ge_{0.53}Sn_{0.10}$-layer. In Sample **C** a $d_{QW} = 10\,nm$ thin $Ge_{0.84}Sn_{0.16}$-layer was embedded in an intrinsic pure Ge-layer.

In order to receive a sharp material interface between $Si_xGe_{1-x-y}Sn_y$ and $Ge_{1-x}Sn_x$, the evaporation of Si was stopped by closing its shutter and thus creating $c_{Sn} \approx 16\,\%$ in the $Ge_{1-x}Sn_x$-layer. Because of the thin layer thickness a relaxation is not expected, leading to a compressive strained $Ge_{1-x}Sn_x$-layer. Growing pure Ge as an intrinsic region is done by closing the shutters of Si and Sn.

B. Device fabrication

The samples were diced to 4 squares with an edge length of $l = 35\,mm$ afterwards. The vertical pin-diodes were structured in a single-mesa-process, so the p-type bottom layers of all diodes on the sample are electrically connected.

The first step in this process is a wet chemically clean with Acetone ($(CH_3)_2CO$), Isopropyl ($CH_3CHOHCH_3$) and in an Oxygen (O_2) plasma to remove (in)organic remains. For the mesa structuring a Silicon dioxide (SiO_2) hard mask process was used, where SiO_2 ($d_{SiO2} = 100\,nm$) was deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) using Tetraethyl orthosilicate (TEOS) as a precursor at a deposition temperature $T_{Dep} = 250\,°C$.

Prior to etching, the SiO_2 was structured with photolithography using the photoresist AZMIR701 followed by Reactive Ion Etching (RIE) using Fluoroform (CHF_3). The mesa etching was performed by Inductive Coupled Plasma RIE (ICP-RIE) with Hydrogen bromide (HBr). The hard mask was removed wet chemically with buffered Hydrofluoric acid (BHF). Afterwards, SiO_2 ($d_{SiO2} = 300\,nm$) was deposited with PECVD as a passivation and isolation oxide. The metallization with sputtered Al was etched using an ICP-RIE dry etch step with HBr followed by a wet etching step with Phosphoric acid (H_3PO_4).

In order to investigate the volume and area-dependent electrical behavior of the samples, circular shaped mesa structures with varied radii $r/\mu m \in \{1.5, 2, 3, 4, 5, 10, 20, 40, 80\}$ were fabricated. In addition to devices with full-faced top-contacts, structures with a SiO_2 oxide window on the top enable electroluminescence measurements for an electrooptical characterization of the devices.

IV. Characterization

A. Crystal Analysis

All samples were characterized by high-resolution X-Ray diffraction (XRD). The high resolution 2θ/ω scans of the symmetric (004) reflex and the reciprocal space maps (RSM) of the asymmetric (-2-24) reflex are shown in Fig. 5 and Fig. 6, resp.

The sharp peak at $2 \cdot \theta = 69.1\,°$ in all three 2θ/ω scans results from the nearly perfect Si (001)-wafer, whereby the background curve at $65.5\,° \leq 2 \cdot \theta \leq 67\,°$ represents the necessary Ge-VS. Due to the sharp peak at $2 \cdot \theta = 66.3\,°$ corresponding to $Si_xGe_{1-x-y}Sn_y$, the $Si_xGe_{1-x-y}Sn_y$-layers show a high quality without a change in the lattice constant for the different intrinsic regions. Additionally, on Sample **C** i-Ge is visible as a high quality crystal at $2 \cdot \theta = 66\,°$. By comparing all samples, the $Ge_{1-x}Sn_x$-QW is observable as thickness fringes at the left side of the graphs.

The RSM in Fig. 6 allows a more detailed look on the crystal structure. The lattice matching of $Si_xGe_{1-x-y}Sn_y$ to the underlying Ge-VS is almost perfect for all samples as the RSM-peaks corresponding to Ge and $Si_xGe_{1-x-y}Sn_y$ overlaps nearly perfectly for all samples. On Sample **B** the RSM-peak corresponding to the thin $Ge_{1-x}Sn_x$-QW is visible at the same in-plane lattice constant $a_{\parallel}$. However, the out-of-plane lattice constant $a_{\perp}$ is increased because of a higher lattice constant a_0 for $Ge_{1-x}Sn_x$ resulting in a strained $Ge_{1-x}Sn_x$-QW. The thin $Ge_{1-x}Sn_x$-QW is also visible on Sample **C**. The i-Ge possesses the same $a_{\parallel}$ as $Si_xGe_{1-x-y}Sn_y$, however $a_{\perp}$ is slightly increased.

Based on the RSM, $a_{\parallel}$ and $a_{\perp}$ and the in-plain-strain $\varepsilon_{\parallel}$ of all $Si_xGe_{1-x-y}Sn_y$-layers are calculated and listed in Tab. 1. For a more accurate measurement all results were calibrated with the well-known lattice constant of the Si-Peak occurring from the Si(001) wafer.

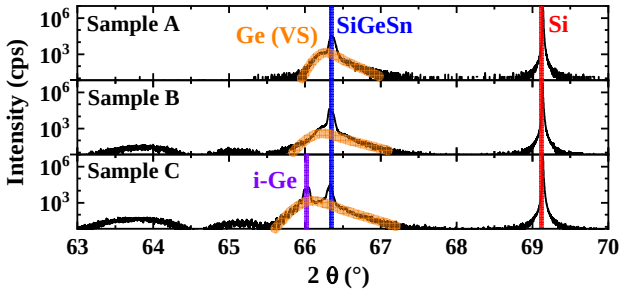

Figure 5. HR-XRD (004) 2θ/ω scans of all samples.

Table 1. In-plane $a_{\parallel}$, out-plane $a_{\perp}$ lattice constants and in-plane strain $\varepsilon_{\parallel}$ for the $Si_xGe_{1-x-y}Sn_y$-layers of all three samples.

Sample	$a_{\parallel}$ (Å)	$a_{\perp}$ (Å)	a_0 (Å)	$\varepsilon_{\parallel}$
A	5.6311	5.6620	5.6443	0.0031
B	5.6331	5.6585	5.6439	0.0026
C	5.6330	5.6628	5.6457	0.0030

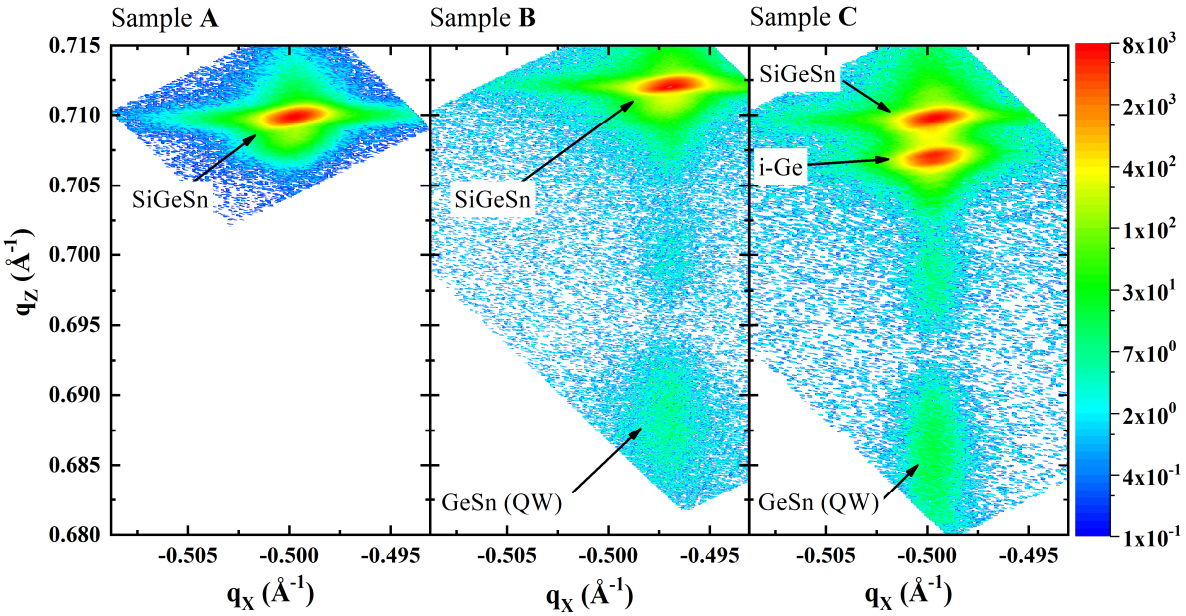

Figure 6. HR-XRD reciprocal space maps of the asymmetric (-2-24) reflex of all samples.

According to the XRD-results, all samples show approximately the same $\varepsilon_{||}$, without a big impact of the introduced $Ge_{1-x}Sn_x$-QW or the i-Ge. With the determined lattice constant a_0 and Vegards Law a calculation of c_{Sn} in the $Ge_{1-x}Sn_x$-QW is possible. However, the XRD-measurements of the thin $Ge_{1-x}Sn_x$-QW are imprecise and therefore the calculated c_{Sn} depends strongly on the selected intensity maximum of the RSM.

All in all, the results of the crystal analysis satisfy the expectations of the crystal quality. The MBE growth went well with lattice matched layers of $Si_xGe_{1-x-y}Sn_y$ on a Ge-VS. Especially, the $Ge_{1-x}Sn_x$-layer is visible as a monocrystalline, strained and unrelaxed layer.

B. Electrical I(V) Characterization

I(V) and TLM measurements were performed on a Keithley 4200SC with a KarlSuss PA200 Manipulator. The diode characteristics were analysed in a voltage range of $V_{ext} \in [-1\,V, 1\,V]$ with a maximum current of $I_{max} \leq 100\,mA$. Breakdown measurements were done up to $V_{ext} \geq -7\,V$. To allow statistically relevant results 480 measurements spread over the three samples were made.

The cross-section area normalized, arithmetic averaged diode characteristics of all fabricated samples are shown in Fig. 7. Functional diodes with exponential forward currents were found on every sample. Especially Sample **A** showed the best results with low dark currents for a ternary alloy and an areal proportionality in forward direction, which suggest a well passivated surface. An areal proportionality is also visible for Sample **B**, however Shockley-Read-Hall-Recombination (SRH) is significantly increased. Together with the higher dark currents it indicates a lower crystal quality. Sample **C** shows an exponential forward current, but in detail also extremely high and linear dark currents without a geometric proportionality. Two reasons for the high dark currents are possible, as Sample **C** contains a different intrinsic region with varied crystal quality and therefore a different band structure. Under the assumption of a perfect monocrystalline and defect-free Sample **C**, the upper limit for dark currents would be similiar to pure Ge pin-diodes due to the higher band gap of $Si_xGe_{1-x-y}Sn_y$ compared to Ge. However, pure Ge pin-diodes grown on the same MBE-unit show significantly lower dark currents of $J_A \approx 8 \cdot 10^{-2}\,Acm^{-2}$ at $V_{ext} = -1\,V$ [11]. Therefore, the high dark currents for Sample **C** have to result from the crystal quality itself.

Obviously, the forward currents of all samples stay small and do not reach the ohmic region dominated by series resistances in the selected voltage range, which inhibit the calculation of a series resistance for the most diodes.

According to the results of TLM measurements described in (*IV C)*, the contact resistance between the Sb-doped $Si_xGe_{1-x-y}Sn_y$ top layer and the Al metallization increased significantly compared to the standard Ge

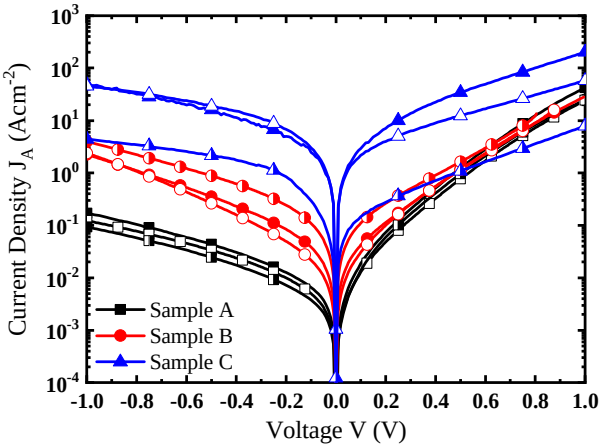

Figure 7. Averaged I(V) characteristics of all samples. Shown are diodes with a radius of 5 µm (■), 10 µm (□), 20 µm (◪).

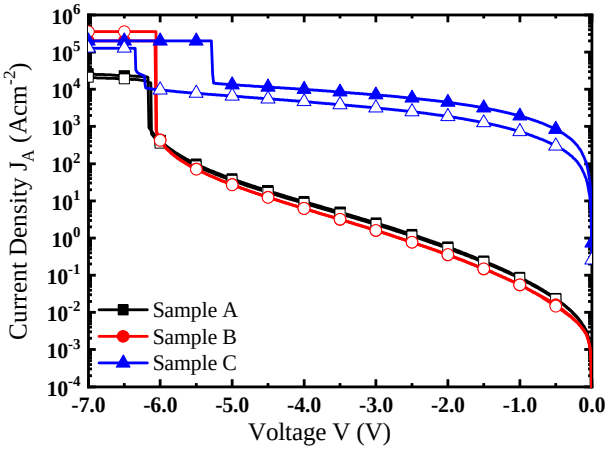

Figure 8. Breakdown characteristics of all samples. Shown are individual diodes with a radius of 4 µm (■), 5 µm (□).

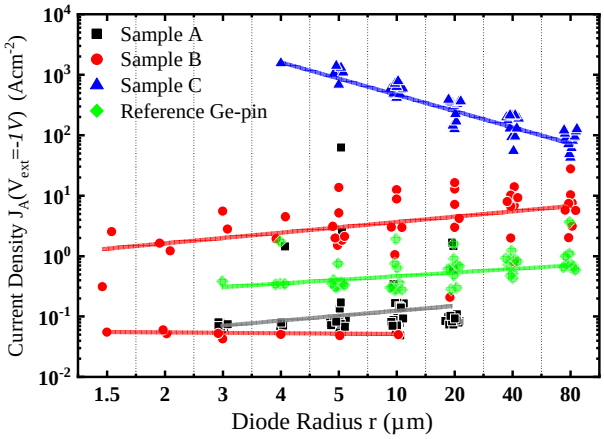

Figure 9. Current densities at a voltage $V_{ext} = -1V$ of working diode sizes. As a reference standard Ge pin-diodes are shown (see II preliminary analysis). For a better overview estimated trend lines were inserted.

pin-diodes in (*II*). This leads to suppressed tunnelling currents through the Schottky-barrier, which results to a presumption of parasitic non-ohmic Schottky junctions.

This is in contrast to the results of the preliminary analysis in (*II*). Therefore, a more detailed investigation on contact materials and design for $Si_xGe_{1-x-y}Sn_y$ seems to be necessary.

However, the effect of parasitic Schottky diodes is negligible for reverse currents of the pin-diode. As reported by Shockley, the dark current depends directly on crystal defects [12], like lattice defects, impurities or inactive dopants, where the charge carriers can recombine. Therefore, low dark currents over a wide voltage range are good indicators to characterize the crystal quality. The measurement system allows currents up to $I_{max} \leq 100\,mA$. Therefore, breakdown measurements were performed for small diodes with radii $r \leq 5\,\mu m$, as shown in Fig. 8. Sample **A** and **B** follow an areal proportionality with low dark currents and a breakdown at $V_{ext} = -6.15\,V$ with a rapidly increasing current density of approx. one to two orders of magnitudes.

A useful indicator for the crystal quality and threading dislocation density of the diodes is the current density (J_A) at $V_{ext} = -1\,V$ shown in Fig. 9. Again, Sample **A** showed the lowest J_A, which are even smaller than the reference Ge-pin-diodes. A typical behaviour is the increasing J_A for larger devices due to the higher amount of crystal defects in the active diode-area, as it can be observed for the reference Ge-pin-diodes. Sample **A** does not show these rising J_A, which indicates a homogenous layer stack with a low number of crystal defects in the active diode-areas. Some diodes of Sample **B** show the same low J_A, while the majority is at $J_A = 8\,Acm^{-2}$. Nevertheless, J_A increases slightly with r, indicating an imperfect homogenous layer stack spread over the sample.

C. *Transmission Line Method Analysis*

TLM measurements according to Shockley are used to characterize the contact resistances R_C and sheet resistances R_{Sh} of the samples [13]. These results are useful to verify the existence of parasitic Schottky-diodes, as estimated in the I(V) characteristics.

The measured resistances of the top layer were not constant and varied significantly with V_{ext}. Consequently, the behaviour of the Schottky-interface between the Sb-doped $Si_xGe_{1-x-y}Sn_y$ and the Al contact is not ohmic. However, the bottom layer was evaluable. The TLM measurements were performed across the sample diagonally in order to investigate a possible position dependence of R_C and R_{Sh}. The calculated R_C and R_{Sh} for the bottom layer are shown in Fig. 10. Although the calculated R_C of the bottom layer are high, the interface between $Si_xGe_{1-x-y}Sn_y$:B and Al exhibit ohmic behaviour with high resistances.

Sample **A** shows the highest R_C and R_{Sh} due to the nearly twice higher measured resistances than for the other samples. Therefore, the deviation of the linear fit (esp. for higher distances of the contact fields), is much higher than for the other samples. This leads to higher residuals and higher R_C and R_{Sh} with a higher standard deviation. The range of R_C and R_{Sh} on Sample **B** is small, thus the results

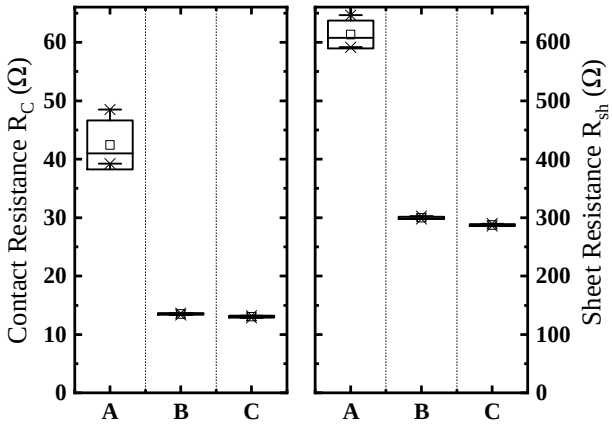

Figure 10. Contact (left) and Sheet (right) resistances of the bottom layer $Si_xGe_{1-x-y}Sn_y$:B for all three samples as a box plot.
Symbols of the box plot:
I) box: standard deviation II) middle square: arithmetic mean III) middle line: median IV) Whisker: 1%-99% span V) outer cross: extremes

are homogenous over the sample leading to a homogenous fabrication of the sample. However, the values are still high, compared to our previous investigations [6]. As the contacted layers of all samples are identical (referred to alloy composition and $N_{B,Sb}$), Sample **C** show similar resistances with the same behaviour as Sample **B**. Considering the TLM results, the higher dark currents (see Fig. 7) for Sample **B**, compared to Sample **A**, have to result from the $Ge_{1-x}Sn_x$-QW. However, Sample **C** show even higher dark currents than Sample **B**, although the TLM results of the B-doped bottom $Si_xGe_{1-x-y}Sn_y$-layers are almost identical. Again, the differences have to result from the i-Ge, which superpose the effects of the $Ge_{1-x}Sn_x$-QW.

The i-Ge on Sample **C** was grown by MBE by closing the shutters of Si and Sn. To avoid Sn segregation in the bottom $Si_xGe_{1-x-y}Sn_y$-layer, T_{Sub} stayed on $T_{Sub} = 200\,°C$, and was not increased to $T_{Sub} = 330\,°C$, which is normally used to grow Ge layers in the used MBE-unit (like the Ge-VS). In reality, the epitaxial growth of Si and Sn cannot be set instantly to zero because of remaining atoms in the vacuum chamber, which creates mixed alloys and gradients at the interface $Si_xGe_{1-x-y}Sn_y$:Ge. Probably, the i-Ge had to form defects and relocations, which destroys the blocking functionality of the fabricated pin-diodes.

V. Conclusion

We investigated the crystal quality and the electrical behaviour of vertical and Ge-lattice matched $Si_{0.37}Ge_{0.53}Sn_{0.10}$ pin-diodes.

The electrical characterization shows fully functional devices with low dark currents and therefore a high quality crystal. In order to reduce doping induced crystal stress, $N_{B,Sb}$ was set to $N_{B,Sb} = 10^{19}\,cm^{-3}$, which still behaves as an ohmic contact at the B-doped $Si_xGe_{1-x-y}Sn_y$ bottom layer, but creates parasitic Schottky-diodes at the Sb-doped $Si_xGe_{1-x-y}Sn_y$ top layer. Therefore, the doping of $Si_xGe_{1-x-y}Sn_y$ with Sb has to be optimized for ohmic contacts in order to create devices with low series resistance, which is essential for possible applications such as light emitting devices. The successful epitaxial growth of an intrinsic $Ge_{0.84}Sn_{0.16}$-layer ($d_{QW} = 10\,nm$) in the centre of the intrinsic $Si_xGe_{1-x-y}Sn_y$ region was verified with similar forward currents and breakdown characteristics.

Future steps consist of electrical-optical characterization to verify the concept of triggered radiative recombination by inserting quantum wells in the intrinsic region, the exploration of the band offsets of $Si_xGe_{1-x-y}Sn_y$ and the lattice matched and defect free growth of Ge in the intrinsic region to optimize the desired SCH (for a possible application as a light emitter) .

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Electrical Characterization of pure Boron-on-Germanium pin Diodes

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***Abstract* - Pure Boron on Germanium deposition was successfully performed using Molecular Beam Epitaxy to form ultra-shallow pin diodes. In order to form the pure Boron on Germanium heterojunction, a 100 nm thick highly Antimony doped Germanium layer was grown on a highly Arsenic doped Silicon(001) wafer by using Molecular Beam Epitaxy. Afterwards, a 5 min annealing step at 830 °C is performed to form a virtual, defect-less Germanium substrate. Growth is then continued with 300 nm of intrinsic Germanium layer. Finally, a few nanometers of Boron were deposited at a temperature of 400 °C. A maximum Boron deposition temperature of 400 °C allows the transfer of this technology to a Back End-of-Line process. A Complementary Metal-Oxide-Semiconductor-compatible fabrication process was utilized afterwards to fabricate single mesa diodes out of the grown layer stacks. The diodes show high ideality, low series resistance and low dark currents.**

Keywords* - *Pure-B, Pure Boron on Germanium, pin-Diodes, Epitaxy, MBE

I. Introduction

The increasing necessity for high performance semiconductor devices requires the development of new technologies and device concepts. Recent development of pure Boron (pureB) layer deposition on n-type Silicon (Si) has shown the formation of ultra-shallow pn-junctions with low series resistance, beneficial for several possible applications such as photodetectors [1] or as injection layer for Insulated Gate Bipolar Transistors (IGBTs) [2]. This is because of the accuracy under which pureB can be deposited by using Molecular Beam Epitaxy (MBE). In contrast to pureB, the implementation of abrupt pn-junctions with homogeneous doped semiconductor layers is quite challenging due to effects like diffusion or segregation. The shallow depletion region could minimize the probability of recombination within the depletion region, which would lead to a better ideality. Despite the recently increased interest in Germanium (Ge) as a potential material for photonic applications and p-channel Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) for future generation Complementary MOS (CMOS), the growth of pureB on Ge has not yet been shown. In this paper, we discuss the electrical characterization of the first pureB on Ge pin-diodes.

II. Growth Procedure

A. Generel growth process

All discussed samples were grown on 4” Arsenic(As)-doped Si(001) substrates with a nominal sheet resistance of $\rho < 0.005\ \Omega\cdot$cm. The growth process was performed in a 6” MBE system, with Si and Ge as matrix materials and Boron (B) and Antimony (Sb) as dopants. Due to other research projects Tin (Sn) is also used as matrix material in the MBE system. Si is evaporated using an electron beam evaporator, while Ge, B and Sb are evaporated with Knudsen effusion cells. The Ge crucible is made of Boron nitride (BN). The growth process starts with an in-situ thermal desorption step at a substrate temperature of $T_{sub,\,TD} = 900$ °C for $t = 5$ min in order to remove the native Silicon dioxide (SiO_2) [3]. Afterwards, a $d_{VS} = 100$ nm thick Sb-doped Ge buffer layer, which will be used as a virtual substrate, with a nominal doping concentration $N_{D,\,VS} = 10^{20}$ cm^{-3} was grown at $T_{sub,\,VS} = 330$ °C. In order to reduce the threading dislocation density, the buffer was annealed at $T_{sub,\,An} = 850$ °C for $t = 5$ min to form a virtual Ge substrate (Ge-VS) [4][7-8] for the subsequent Ge growth. This is the first time that a Ge-VS is actively Sb-doped in order to use it as an active layer in a pn-junction made from pure Ge. On the Ge-VS, an intrinsic Ge layer with a thickness of $d_{i\text{-}Ge} = 300$ nm was grown at $T_{sub,\,Ge} = 330$ °C.

Since the MBE is also used for the evaporation of Sn, a contamination of the layers with Sn is assumed due to the low vapour pressure of Sn. The Sn contamination

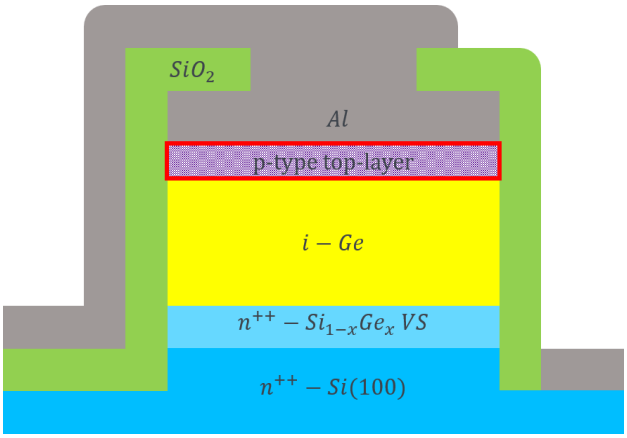

Figure 1 a). General sample structure

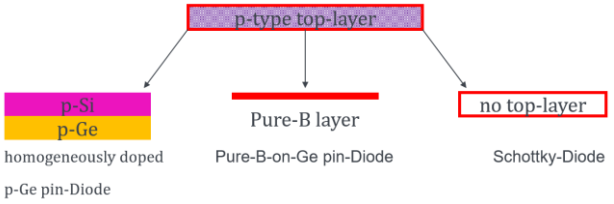

Figure 1 b). Top-layer variation

concentration of the Ge layers is strongly dependent on the Ge growth temperature due to surface segregation of Sn [5]. Therefore, a specific Sn surface concentration is remaining after the growth of the intrinsic Ge region. Also Sb tend to segregate [9], hence not only a Sn surface concentration has to be assumed, but a Sb contamination as well. In order to remove the Sn and Sb, a second in-situ annealing step at $T_{sub,\,An} = 750$ °C for $t = 5$ min was performed to desorb the Sn and Sb from the surface. Subsequently, the pureB with an estimated thickness of d_B = 3-5 nm was deposited directly on the Ge surface at $T_{sub,\,B} = 400$ °C. Finally, after the sample was taken out of the MBE, $d_{Al} = 50$ nm of Aluminium (Al) were sputtered on top to protect the pureB from atmospheric influences and mechanical damage during further processing. An illustration of the layer stack can be seen in Fig. 1 a).

B. *Sample Variation*

In order to prove, that the pureB forms a pn-junction, a Schottky reference without the pureB was also fabricated. Furthermore, a Ge nip-diode with a homogeneous B-doped top layer (TL) was produced as well. In this sample, the pureB was replaced by a highly B-doped $d_{Ge,\,TL} = 100$ nm thick Ge TL with a doping concentration of $N_{A,\,Ge,\,TL} = 10^{20}$ cm^{-3}. In order to ensure a good ohmic contact, a final $d_{Si,\,TL} = 100$ nm thick Si TL with $N_{A,\,Si,\,TL} = 10^{20}$ cm^{-3} completes the layer stack. Both layers were grown at $T_{sub,\,TL} = 400$ °C. The mentioned variations can be seen in Fig. 1 b).

III. Fabrication Procedure

Following MBE growth, a single mesa process was used to fabricate diodes. The mesa structures were etched using a combination of wet etching and Reactive Ion Etching (RIE). The Al cap was etched using Phosphoric acid (H_3PO_4). The semiconductor layers were etched afterwards with RIE with Tetrafluoromethane (CF_4) as etching gas. Afterwards, the mesa structures were passivated using Plasma-Enhanced Chemical Vapor Deposition (PECVD) to deposit a $d_{SiO2} = 300$ nm thick SiO_2 with Tetraethyl orthosilicate (TEOS) as precursor at $T_{Sub,\,TEOS} = 250$ °C. Contact holes were etched using RIE with Fluoroform (CHF_3) as etching gas. The last 30 nm of SiO_2 were wet etched with buffered Hydrofluoric acid (HF) to avoid surface roughening by RIE. Finally, a $d_{Al} = 800$ nm thick Al contact metallization was sputtered afterwards and structured with a H_3PO_4 wet etch step.

IV. Electrical Characterization

In order to investigate the electrical behavior of the fabricated diodes, DC measurements were performed after processing. For a better comparison and analysis of the crystal structure, diodes with radii ranging 1.5 µm to 80 µm were characterized.

A. *Characterization of the pureB-on-Ge nip-diodes*

The equivalent circuit of the pureB-on-Ge nip-diodes was approximated through an ideal nip-diode with a series resistance R_s as seen in Fig. 2. The *J(V)* characteristic of the pureB-on-Ge nip-diodes is shown in Fig. 3. In the diagram, only diodes with a radius of 1.5 µm and 80 µm are displayed. In order to compare the electrical properties, the series resistance R_s and ideality factor n_{id} are calculated using Eq. (1) and (2) [6].

$$R_S = \frac{d}{dI}\left(I \cdot \frac{dV}{dI}\right) \tag{1}$$

$$n_{id} = V_T \cdot \left(\frac{d(\ln(I))}{dV_{ID}}\right)^{-1} \tag{2}$$

In both Eq.s (1) and (2), where I is the measured current, V is the applied voltage, V_T is the thermal voltage and $V_{ID} = V - R_s \cdot I$ is the voltage applied to the diode, only. The calculated values of R_s and their standard deviation are shown in Fig. 4. Generally, series resistance values for bigger sizes can be fitted with a hyperbolic function $(f(A) \sim A^{-1})$. Therefore it was assumed that R_s could be described through Eq. (3).

$$R_s = \rho_S \cdot \frac{d}{A} \tag{3}$$

Where ρ_S is the specific resistance, A is the cross sectional area and d the thickness of the active zone. The fitting of R_s became better when just diodes with $r > 3$ µm were fitted separately. This observation was the reason to think about the different structures which are responsible for the

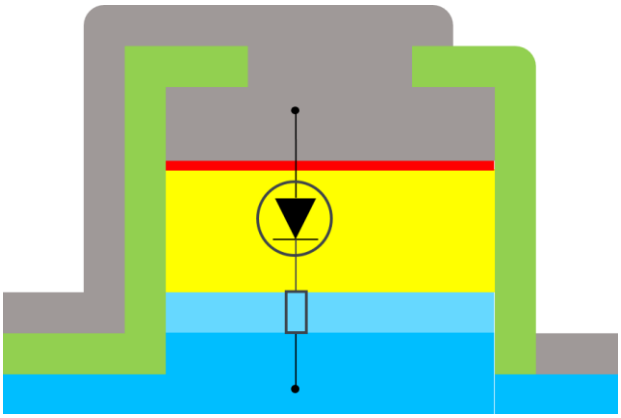

Figure 2. Equivalent circuit of the pureB-on-Ge nip-Diode

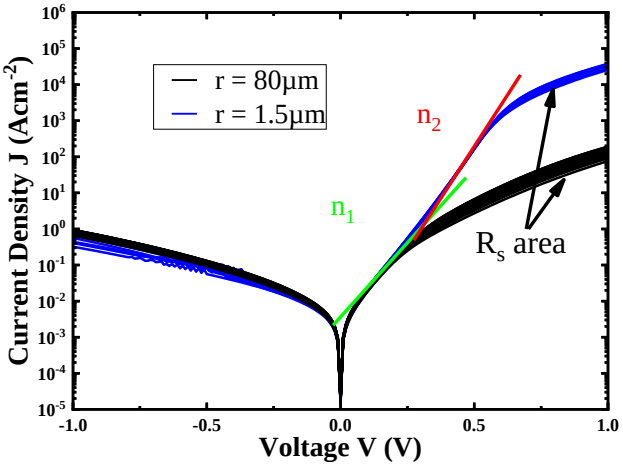

Figure 3. *J(V)* characteristic of the pureB-on-Ge nip-diodes

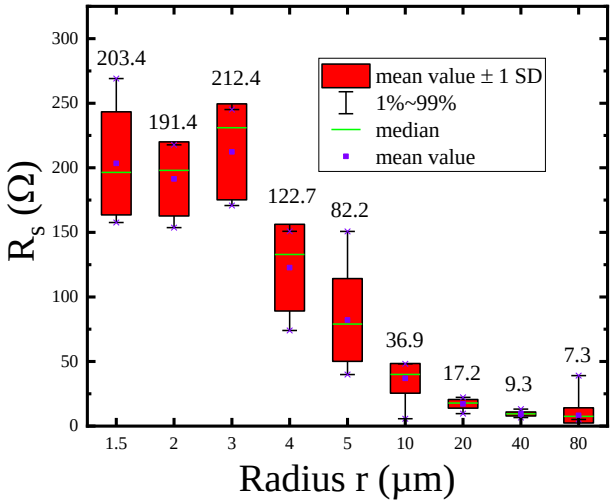

Figure 4. Series resistance for the pureB-on-Ge nip-diodes

series resistance. As seen in Fig. 5 the current has not just to flow through the mesa structure but also through n^+-Si on which the bottom contact is connected. Therefore two main resistances which cause the series resistance are assumed, one caused by the mesa (R_M) and another caused by the n^+-Si (R_{Si}). The required path, which the current has to flow through in the n^+-Si depends on the radius of the diode and is larger than the path through the mesa. Therefore, the assumption is made that R_{Si} could cause the main part of the series resistance. R_{Si} should strongly depend on the electric flow field in the n^+-Si before it is entering the mesa. Due to observations the assumption was made that the series resistance could rather depend on the radius r than on the area A. This assumption can be explained through the fact that with rising radius the current path in the n^+-Si is rising which should cause an increasing of R_{Si} but also the cross sectional area of the electric flow field is rising which leads to a decreasing R_{Si}. With the assumption that the effect of the increasing area is stronger than the larger path the assumption $R_{Si} \sim \rho_0 \cdot r^{-1}$ was used to describe R_{Si}. In order to investigate for which diode size which resistance is dominating the series resistance, all R_s values were normalized using Eq. (4) and (5). If the series resistance R_s is dominated by R_M the normalized values of R_s should show a constant behavior if they are normalized with the area A

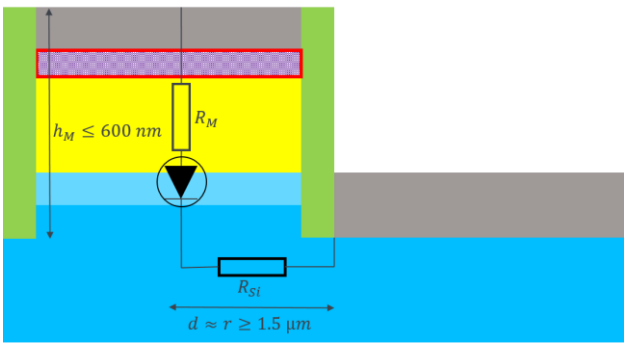

Figure 5. Schematic illustration of the different resistance which cause the series resistance

$$R_s \cdot A = \rho_S \cdot d = R_{s,A}. \quad (4)$$

If R_s is dominated by R_{Si} the normalized values of R_s should show a constant behavior if they are normalized with the radius r

$$R_s \cdot r = R_{s,r}. \quad (5)$$

Figure 6 is showing the values of the normalized series resistance $R_{s,r}$. The normalized values $R_{s,r}$ form diodes with 10 µm ≤ r ≤ 40 µm show a constant behavior which indicate a strongly R_{Si} affected series resistance. The values of $R_{s,r}$ for diodes with $r \leq 5$ µm show a slightly dependence of the radius. The values of the biggest device $r = 80$ µm show a higher value than the others. The observed behavior, especially for the smaller ($r \leq 2$ µm) devices, is an indication that the series resistance is not just caused by R_{Si} but also by R_M. The values form $r = 80$ µm could be higher due to the current flow field. Figure 7 is showing the normalized series resistance $R_{s,A}$. An increasing value of $R_{s,A}$ with increasing radius can be

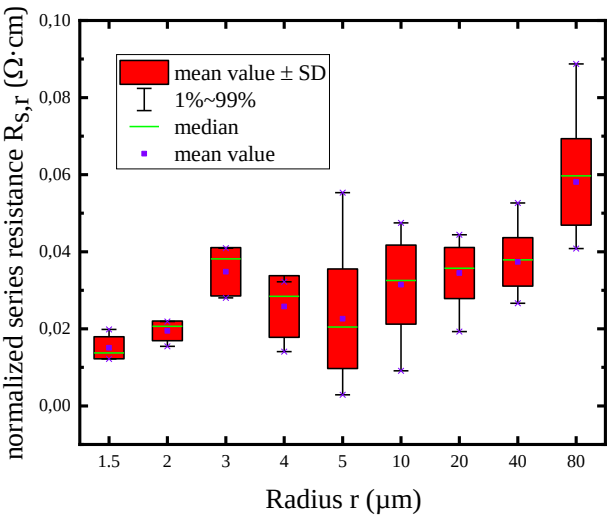

Figure 6. Normalized series resistance $R_{s,r}$ for the pureB-on-Ge nip-diodes

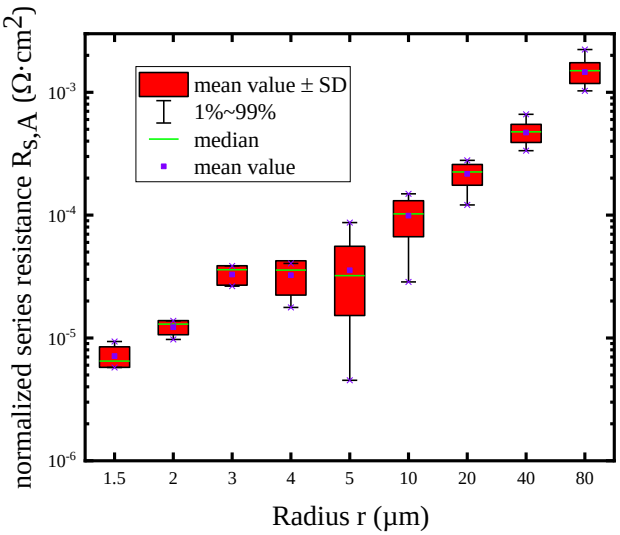

Figure 7. Normalized series resistance $R_{s,A}$ for the pureB-on-Ge nip-diodes

observed for diodes with $r \leq 2$ µm and $r \geq 10$ µm. $R_{s,A}$ for 3 µm $\leq r \leq 5$ µm show a constant behavior. With the results from both normalized series resistances the assumption was made that smaller devices are stronger affected by R_M than by R_{Si}. Devices with radius 3 µm < r < 20 µm appear to be affected by R_M as well as by R_{Si}. Therefore diodes with $r \geq 20$ µm are stronger affected by R_{Si} than by R_M. Due to the different dependences of the series resistances and the structures which affect it, a normalization will show for some diodes a constant behavior and for the others a dependence. Therefore the normalized values cannot be compared due to their different series resistance dependences.

The ideality factor is calculated with Eq. (2) and shown in Fig. 8. In general, the ideality factor is rather high which indicates a high defect density. Furthermore, a decrease of the ideality factor with decreasing diode size can be observed as expected due to a lower amount of defects at a constant defect density. Those defects can be explained by point defects which could be caused by the previous mentioned Sn contamination within the wafer. There is a probability of Sn atoms on interstitials, which can cause recombination centers in the crystal. Even Sn atoms on lattice sites can cause recombination due to the mechanical stress within the crystal.

Those traps, defects and the resulting high ideality factor explain the strong Shockley-Read-Hall (SRH) recombination currents which can be seen for almost the current until the *J(V)* characteristic is going into the series resistance dominated area. As seen in Fig. 3, the dark current is strongly influenced by charge carrier generated current, which is also an indication of a high defect density in the crystal. This result is corresponding with the results from the ideality factor.

B. *Characterization diodes with p-type Ge instead of pureB*

The equivalent circuit is described through a diode with a series resistance like for the pureB-on-Ge nip-diodes. Because of the high doped Si on top, the metal-semiconductor contact can be expected to be an ohmic

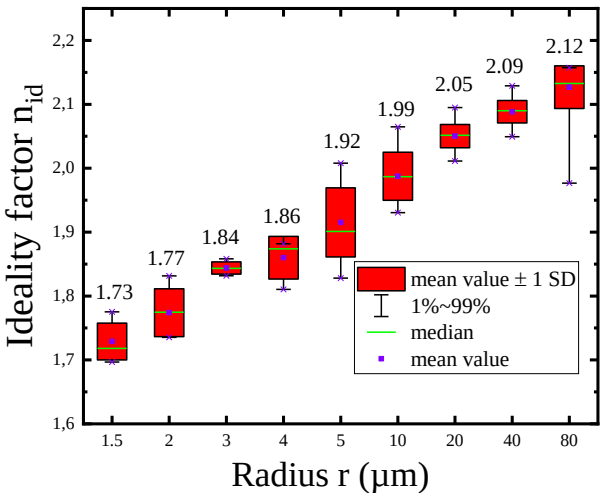

Figure 8. Ideality factor of the pureB-on-Ge nip-diodes

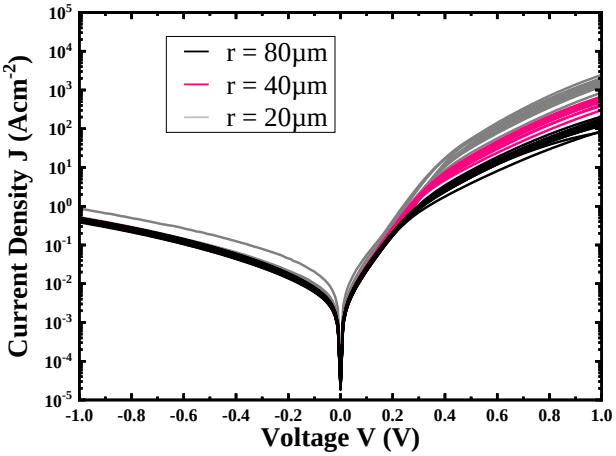

Figure 9. *J(V)* characteristic of the reference Ge-nip-diodes

contact. Therefore, the only relevant junction is the nip-junction which is formed by the n^{++}-Ge, i-Ge and the p^{++}-Ge top contact. All measurements and calculations were performed in the same way as for the pureB-on-Ge nip-diode which was described previously.

The *J(V)* characteristic is shown in Fig. 9. Due to problems during the metallization etching, only the devices with a radius $r \geq 20$ µm worked and could be analyzed. For Voltages $V_0 > 0.2$ V, the behavior changes to the resistance dominated region. Due to the small amount of data, no further investigation on the resistance behavior was performed. The calculated values for the ideality factor *nid* are rather high, the mean value for all three diode sizes is around $n_{id} = 2$. Therefore, a high defect density is assumed here, too, which would also explain the strong SRH current influence. As seen Fig. 9 the dark current is strongly influenced by generating current which could also be explained by a larger incidence of defects within the diode area.

C. *Characterzation of the Schottky diodes*

An equivalent circuit for the Schottky reference diode was made with a Schottky contact and a series resistance Fig. 10. The *J(V)* characteristic is shown in Fig. 11. Like for the pureB-on-Ge nip-diodes just diodes with a radius of r = 1.5 µm and r = 80 µm are shown in the diagram. In

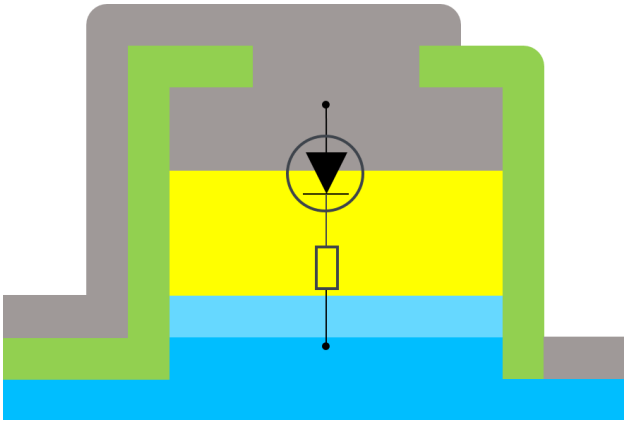

Figure10. Equivalent circuit of the Schottky reference diode

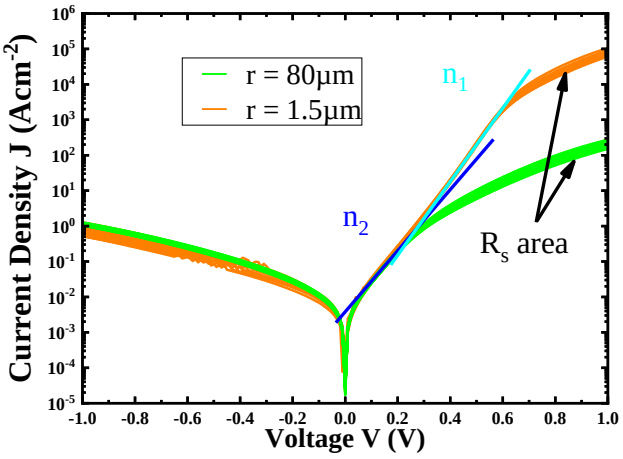

Figure 11. *J(V)* characteristic of the Schottky reference diodes

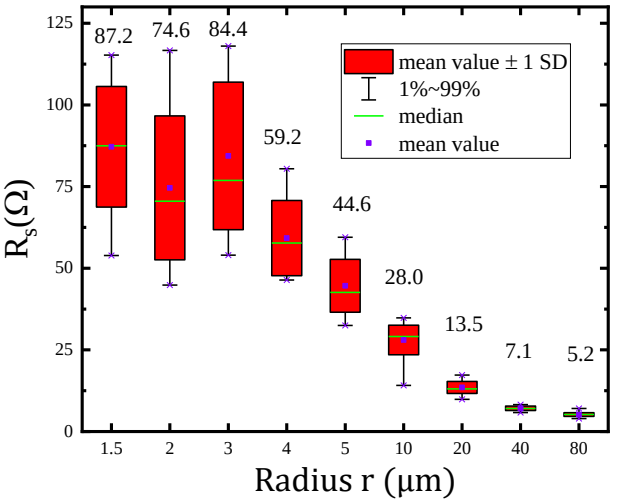

Figure 12. Series resistance for the Schottky reference diodes

general, the Schottky reference diode show an identical electrical behavior like the pureB-on-Ge nip-diodes. The series resistance and normalized resistances presented in Fig. 12 and 13 show a similar behavior like those from the pureB-on-Ge nip-diodes. Therefore, the series resistance dependence of R_{Si} and R_M is nearly the same for both diode types. This is an indication that the series resistance rather depend on the diode structure and the properties of this structure like conductivity than on the specific diode type. The ideality factors shown in Fig. 13 are rather high like for the pureB-on-Ge nip-diodes, which leads to the conclusion that the defect density in the crystal is rather

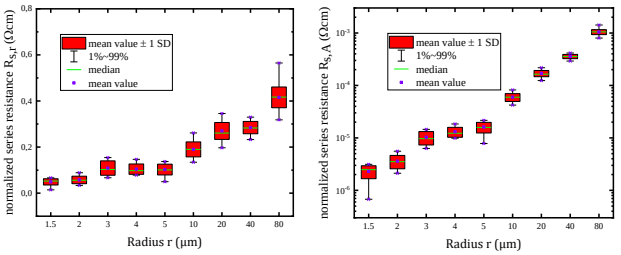

Figure 13. Normalized series resistance $R_{s,r}$ (left) and $R_{s,A}$ (right) from the Schottky reference

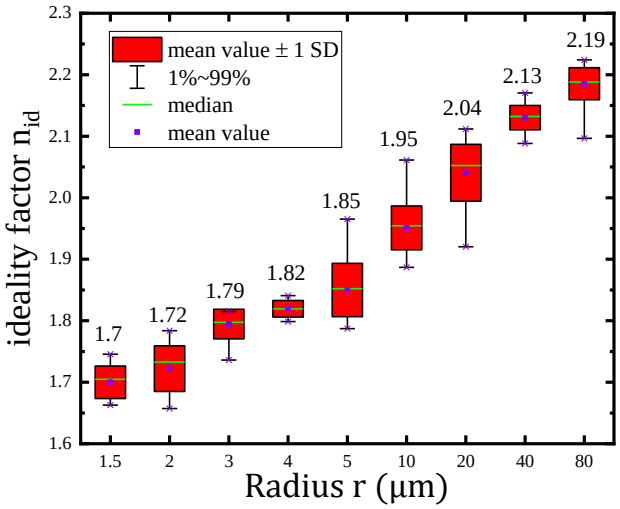

Figure 14. Ideality factor of the Schottky reference diode

high. Those similarities could be explained by the same assumptions which are made for the pureB-on-Ge nip-diodes described in section IV.A 'Characterization of the pureB-on-Ge nip-diodes'.

V. COMPARISON OF THE DIFFERENT SAMPLES

In order to compare pureB-on-Ge nip-diodes with all references, the *J(V)* characteristics from the Reference - diodes are plotted together with the pureB-on-Ge nip-diodes. As seen in Fig. 15 the pureB-on-Ge nip-diode and Schottky reference diode show a similar behavior. The same observation can be made for the pureB-diodes and the nip-diodes, so ale three diode types show an identical behaviour. This leads to the assumption that in every diode the same pn-junction is observed. Because of the BN crucible a B contamination has to be assumed which leads to a parasitic p-type background doping in the grown stacks. Fortunately, it is not affecting the highly doped layers but the i-Ge is rather a p^--Ge due to the background doping around $N_A \approx 10^{16}\,cm^{-3}$. Therefore, the Schottky reference diode has to be considered as a $n^{++}p^-$-junction with Al as contact material due to the p-type background doping. For the Schottky reference diode the Schottky contact can be described through a resistor because of the Fermi-level pinning for p-type Ge/ metal junctions [10]. With those new results all other *J(V)* characteristics have to be revised, too. The pureB-on-Ge and Ge-nip- diodes can be considered as psn diodes, which means that neither the equivalent circuit nor the interpretation of the behavior has to be changed drastically. As proof for this assumption the width of the depletion region in the p^--Ge was calculated. Because of the highly doped Ge-VS d_p was approximated trough Eq. (4). Described trough

$$d_p = \sqrt{\frac{2\varepsilon_0\varepsilon_{rel}}{qN_A}V_{bi}} \tag{4}$$

$$V_{bi} = \frac{k_B T}{q} \cdot \ln\left(\frac{N_D \cdot N_A}{{n_i}^2}\right) \tag{5}$$

In those equations the parameters are given through $\varepsilon_{rel,Ge} = 16$, $N_A = 10^{16}$ cm^{-3}, elementary charge

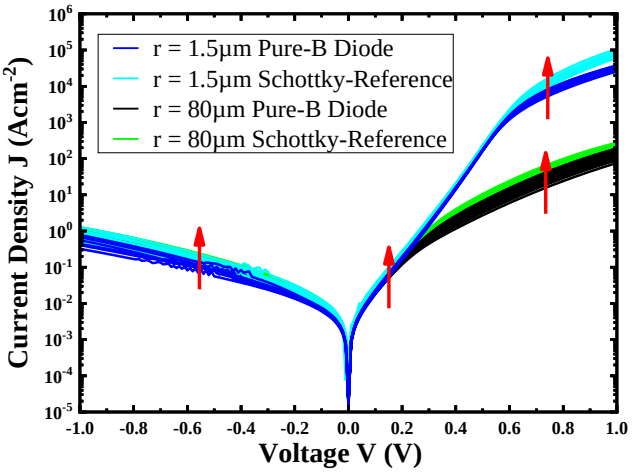

Figure 15. PureB-on-Ge nip-diodes and the Schottky reference diode plotted together

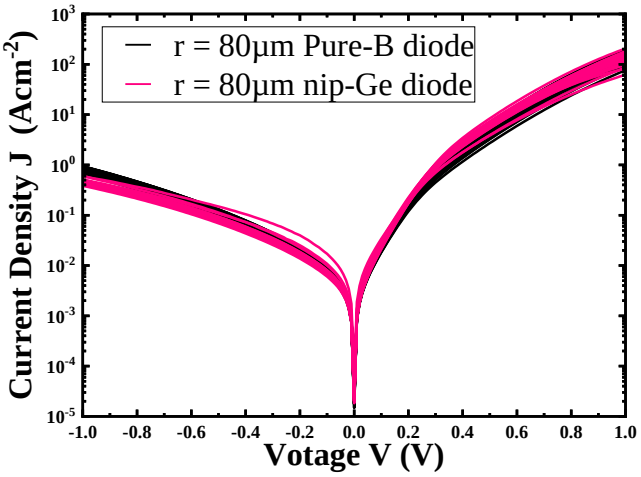

Figure 16. PureB-on-Ge nip-diodes and Ge-nip-diodes plotted together

$q = 1.6 \cdot 10^{-19}$ As, $\varepsilon_0 = 8.854 \cdot 10^{-12}$ $AsV^{-1}m^1$, $N_D = 10^{20}$ cm^{-3} and $n_i = 2.33 \cdot 10^{13}$ cm^{-3}. All values are from [11], measured at $T = 300$ K. Those calculation show that the width $d_p = 312$ nm is larger than the actual width of the i-Ge layer, which means a psn-junction could be formed by this constellation. Because of this results, Fig. 13 shows now the behavior of the pureB-on-Ge nip-diodes compared to a $n^{++}p^-$-junction. Both diode types show a similar behavior for their *J(V)* characteristic. This leads to the conclusion that those pureB-on-Ge nip-diodes could be strongly influenced by this pn-junction formed by the n^{++}-VS and the background p-type doped i-Ge. It has to be considered that pureB deposited one p-Ge won´t show a p-type semiconductor behavior if the doping concentration of the p-Ge is too high. Therefore, the background doping of $N_A \approx 10^{16}$ cm^{-3} seems to be too high. It appears that the pureB is responsible for a higher series resistance and a lower current density, but also for a better, means lower, dark current under reverse bias. This result is supported by the comparison of the pureB-on-Ge nip-diodes with Ge-nip-Diodes. Those show an even more similar behavior seen in Fig. 16.

VI. Conclusion

We reported the successful growth and fabrication of pureB-on-Ge nip-diodes in order to characterize the electrical behavior of a pureB layer on top of Ge. It was also for the first time that a VS was successful Sb doped and used as active n-layer in a pn-junction. The different electrical characteristics of the diodes were compared with additional fabricated reference diodes. A further analysis of the electrical characteristics allowed us the extraction of the series resistance, the ideality factor and the dark current, which show all an identical behavior.

Furthermore, the results for smaller devices show better electrical properties than for the bigger devices which can be traced back to the presence of different types of crystal defects.

Our research indicated, that a pureB on a p-type Ge just cause a good semiconductor/metal contact but not an active semiconductor layer if the p-type Ge is to highly doped. However, since it is difficult to differ between the two types of pn-junctions, further investigations on pureB-on-Ge are necessary to prove it.

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Electrical Characterization of Low-Temperature Boron on Silicon Deposition utilizing Molecular Beam Epitaxy

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***Abstract* - Pure Boron on Silicon junctions are commonly deposited at temperatures ranging from T_{sub} = 400 °C to T_{sub} = 700 °C using Chemical Vapor Deposition. In this work, the low-temperature deposition of Boron on Silicon using Molecular Beam Epitaxy is investigated through electrical characterization, as well as an evaluation of the surface morphology. We also discuss how lower processing temperatures enable the employment of pure Boron deposition as a back end-of-line fabrication step where lower thermal budgets are required.**

Keywords – Pure Boron on Silicon; low-temperature; Molecular Beam Epitaxy; ultra-thin

I. INTRODUCTION

Recently, pure Boron (B) on Silicon (Si) junctions have received a lot of attention due to their potential as photodetectors [1–3] and power devices [4]. The main advantage of this material system is that it forms a very shallow junction underneath the pure B layer (pureB) in the Si. The B atoms directly at the Si interface form acceptor states. A fraction of the B atoms at the interface is then able to extract electrons from the n-type Si and retain them against the electric field, which builds up holes due to charge separation [5, 6]. The Si at the interface of the B then behaves p-type due to the electron extraction, hence creating a pn-junction with the n-type Si below.

The fact that only the first few atomic layers at the interface are active enables the use of very thin pureB, which in turn leads to a reduction of series resistance and device size. In addition, recombination within the depletion region can be kept to a minimum as the majority of the depletion region is contained within the n-type Si substrate.

Typically, ultra-thin pureB is deposited at temperatures between T_{sub} = 700 °C and T_{sub} = 400 °C using Chemical Vapor Deposition (CVD) [7, 8]. Another deposition method, which is able to deposit pureB, is Molecular Beam Epitaxy (MBE). This paper investigates, whether pureB deposition works at the aforementioned temperatures using MBE and evaluates that employing two different diode structures. All low-temperature pureB discussed in this work were exclusively deposited using MBE.

A major difference between the two deposition techniques is the absence of gases or precursors in the MBE chamber. Consequently, our pureB is not Hydrogen (H) - rich, like ones made with CVD.

Since the aforementioned common deposition temperature of T_{sub} = 700 °C exceed the thermal budget of many back end-of-line (BEOL) fabrication steps, B deposition is generally done quite early in the fabrication process. The extremely thin pureB must therefore often be protected against the subsequent processing. For the purpose of this work, we also investigate the functionality of pureB deposited at extremely low temperatures and their potential as a BEOL fabrication step.

It is expected that the quality of the pureB, as well as the B-Si interface, vary with different deposition temperatures. Only the first few atomic layers of B are well aligned to the Si below, above the B gets amorphous. That is also why we generally write about deposition in this paper instead of growth. The impact of the temperature on the characteristics of the resulting layers is also investigated as well as surface morphology.

II. DEVICE STRUCTURE AND FABRICATION

To show the general behavior of the abovementioned pn junctions and to show the ability to implement this fabrication scheme as BEOL process, two different types of diode devices were fabricated. One consisted of diodes where the pureB was deposited into Silicon dioxide (SiO_2) windows as it is generally done with CVD [3] and how it would be employed in a BEOL process. We also realized mesa structure diodes. They had their pureB deposited at the beginning of the fabrication process at a wide range of temperatures. This allowed for the exclusion of perimeter effects, which diodes with pureB deposited into SiO_2 windows suffer from.

A. Diode Fabrication using pureB Deposition into SiO_2 Windows

This series of diodes aimed to demonstrate the applicability of low-temperature B deposition as BEOL process. Therefore, the pureB was deposited at T_{sub} = 400 °C within SiO_2 windows. The general structure of these devices is shown in Fig. 1.

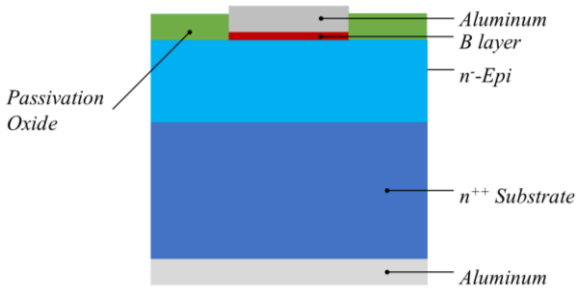

Figure 1. General structure of the diodes with pureB deposition into oxide windows

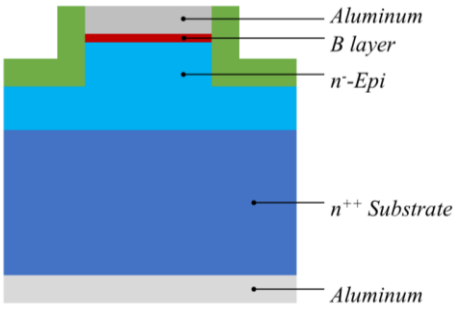

Figure 2. General structure of the pureB diodes fabricated for the temperature series

The samples with pureB deposition into SiO_2 windows employed commercially acquired n-doped Si substrates with a (100) crystal orientation and a resistivity of $\rho_{Sub} = 0.01\ \Omega\cdot$cm. The substrates had 3 µm of epitaxially deposited Si on top, which was low n-type doped and had a resistivity of $\rho_{epi} = 30\ \Omega\cdot$cm. That translates into a dopant concentration of $N_D \approx 1\cdot10^{14}$ cm^{-3}.

The substrates were first cleaned using a standard RCA process. A d_{Ox} = 300 nm thick SiO_2 layer was then deposited using Plasma Enhanced CVD (PECVD) with Tetraethyl orthosilicate (TEOS) precursor. The SiO_2 layer was then structured using photolithography and Reactive Ion Etching (RIE). It was not fully etched through using RIE, to mitigate surface roughness. To then fully open the windows in the SiO_2, the residual SiO_2 was etched wet-chemically with buffered Hydrofluoric acid (BHF). The resist was then removed in an Oxygen (O_2) plasma and subsequent cleaning. Immediately afterwards, the samples were put into the MBE to mitigate any growth of native SiO_2.

The samples are heated to T_{sub} = 700 °C for thermal desorption. The substrate temperature is then adjusted to the desired deposition temperature and B is deposited from a Knudsen effusion cell. For more in-depth information on the MBE system used and the deposition procedure refer to [9]. Finally, the Al top- and bottom contacts were sputtered and the top contact was structured by using photolithography and Inductively Coupled Plasma RIE (ICP-RIE).

B. *Fabrication of Single Mesa pureB Diodes*

The aim of the second series of diodes was to have a broader spectrum across deposition temperatures from T_{sub} = 700 °C down to deposition at T_{sub} = 400 °C. In detail, the pureB was deposited at T_{sub} = 700 °C, 600 °C, 500 °C and 400 °C. Fig. 2 shows the general structure of these diode devices.

For this series of diodes, the same type of substrate was used as for the previous series. The substrates were cleaned with a standard RCA process with subsequent etch in HF to remove native SiO_2. Immediately afterwards, the pureB was deposited as described in the previous section at the abovementioned deposition temperatures.

To protect the pureB from mechanical damage during the further processing, d_{Al} = 100 nm of Al was then sputtered on top. The Al was structured by using photolithography and wet etching, such that the photoresist and the Al act as a hard mask for the subsequent mesa etch using RIE. The mesas were then formed through RIE etching with a Sulfur Hexafluoride (SF_6) / Argon (Ar) gas mixture. Due to the combination of the physical and chemical etching, as well as different etching rates along B grain boundaries, surface roughness was observed after etching on the now exposed Si surface. The resist was then removed in an O_2 plasma and subsequent cleaning.

The Si surface is then passivated with a d_{Ox} = 350 nm SiO_2 passivation oxide deposited with PECVD using TEOS as precursor. SiO_2 windows were then formed using photolithography and RIE etching. Here, the SiO_2 was also not completely etched through by RIE and afterwards fully opened using BHF. The Al is then sputtered on the front and the back as contacts. Finally, the front is structured to form the top device contacts.

Note that the mesa does not reach through the lowly doped drift-zone. Therefore, both device types featured backside cathode contacts and vertical current flow through the full thickness of the substrate.

III. Measurements and Results

A. *Measurement Methodology*

All diodes were evaluated using DC-measurements within the range of V_A = [-1.5 V, 1.5 V], as well as up to the breakdown voltage under reverse bias. The ideality factors were extracted by fitting a linear function to the characteristic in an exponential plot and solving the Shockley equation for the ideality. The intercept of the fitted linear function at zero volts was then taken as the saturation current. Furthermore, the series resistance was approximated by a linear fit in the linear plot of the diodes' characteristics. PureB diodes generally show a very low leakage current, which is within the boundary of the measurement range of the utilized measurement setup.

Furthermore, pureB deposited for the diodes with mesa structures was analyzed using Atomic Force Microscopy (AFM) to investigate the surface topography variation with different deposition temperatures.

B. Electrical Characteristics of the SiO_2 Window Diodes

So far and to the best of our knowledge, pureB junctions were investigated using oxide window structures, only. Samples presented here show the same characteristic behavior comparable to diodes in [3]. Seen in Fig. 3 is the $I(V)$ characteristic of a typical diode. The oxide windows of the given device had a radius of $r = 5$ µm. All diodes measured exhibit idealities within a range of $n_{id} = 1.05$ and $n_{id} = 1.15$. Another characteristic behavior of pureB junctions is the exceptionally small leakage current, which is as low as $I_{off} = 1 \cdot 10^{-12}$ A - $3 \cdot 10^{-12}$ A. With the above given geometry, the current density of the shown diode is in the range of $J_{off} = 1.27 \cdot 10^{-6}$ A·cm^{-2} – $3.8 \cdot 10^{-6}$ A·cm^{-2}. The low leakage current is leading to a high I_{on}/I_{off} current ratio of more than nine orders of magnitude.

C. Electrical Characteristics of the Mesa Diodes

Shown in Fig. 4 is an overview of the $I(V)$ characteristics of the pureB diodes with mesa structure for different deposition temperatures. The featured diodes also possess the same geometry with a mesa radius of $r = 5$ µm. Diodes of all deposition temperatures exhibited the characteristically low leakage current of the pureB junction, an ideality factor in the region of $n_{id} = 1.2$ and a high I_{on}/I_{off} current ratio.

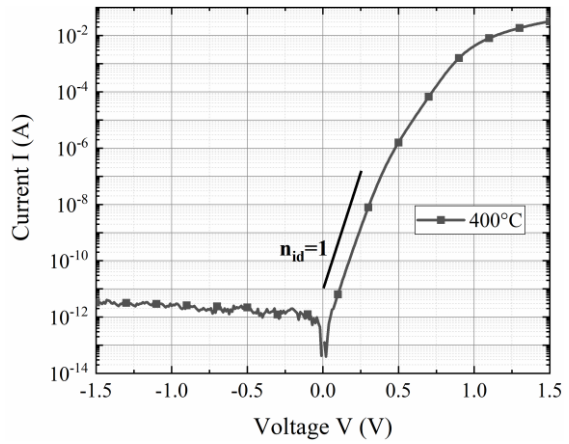

Figure 3. $I(V)$ characteristics of SiO_2 window diodes deposited at $T_{sub} = 400$ °C with a radius $r = 5$ µm

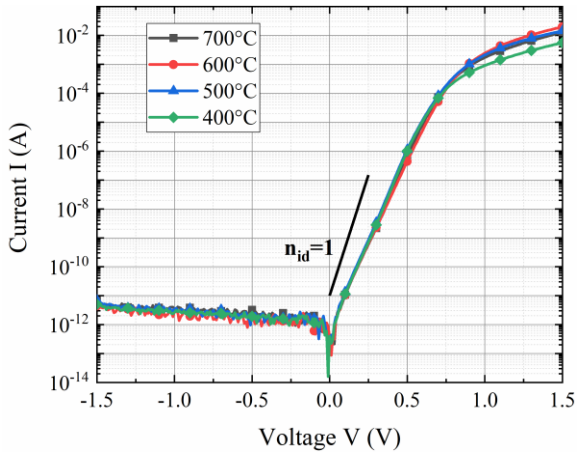

Figure 4. $I(V)$ characteristics of mesa diodes at different deposition temperatures with a radius $r = 5$ µm

It should also be noted that the characteristics were very similar for all deposition temperatures. The measurements show that the functionality of MBE deposited pureB is not impaired by low-temperature deposition.

Diodes with radii larger than $r = 10$ µm showed large SRH consistently, by having an ideality close to $n_{id} = 2$ at low forward voltages and comparatively large reverse current. This phenomenon is exemplarily shown at diodes of different sizes, deposited at $T_{sub} = 700$ °C, in Fig. 5. Diodes of all deposition temperatures showed this behavior with no dependence on the deposition temperature visible. Such behavior is caused by defects, either within the first monolayers of the pureB or the substrate itself. The defects were introduced during processing because the defect density is not dependent on deposition temperature and the sample with deposition in oxide windows did very rarely show such recombination effects.

Given the fact that all mesa structure diodes with radii of $r = 20$ µm or larger show consistently increased leakage current, whereas diodes with radii of $r = 10$ µm exhibit mostly ideal behavior, suggests that the defect density is inversely proportional to diode sizes. Taking the abovementioned radii, means that there is at least one defect per $A = 1.3 \cdot 10^{-5}$ cm^2 (for the $r = 20$ µm diode), but less than one defect per $A = 3.1 \cdot 10^{-6}$ cm^2 (for the $r = 10$ µm diode). This equates to a defect density within the range of $D = 8 \cdot 10^4$ cm^{-2} and $3 \cdot 10^5$ cm^{-2}. Smaller diodes showed ideal leakage as can be seen in Fig. 6, where the leakage of diodes with mesa structure and a $r = 5$ µm radius are compared across the whole temperature range.

Neither the average nor the distribution of leakage currents were dependent on deposition temperature and are consistently low.

D. Comparison of the two Device Types

Shown in Fig. 7 are the $I(V)$ characteristics of a mesa pureB diode and an oxide window pureB diode. Both diodes were processed at $T_{sub} = 400$ °C and had an active area radius of $r = 5$ µm. One difference observed is the difference in ideality. The mesa diodes of all deposition temperatures and large radii showed a lower slope during turn-on and exhibited increased current under low injection, which was comparable to SRH recombination in standard pn-junctions. Only mesa diodes exhibited this phenomenon and neither the here presented SiO_2 window diodes nor other pureB diodes presented in [1–3, 8] show such behavior. It could be the case that the etching of the pureB using RIE introduced weak spots around the circumference and therefore introduced current paths, which might lead to such behavior. This emphasizes that B deposition is ideally done as a BEOL processing step to mitigate damage to the pureB.

In addition, both structures show the same leakage current under reverse bias despite the difference in structure. The series resistance of the mesa diode is higher due to the current confinement within the mesa in comparison to the oxide window structure.

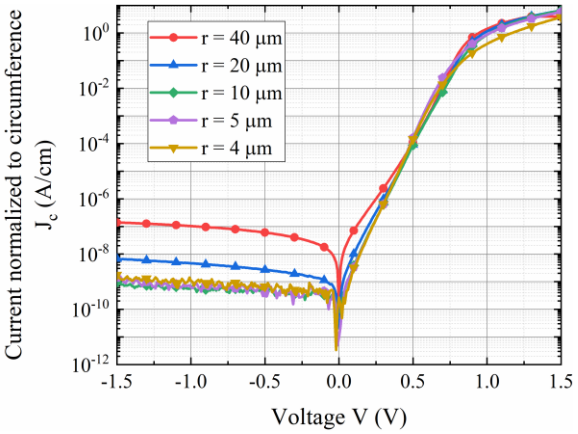

Figure 5. *I*(*V*) characteristics of the pureB diodes with mesa structure of different geometries deposited at T_{sub} = 700 °C

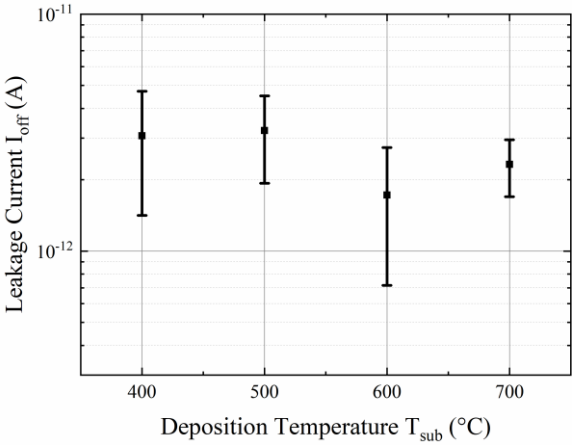

Figure 6. Leakage current of diodes with mesa structures with a radius of r = 5 µm mapped across deposition temperatures

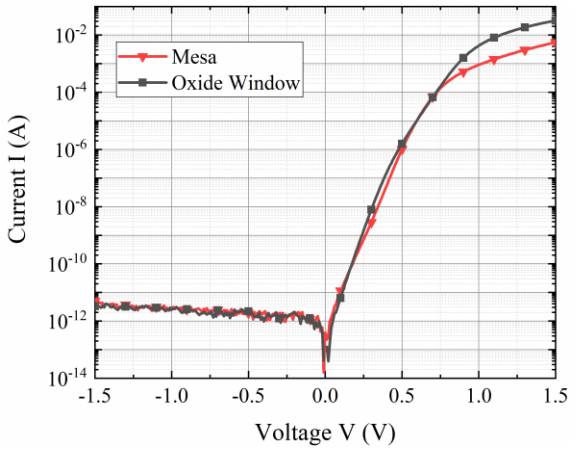

Figure 7. Comparison of mesa and oxide window diodes using same deposition temperature (T_{sub} = 400 °C) and same geometry (r = 5 µm)

E. Avalanche breakdown

In order to calculate the ideal breakdown voltages for the given diodes, the pureB junctions were considered one-sided abrupt pn-junctions. For such junctions the ideal breakdown voltage is given in [10] as such:

$$V_{BD} = \frac{\varepsilon_0 \cdot \varepsilon_{Si} \cdot {E_m}^2}{2 \cdot q \cdot N_D}. \quad (1)$$

In this equation, ε_0 is the permittivity in vacuum, ε_{Si} is the relative permittivity in Si and q is the elementary charge. E_m is the maximum electric field at the pn-junction and N_D is the donor concentration within the drift layer. Due to the $p^+n^-n^+$ structure of the diodes, the ideal breakdown voltage V_{BD} decreases due to the punch-through of the electric field through the drift region. The reduced breakdown voltage V_{BD}' can be calculated by the following approximation made in [10]:

$$\frac{V'_{BD}}{V_{BD}} = \left(\frac{W_{drift}}{W_{Dm}}\right) \cdot \left(2 - \frac{W_{drift}}{W_{Dm}}\right). \quad (2)$$

W_{drift} is the thickness of the drift layer and W_{Dm} is the width of the depletion region at breakdown in a regular pn-junction. W_{Dm} can be calculated by solving the equation for the absolute value of the electric field of a pn-junction in [10] for W_{Dm}.

Assuming a donor concentration $N_D = 1 \cdot 10^{14}$ cm^{-3} in the drift-zone and a thickness of W_{drift} = 3 µm of the drift layer, as well as a breakdown field for doped Si with the aforementioned dopant concentration of $E_m = 2.5 \cdot 10^5$ V·cm^{-1} [10], the ideal breakdown voltage is V_{BD}' = -74.3 V.

Shown in Fig. 8 are the breakdown voltages across the whole deposition temperature range. All the breakdown voltages cluster within a narrow voltage interval of $\Delta V_{BD,real}$ = [+2V, -3.5V] around the calculated ideal breakdown voltage independent of diode geometry or deposition temperature. This means that perimeter effects are not visible at breakdown, especially not for the diodes, which had their B deposited inside oxide windows, even though there were no precautions taken to eliminate perimeter effects, like guard rings or in-diffusion.

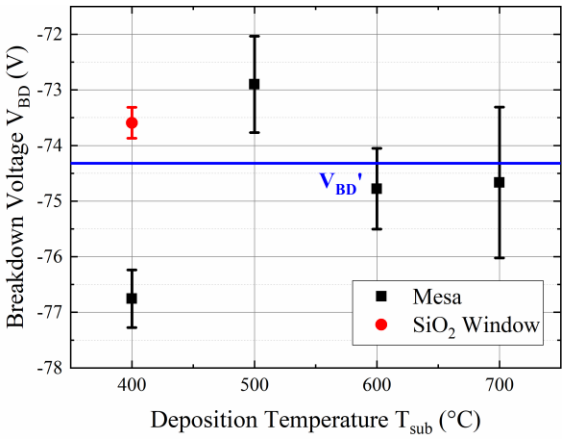

Figure 8. Breakdown voltages of pureB diodes of different deposition temperatures

In Fig. 9, four typical breakdown characteristics of mesa diodes, which had their pureB deposited at different temperatures, are shown. All devices exhibit an acceptable amount of leakage within the range of V_A = [-10V, 0V]. Towards more negative voltages, the leakage current increases to and saturates at around $I_L = 10^{-6}$ A. Diodes, which had their pureB deposited at lower temperatures showed increased leakage already at lower reverse bias. This can be attributed to the change in the surface morphology of the pureB when deposited at different temperatures. The increasing leakage at higher reverse bias is likely due to perimeter effects because no precautions, such as guard rings, were implemented.

F. PureB properties

The quality and roughness of the pureB were evaluated using AFM analysis. An $A_{AFM} = 1\ \mu m^2$ area was measured in the middle of every sample. Fig. 10 shows the surface roughness of B deposited at different temperatures. It can be observed, that with increasing deposition temperature, the surface texture changes from a lower grain size with sharper peaks to bigger grain size and less sharp peaks. However, the rms height of the surface roughness stays the same throughout the samples with $h_{rms} = (2.76 \pm 0.25)$ Å and has no dependence on the deposition temperature. The different surface textures can be explained by the different mobilities of the B atoms at the surface of the sample at different deposition temperatures.

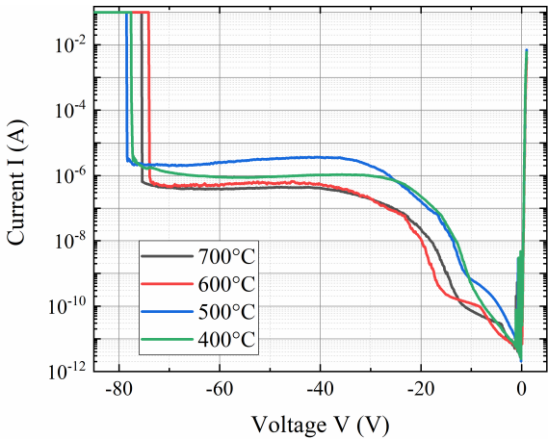

Figure 9. Breakdown characteristics of mesa diodes with equivalent geometry (r = 10 µm) and at different deposition temperatures

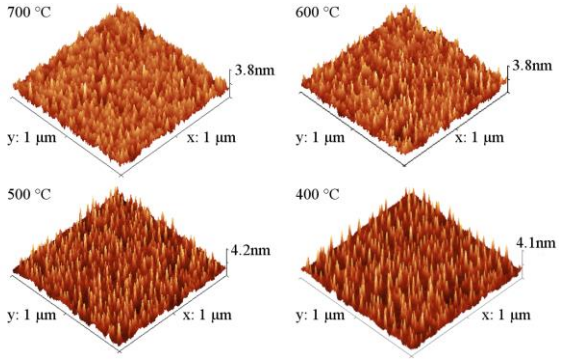

Figure 10. AFM images of the surface roughness of the low-temperature deposited pureB

At temperatures greater or equal to T_{sub} = 400 °C, the mobility of the B atoms at the surface enables the B to move along the surface and cluster together, which explains the fine granular structure with the sharp peaks. Towards high deposition temperatures of T_{sub} = 600 °C and T_{sub} = 700 °C the energy of the indifidual B atoms is high enough that clustering might not be favorable anymore. At those temperatures, the grains tend to stay flatter and do not develop such peaks, which leads to a more homogenous distribution.

IV. CONCLUSIONS

In this work MBE deposited pureB was investigated. Working diodes were manufactured with pureB deposited at T_{sub} = 400 °C with idealities close to n_{id} = 1, low leakage and breakdown close to the ideal value for equivalent pin diodes. It was shown that the low-temperature deposition yields very good pureB diodes independent on deposition temperature, which had minimal effect on the IV characteristics. The comparison of the mesa diodes, which received their boron deposition front end-of-line, with the SiO_2 window diodes showed that processing can lead to worse idealities. Therefore, it is preferable to employ the low-temperature B deposition as BEOL process with a substrate temperature of T_{sub} = 400 °C during deposition

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Impact of ultra-thin-layer material parameters on the suppression of carrier injection in rectifying junctions formed by interfacial charge layers

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Abstract - Pure amorphous boron (PureB) deposition on Si is used to fabricate ultrashallow low-saturation-current p^+n-like diodes even at process temperatures where the boron is not expected to diffuse into the bulk Si. It has been proposed that the bonding of the B atoms to the Si creates a monolayer of fixed negative charge that attracts holes to the interface. In this paper, an investigation using semiconductor simulation tools is performed starting from an all-Si test structure where suppression of electron injection from an n-Si bulk was achieved by introducing a large concentration of negative fixed charge that attracts holes to the interface between a thin-film top-layer and the bulk. This introduces a barrier which lowers the electron saturation current density of the simulated diode to become comparable to or lower than the saturation current density of holes injected into the bulk. The material properties of the top-layer such as electron mobility and tunneling mass, bandgap and electron affinity are individually varied from default Si-values to values typical for amorphous boron layers indicating that a critical concentration of negative fixed charge is always needed for suppression of the electron injection.

Keywords – pure amorphous boron, PureB, negative fixed interface charge, carrier injection, ultra-thin-layer, TCAD

I. INTRODUCTION

In advanced CMOS and other nanoscale silicon device technologies, the fabrication of junctions with appropriately shallow junction depths, low leakage current and low series resistance, remains challenging. Monolayers could be used as a doping-source activated by thermal [1] or laser [2] annealing which inevitably increases the junction depth. Thus the fabricated diodes then function as conventional p-n diodes. In contrast, a pure boron layer (PureB) deposited in an anode region on the Si provides attractive p^+n-like diode characteristics that are comparable to those of conventional deep junctions, albeit for junction depths of only a few nanometer. To our knowledge, the so-called PureB technology is the only example of diode fabrication with deposited dopant atoms where these are not driven into the Si. Depositions down to 250°C using chemical-vapor deposition (CVD) or down to 400°C using molecular beam epitaxy (MBE) offer back-end-of-the-line (BEOL) CMOS compatibility for fabrication of photodiodes [3], [4].

In addition to the electron blocking power that such a layer would give, PureB diodes fabricated as photodiodes with PureB-only light-entrance windows have also shown a very high stability with respect to high-dose irradiation with beams such as extreme-ultraviolet (EUV) light and low-energy electrons that carry so much energy with them that they readily degrade oxide interfaces. This, together with the nm-shallow distance to the radiation sensitive Si layer, has led to a rapid commercialization of PureB detectors for monitoring low-penetration depth beams such as those used in advanced lithography and electron microscopy systems [5], [6], applications for which also PureB single-photon avalanche diode (SPAD) detectors with low dark count rate [7] are under development.

At present, the physical mechanism behind the attractive PureB diode behavior still needs to be fully understood. Based on extensive experimental material, it has been proposed that a monolayer of acceptor states formed at the interface by B-to-Si bonds, is responsible for creating a layer of fixed negative charge that can maintain an interfacial hole layer [3], [8], [9]. Measurements have confirmed that the conductance along the PureB-Si interface is high even for deposition at 400ºC where no doping of the bulk Si is expected [10]. From bipolar transistor measurements with PureB emitters, it was concluded that the concentration of holes at the interface would have to be larger than 10^{14} cm^{-2} to be able to explain the very low base current, i.e., very high electron blocking power [9].

Most of the PureB material parameters are not well-known while material parameters of other boron layer depositions may vary depending on the fabrication method. To understand the impact that a negative interface charge has on the *I-V* characteristics of the fabricated diodes, we have already modeled PureB devices assuming an all-Si test structure. Suppression of the electron injection from bulk was achieved by assuming a large concentration of negative fixed charge between the Si top-layer and the bulk [3]. In this work, we vary the material properties of the top-layer such as mobility of electrons, bandgap and electron affinity to values typical for amorphous boron layers. A critical concentration of negative fixed charge is always

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found to be necessary to explain the rectifying junctions formed by interfacial charge layers.

II. MATERIAL PROPERTIES OF AMORPHOUS BORON

Amorphous boron is a semiconducting material whose bandgap can significantly vary depending on the exact processing conditions. Hydrogenated amorphous boron films reported in [11] have an optical bandgap in the range between 1.4 eV and 1.7 eV with photoconductivity as low as 10^{-9} S/cm. These bandgap values are consistent with the values reported in [12] where the hydrogenated amorphous boron films were heat treated at 400°C for 200 hr which caused a decrease of the optical bandgap from 2.19 eV to 0.9 eV. The decrease of the bandgap is attributed to the reduction of the hydrogen content in the films [12].

Amorphous boron films prepared with different deposition techniques consistently showed lower bandgap than that of Si with variations in the measured value. The electrical bandgap of boron films grown by MBE was found to be 0.6 eV as measured by the electrical conductivity method [13]. Kuhlmann et al. [14] reported an optical bandgap of ≈ 0.75 eV for the several μm thick amorphous boron evaporated films. Electron-beam deposited amorphous boron films with thicknesses between 100 nm and 200 nm showed optical bandgaps of 0.5 eV [15]. Due to the presence of crystallization during the deposition of the amorphous layers, the bandgap could increase to values specific for a more ordered system such as α-rhombohedral boron or β-rhombohedral boron which have optical bandgaps of 2 eV and 1.6 eV, respectively [16]. This was also observed in [17] where the optical bandgap increased from 1.05 eV to 1.4 eV with an increase of the deposition temperature from 700°C to 900°C. One source also reported a thermal bandgap of bulk amorphous boron of 1.3 eV which is higher than that of Si [18].

The conductivity of the amorphous boron layers was found to be in the range from 10^{-3} S/cm to 10^{-5} S/cm at room temperature [13], [18]–[21]. Mobility and conductivity measurements identified that the majority carriers in the amorphous boron layers are holes [19]–[21]. This was also confirmed by scanning tunneling microscope (STM) measurement of a B-complex at the Si surface that places the Fermi level near the valence band edge [22] which is characteristic of p-type doped semiconductors. The values of conductivity, mobility and doping concentrations that have been measured for amorphous boron material in various sources are listed here:

- Boron films grown by MBE had a conductivity at 300 K of 1.5×10^{-5} S/cm [13]. The thermal dependence of the conductivity measured for the material [13] showed a $\log(\sigma)$ versus $T^{-1/4}$ behavior characteristic of the Mott's variable range hopping (VRH) conduction [23].

- The solid source molecular beam deposited films described in [19] had a conductivity in the range from ≈ 10^{-3} S/cm to ≈ 10^{-4} S/cm for growth temperatures between 200°C and 800°C, respectively. The measured drift mobility at room temperature was approximately 10 cm^2/Vs while the concentration of holes was very low to be consistent with the measured low conductivity and ranged from 5.5×10^{15} cm^{-3} to 3.5×10^{13} cm^{-3}.

- Golikova showed an increase of the conductivity at room temperature from 1.6×10^{-6} S/cm to 10^{-3} S/cm for bulk and amorphous boron film samples, respectively [20]. The films were produced by sputtering crystalline boron on a quartz surface at 300°C-350°C with a resulting film thickness less than 1 μm. The mobility at room temperature was 2.2×10^{-1} cm^2/Vs while the concentration of the carriers was not determined.

- In [21], a bulk amorphous boron sample was measured and the conductivity was equal to 7.6×10^{-5} S/cm. The measured mobility was in the range of 1×10^{-2}-1×10^{-3} cm^2/Vs, while the doping concentration was assumed to be approximately 10^{16} cm^{-3}.

- Samples prepared by plasma assisted chemical vapor deposition from boron trichloride gas (BCl_3) were only amorphous to some extent since high temperatures of 700°C-900°C caused the crystallization of the samples to α-rhombohedral boron [17]. The measured Hall mobility was between 5×10^{-3} and 10^{-1} cm^2/Vs while the hole concentration was measured to be between 10^{16} and 10^{18} cm^{-3} [17].

- Time-of-flight measurements were performed on boron samples with thicknesses between 1.2 μm and 1.6 μm deposited on a silicon surface by an electron-beam evaporation technique [24]. Substrate temperatures were 200°C, 300°C and 350°C. From the measurements, hole drift mobility values between 5×10^{-2} and 5×10^{-1} cm^2/Vs were extracted while the electron drift mobility was 3×10^{-1} cm^2/Vs at room temperature. The mobility decreased with decreasing temperature which was explained by variable range hopping conduction.

Due to the difference in bandgap, amorphous boron should form a heterojunction when deposited on Si. In a simplified heterojunction model the band alignment between two semiconductor materials is determined by the electron affinity which can be modeled using Anderson's rule [25]. To the best of our knowledge, the electron affinity of amorphous boron material has not been reported in the literature. The electron affinity of the amorphous boron material could be extracted from measurements of the Schottky barrier height found for amorphous-boron metal systems and applying Schottky–Mott rule [25]. In [26], a gold electrode was contacted to amorphous boron films forming a Schottky contact with a barrier of 0.43 eV. The work function of gold is 5.1 eV [27] which gives an electron affinity of 4.67 eV. Significantly lower affinity can be extracted from a similar calculation based on the data of the Schottky barrier height of copper to hydrogenated amorphous boron [28]. The Schottky barrier height of a Cu/a-B:H interface was measured to be 0.8 ± 0.16 eV [28] while the copper work function is 4.7 eV [27]. The affinity of the a-B:H film can be calculated to be equal to 3.9 ± 0.16 eV. The same authors also reported the conduction and valence band offsets of the hydrogenated amorphous boron films to silicon in an a-B:H/Si configuration [29]. The conduction band offset of a-B:H/Si was found to be 0.15 ± 0.16 eV while the valence band offset of the a-B:H/Si heterojunction was equal to 0.15 ± 0.1 eV [29]. The conduction band offset variation led to the conclusion that the affinity of the a-B:H layer could be equal to the values measured for Si. In addition, the semiconductor work

function can also be used to construct a band diagram of a heterojunction knowing the position of the Fermi level. The semiconductor work function of polycrystalline boron was found to range from 4.3 eV to 4.45 eV for the photoelectric work function [27], [30]. If assumed that the Fermi energy is very close to the valence band edge which is specific to a highly-doped p-type semiconductor, one can find the affinity in the same range as calculated for the a-B:H films. The value of the effective density of states of boron is important for the calculation of the Fermi level energy inside the bandgap. The effective mass of holes in β-rhombohedral boron was found to be close to m_0 ($m_h^* \approx m_0$) [31] while the effective density of the valence states in amorphous boron is 10^{22} cm^{-3} [32].

An overview of the material properties of amorphous boron found in the literature is presented for both bulk-boron samples and samples where the boron is deposited in the form of a thin film. The properties are summarized in Table I.

III. Electrical Modeling

When contacted by p^+ implanted regions, PureB devices can achieve *I-V* characteristics comparable to conventional implanted p^+n junction in terms of low dark currents even for 1-nm thick PureB layers deposited at temperatures as low as 250°C [3]. From the past experimental PureB device results it appears that, when metallized, the PureB thickness does not play a role for the electron blocking effect if it is more than 2 nm and free of weak spots that were sometimes identified in connection with Si surface contamination before B deposition [3], [33]. The thickness does, however, present a significant series resistance if it exceeds the tunneling thickness of about 3 nm because the pure boron resistivity is > 500 Ω-cm [34]. Therefore, for advanced transistor applications it is desirable to have as thin as possible a layer. For very thin PureB layers less than 2 nm the electron injection current was seen to increase by decades, giving Schottky-like characteristics. Therefore, besides the effect of a negative fixed interface-charge, the influence of the metallization is also studied in the simulations.

A. Model parameters and all-Si simulations

For the simulations, Sentaurus Device [35] TCAD software was used. The basic all-Si test structure shown in Fig. 1 was simulated for varying thickness of the deposited top layer, t_{PB}, representing the PureB. The total thickness of the simulated n-type bulk-Si region was set at 500 µm with constant doping 10^{15} cm^{-3}. A fixed negative interface charge, N_I, was defined between the bulk-Si and the top-layer and varied between 10^{10} cm^{-2} and 5×10^{14} cm^{-2}. The

TABLE I. Properties of Amorphous Boron Material

	Range	Reference
Bandgap	0.5 eV - 1.7 eV	[11]-[18]
Conductivity	10^{-3} S/cm - 10^{-5} S/cm	[13], [18]–[21]
Doping	≈3×10^{13} cm^{-3} - 10^{18} cm^{-3}	[17], [19], [21]
Mobility	1×10^{-3} cm^2/Vs - 10 cm^2/Vs	[17], [19]-[21], [24]
Affinity	4.67 eV; 3.9 ± 0.16 eV	[26], [28]

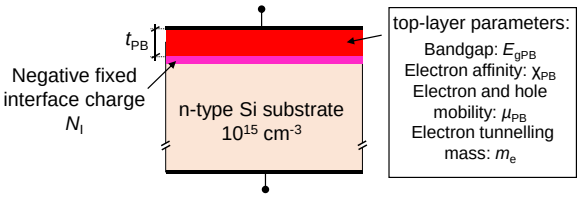

Fig. 1. Cross section of the simulated structure with indicated material parameters of the top layer.

doping of the top-layer, N_{PB}, was set to 10^{18} cm^{-3} as has been reported from experiments with amorphous boron [17]. Boron diffusion into Si is neglected. An Al-metal contact with a work function of 4.1 eV [35] was defined as contact to the top-layer. Band alignment and formation of the Al/top-layer barrier were chosen to follow the Schottky contact model [25] while Schottky-barrier height lowering was neglected. The thermionic emission model was simulated [36] and non-local tunneling to the anode contact was modeled [35] with tunneling mass for holes of $0.1\times m_0$, while tunneling mass for electrons, m_e, was varied from $0.1\times m_0$ to $0.8\times m_0$, where m_0 denotes the electron rest mass. Philips unified mobility model was applied [37]. Electron and hole concentrations are governed by Fermi-Dirac statistics. The material properties of the top-layer such as mobility of electrons and holes, μ_{PB}, bandgap, E_{gPB} and electron affinity, χ_{PB}, are individually varied from default Si-values to values typical for amorphous boron layers as indicated in Fig. 1.

The *I-V* characteristics of the all-Si structure were simulated and saturation current densities for electrons, I_{Se}, and holes, I_{Sh}, have been extracted for N_I between 10^{12} cm^{-2}

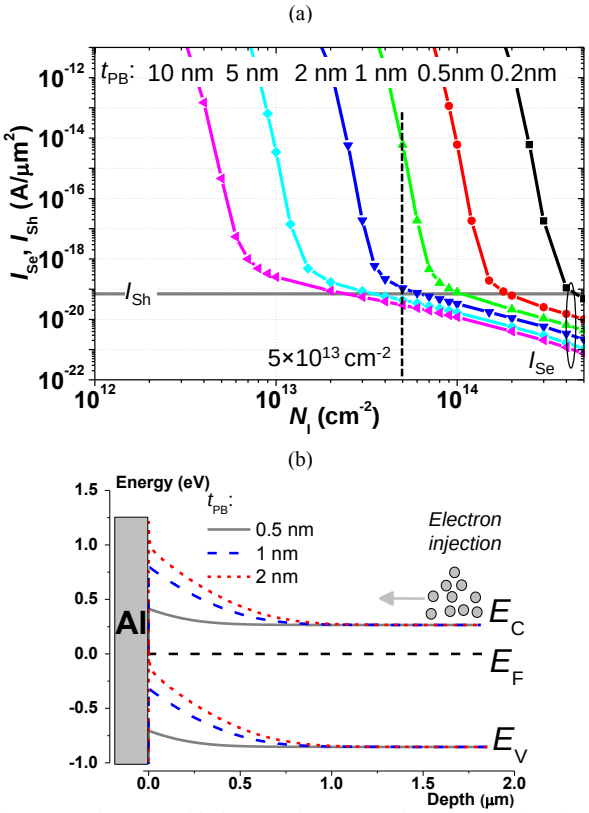

Fig. 2. (a) Electron and hole saturation current densities as a function of N_I extracted for a device with an Al/top-layer contact and t_{PB} = 0.2 nm, 0.5 nm, 1 nm, 2 nm, 5 nm and 10 nm. (b) Band diagram for N_I=5×10^{13} cm^{-2} and t_{PB} = 0.5 nm, 1 nm and 2 nm at V_D = 0 V.

and 5×10^{14} cm^{-2} and are shown in Fig. 2a. For the same concentration of negative interface charge, assuming an Al contact to the top layer causes band bending which lowers the barrier for electron injection as indicated in the band diagram shown in Fig. 2b. The distance between the Al contact and the PureB-Si interface, determined by the PureB layer thickness, dominates the accumulation of holes at the interface. Since the t_{PB} changes the concentration of holes at the interface, it is seen to have an impact on the built-in electric field and depletion region in Si. In the simulated all-Si test structure, suppression of electron injection from the bulk was achieved by introducing a large concentration of holes at the interface. The potential barrier formed in this way can lower the I_{Se} of the diode to become comparable to or lower than I_{Sh}.

B. Electron and hole mobility in the top-layer

Default mobility of carriers in the top-layer and the bulk Si was defined by the doping dependent Philips unified mobility model which resulted in an electron mobility of 65 cm^2/Vs and hole mobility of 44 cm^2/Vs for $N_{PB} = 10^{18}$ cm^{-3}. The mobility of holes in the top-layer was substituted for values found in the literature for amorphous boron material ranging from 10 cm^2/Vs to 10^{-3} cm^2/Vs [17], [19]–[21], [24]. For simplicity, the values of mobility for both the electrons and holes were defined to be the same, μ_{PB}, and were set to the values of 1 cm^2/Vs, 10^{-1} cm^2/Vs and 10^{-2} cm^2/Vs. The simulations were performed for devices with t_{PB} = 1 nm and 10 nm. Electron and hole tunneling masses are $0.1\times m_0$. The electron and hole saturation current density as a function of N_I for both structures and all the mobility values are shown in Fig 3. For comparison, the I_{Se} of the device with the default Si mobility of the top-layer is also shown. The I_{Se} is the same irrespective of the mobility of the top-layer. The top-layer is thin and electron saturation current density is defined only by thermionic emission or tunneling through the barrier and the impact of the low mobility on the minority carrier diffusion can be neglected.

C. Electron affinity of the top-layer

PureB-Si represents a heterojunction and alignment of the two types of semiconductor materials depends on the affinity of each material as can be explained by Anderson's rule [25] which is used in the TCAD simulations. The exact affinity of the PureB material has not yet been measured, and the literature sources do not report the affinity of any amorphous boron materials. The affinity of (hydrogenated) amorphous boron layers has been determined indirectly to vary in the range between 3.7 eV and 4.7 eV [26], [28] as discussed in Section II. Affinity of the top-layer, χ_{PB}, is therefore varied from default Si value which equals approximately 4.1 eV [35] to the values of 3.7 eV, 3.9 eV, 4.3 eV and 4.5 eV. The bandgap of top-layer is defined according to default Si value.

The simulations of I_{Se} and I_{Sh} for the devices with t_{PB} = 1 nm and 10 nm were performed and are shown as a function of N_I in Fig. 4a. Simulations are performed for χ_{PB} = 3.7 eV, 3.9 eV, 4.1 eV, 4.3 eV and 4.5 eV while other parameters have default Si values. For devices with t_{PB} =10 nm having the same N_I, the change of the affinity in the top-layer changes the shape of the barrier since the heterojunction formation impacts the concentration of electrons and holes in both the top-layer and near the top-layer/bulk-Si interface. The band diagram is plotted in Fig. 4b at V_D = 0 V for simulated structure with t_{PB} = 10 nm, N_I = 2×10^{13} cm^{-2} and χ_{PB} varied as: 3.7 eV, 4.1 eV and 4.5 eV. With an affinity of the top-layer lower than 4.1 eV, more holes are found in the top-layer region and a higher barrier is located in the top-layer. On the other hand, the hole concentration on the bulk-Si side of the interface decreases. The barrier in the bulk region also decreases which will allow higher injection of electrons. For χ_{PB} lower than 4.1 eV, larger N_I is needed to increase the barrier in the bulk-Si side to ensure the same blocking of the electron injection from the bulk. For χ_{PB} > 4.1 eV more holes are generated at the bulk-Si side of the top-layer/bulk-Si interface and the barrier for the electron injection is roughly the same as for the default Si value of χ_{PB}.

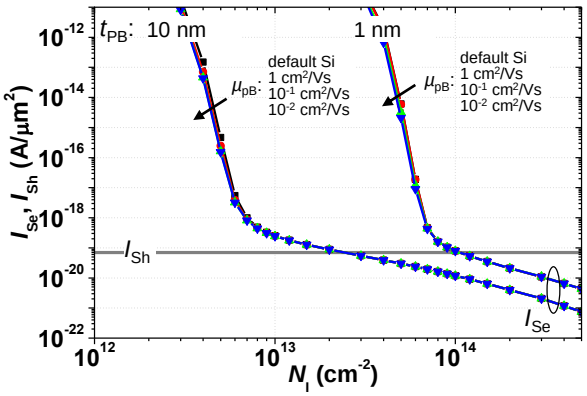

Fig. 3. Electron and hole saturation current densities as a function of N_I extracted for the device with t_{PB} = 1 nm and 10 nm for a top-layer having an electron and hole mobility: default for Si, 1 cm^2/Vs, 10^{-1} cm^2/Vs or 10^{-2} cm^2/Vs.

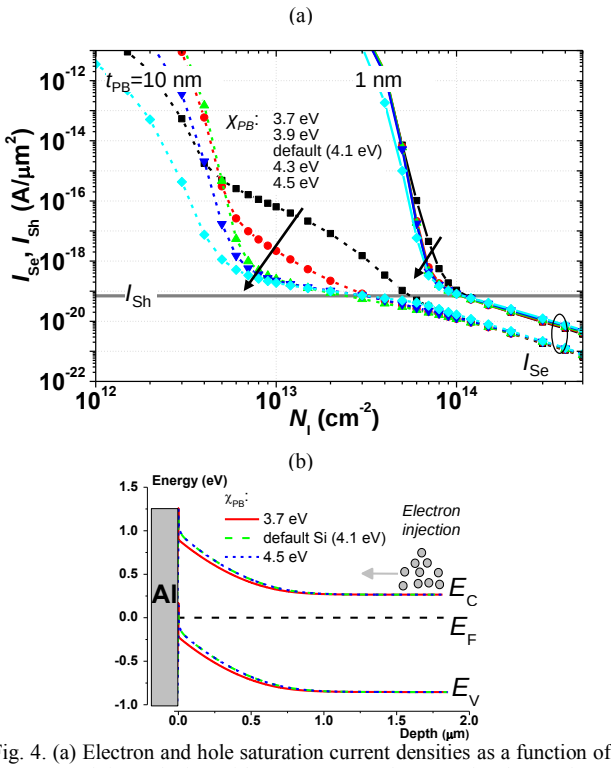

Fig. 4. (a) Electron and hole saturation current densities as a function of N_I extracted for a device with t_{PB} = 1 nm and 10 nm for the top-layer having electron affinity, χ_{PB}: 3.7 eV, 3.9 eV, 4.1 eV, 4.3 eV and 4.5 eV. (b) Band diagram at V_D = 0 V for the simulated structure with t_{PB} = 10 nm, N_I = 2×10^{13} cm^{-2} and χ_{PB}: 3.7 eV, 4.1 eV and 4.5 eV.

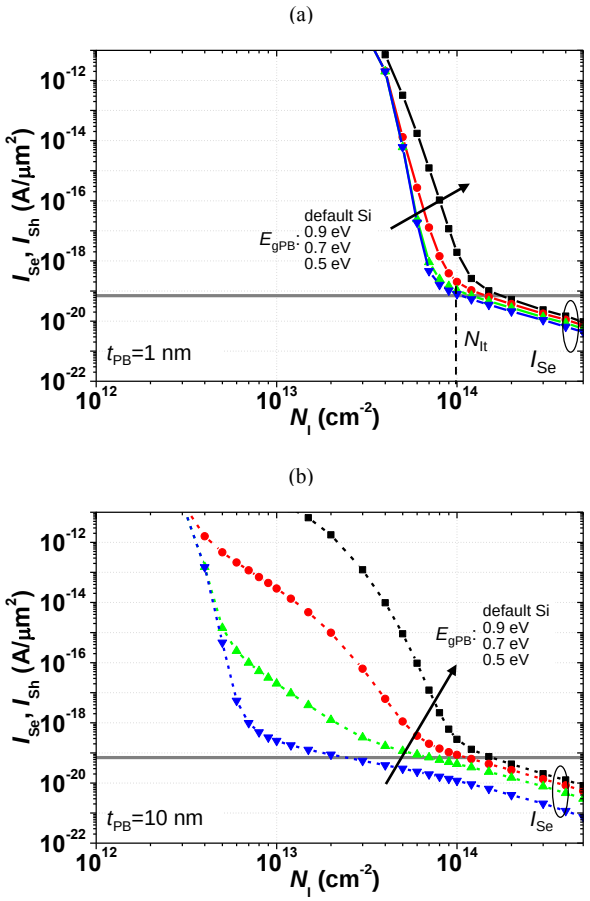

Fig. 5. Electron and hole saturation current densities as a function of N_I extracted for a device with: (a) t_{PB} = 1 nm; (b) t_{PB} = 10 nm. The bandgap of the top-layer is varied as: default Si value, 0.9 eV, 0.7 eV and 0.5 eV.

D. Bandgap of the top-layer

A change in the bandgap of the top-layer, E_{gPB}, causes a discontinuity at the interface which will change the hole concentration near the top-layer/bulk-Si interface. The impact of the bandgap change on the suppression of electron injection was simulated. The simulation results for I_{Se} and I_{Sh} as a function of N_I of the structure with t_{PB} = 1 nm are shown in Fig 5a and for t_{PB} = 10 nm in Fig 5b. All other material parameters have their default values. The N_I needed to decrease I_{Se} to values below I_{Sh} was designated as N_{It}. For t_{PB} = 1 nm, N_{It} increases from 1×10^{14} cm^{-2} for the default Si bandgap of the top-layer to the values of 1.8×10^{14} cm^{-2} for E_{gPB} = 0.5 eV. For t_{PB} = 10 nm the difference in N_{It} is even larger and N_{It} increases from 2.4×10^{13} cm^{-2} for the default Si bandgap of the top-layer to values of 1.6×10^{14} cm^{-2} for E_{gPB} = 0.5 eV. The band diagram at V_D = 0 V for the structure with t_{PB} = 10 nm having N_I = 2×10^{13} cm^{-2} is shown in Fig. 6 for varied bandgap of the top-layer as listed in the figure. For low E_{gPB}, the bulk-Si near the top-layer/bulk-Si interface can be completely depleted of holes. The decrease of the bandgap will reduce the barrier seen by the electrons injected from the bulk. Therefore, the N_I needed to set the same potential barrier for suppressing the electron injection will be higher if the top-layer has a bandgap narrower than the default Si value.

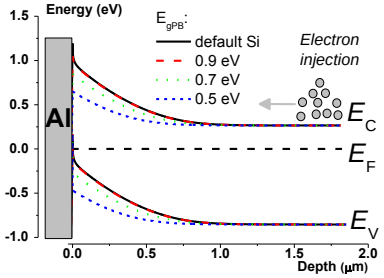

Fig. 6. Band diagram at V_D = 0 V for the simulated structure with t_{PB} = 10 nm, N_I = 2×10^{13} cm^{-2} and E_{gPB}: the same as in Si (≈1.1 eV), 0.9 eV, 0.7 eV and 0.5 eV.

E. Electron tunneling mass

Besides the material parameters of the top-layer, the tunneling mass of the electrons also affects the I_{Se} of the diode. The default values for both the electron and hole tunneling masses were the same in the top-layer and in the bulk-Si and by default equal $0.1\times m_0$. When the barrier for electrons, formed by the negative fixed charge, is sufficiently high, the carriers can only be transported through the barrier by tunneling. Increasing the electron tunneling mass will lower the tunneling probability and I_{Se} will decrease. The impact of the electron tunneling mass on the electron saturation current density of the test structure was simulated and the results for t_{PB} = 1 nm and 10 nm are shown in Fig. 7. The electron tunneling mass was varied as $0.1\times m_0$, $0.3\times m_0$, $0.5\times m_0$ and $0.8\times m_0$. All other material parameters were set to the default Si values. The tunneling component of the electron current starts to dominate the I_{Se} for values lower than 10^{-18} A/μm^2 and it does not affect the critical concentration of the negative fixed charge needed to lower I_{Se} below I_{Sh}. The hole tunneling does not affect electron injection suppression and is only important for transport of holes from the contact to the interface. Most probably, tunneling is governed by VRH conduction characteristic to amorphous materials [23]. However, modeling of VRH is not supported by TCAD simulations. To this end, tunneling of holes is simulated by assuming a constant hole tunneling mass.

IV. Conclusions

The rectifying behavior of junctions formed by PureB deposition is suspected to come from PureB-Si interface where negative fixed charge is responsible for the accumulation of holes. The thus formed barrier then stops injection of electrons from the Si bulk lowering the dark current of diodes where the PureB layer is deposited in the anode region. The simulation study presented in this paper confirms that a concentration of fixed negative charge

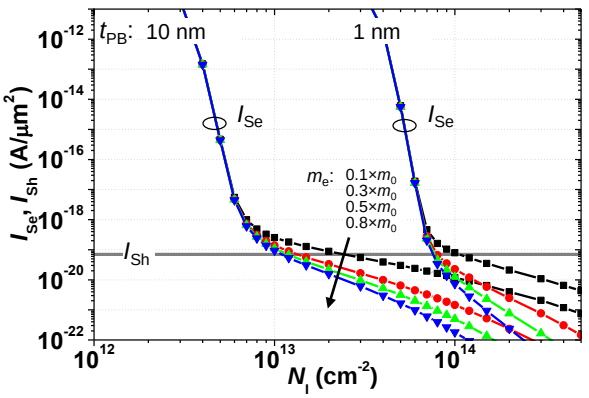

Fig. 7. Electron and hole saturation current densities as a function of N_I extracted for a device with t_{PB} = 1 nm and 10 nm for the electron tunneling mass of: $0.1\times m_0$, $0.3\times m_0$, $0.5\times m_0$ and $0.8\times m_0$.

could be responsible for low saturation current densities of PureB diodes if it is high enough. Material properties of the boron layer may considerably vary with deposition conditions and most of the PureB material parameters are not well-known. An investigation where a large number of material parameters of the ultra-thin layer were varied was performed to gain insight into effectiveness of the barrier formed by the negative fixed interface charge. The variations in affinity, mobility, electron tunneling mass, and bandgap all confirmed that a critical concentration of negative fixed charge is needed to lower the I_{Se} below the I_{Sh}. Depending on the thickness of the layer, effective suppression of electron injection is achieved for N_I from $\approx 10^{13}$ cm^{-2} to $\approx 2\times10^{14}$ cm^{-2}.

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Reverse breakdown and light-emission patterns studied in Si PureB SPADs

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***Abstract* – The relationship between light-emission patterns from silicon avalanche-mode light-emitting diodes (AMLEDs), and avalanche breakdown was investigated using photodiodes fabricated in pure boron (PureB) technology. The quality of the diodes ranged from high-quality, low dark-current devices with abrupt breakdown characteristics that were suitable for operation as single-photon avalanche diodes (SPADs), to diodes with gradually increasing reverse currents before actual breakdown. The reverse *I-V* characteristics were measured and correlated to light-emission data obtained simultaneously using a PureB photodetector, and inspected using a camera with which distinct emission patterns could be identified. When increasing the voltage far past breakdown, light emission invariably becomes dominant at the photodiode periphery. Based on the examination of a large variety of anode geometries, it is concluded that the most efficient light emission per consumed power is achieved with defect-free narrow-anode diodes that also are applicable as low-dark-count-rate SPADs.**

Keywords – Single-photon avalanche diode (SPAD); optocoupler; silicon; pure boron; avalanche breakdown; defects; light-emitting diode (LED); avalanche-mode LEDs

I. INTRODUCTION

High speed optical interconnects are an attractive option for increasing data transmission speeds in CMOS circuits. Ideally this should be realised using silicon (Si) diodes to exploit established CMOS fabrication facilities. Several reports have shown that using avalanche-mode light-emitting diodes (AMLEDs) rather than more commonly used forward-mode LEDs (FMLEDs) could be of advantage [1]–[5], due to the high modulation speed of AMLEDS [6] and the large overlap between the emission spectrum of AMLEDS and the spectral sensitivity of Si photodiodes (PD) [2], [5]. Recent work shows that optocouplers integrated in CMOS can be realised using a PureB AMLED and a PureB SPAD pair. [7], [8].The high photon-sensitivity of single photon avalanche diodes (SPADs) has also meant that they are gaining ground as high-resolution imaging arrays for medical applications [9] and as detectors of automotive LIDAR systems [10]. In [8] a pulse position modulation scheme was used to analyse the data transmission capabilities of the PureB AMLEDs. Some of the results of this analysis are shown in Fig. 1. It was concluded that for low bit-error rates, defect-assisted breakdown of the diode was an advantage. Since large devices had a high probability of containing defects, these performed better in this respect. In [11] the consequences of incorporating defects in AMLEDs was studied with respect to the steady-state light emission efficiency which is defined as detected photocurrent per consumed LED power. In the present paper a more detailed investigation is presented. To this end the effect of defects, doping, and geometry on avalanche breakdown, detected photocurrent, and emission patterns were recorded and analysed.

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II. EXPERIMENTAL METHODS

A. Device Fabrication

Devices were fabricated on (100) silicon wafers as shown in Fig. 2. As described in more detail in [11] 3 different cathode contacting regions were implemented. On p-type substrates the anode was placed in an n-type region grown eptiaxially on an n^+-buried layer, which was contacted by implanting n^+ plugs to reduce series resistance

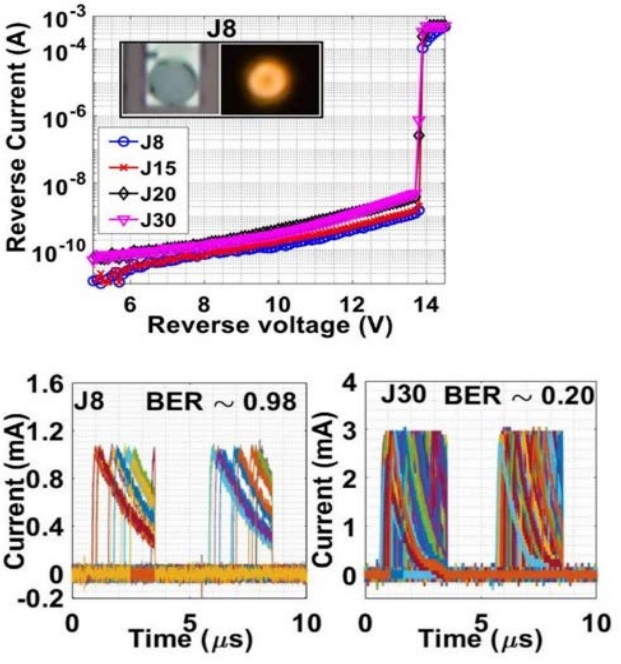

Figure 1. Results presented in [8]. Top: *I-V* characteristics of circular PureB AMLEDs with diameters of 8 µm, 15 µm, 20 µm, and 30 µm. The inset shows a micrograph of the device in the "on" and "off" state. Bottom: Transient waveforms of I_{AMLED} for 8 µm and 30 µm devices while they were biased at −17.6 V. Showing that 8 µm have an unacceptably high BER and that larger 30 µm devices have a far lower BER.

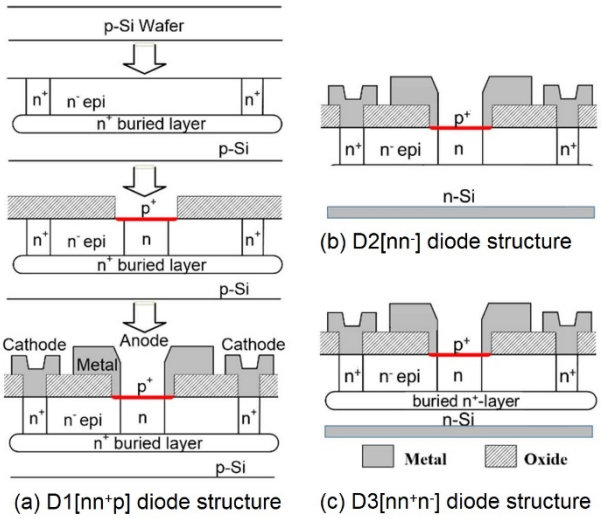

Figure 2. The diode structure and basic process flow for diodes with a buried n^+ layer on p-type and n-type silicon, and diodes without a buried n^+ layer on n-type silicon. Taken from [11].

(Fig. 2a). This design was also processed on n-type wafers where contacting was performed from the back of the wafer (Figs. 2b and 2c). Some of these devices were also fabricated without the n^+ buried layer (Fig. 2b). In the following the 3 device types will be referred to as the D1[nn^+p], D2[nn^-], and D3[nn^+n^-] diode structures, respectively. In all devices an n-enrichment region was formed by implanting phosphorus through 30 nm thermally grown silicon oxide to set the breakdown voltage (V_{br}) in the central region of the anode. The P^+ implantation was performed at 40 keV to a dose of $n = 1 \times 10^{12}$ cm^{-2} , 3.5×10^{12} cm^{-2}, 6×10^{12} cm^{-2} or 8.5×10^{12} cm^{-2}, all followed by an implant at 300 keV to a dose of 5×10^{12} cm^{-2}.The anode regions were defined by etching windows in the oxide surface isolation and depositing PureB to a layer thickness of approximately 3 nm following the process described in [12]. The layer was deposited at 700°C and driven in for 1 min at 850°C. The resulting surface doping created a junction with a thickness of approximately 15 nm with a sheet resistance in the p-type region of 1.7 kΩ/sq. To complete the devices, aluminium layers were deposited on both sides of the wafer and patterned to form electrodes to contact the anode perimeter and the cathode.

An overview of the emission characteristics of the devices was provided in [11], where it was found that devices belonging to the same type, D1[nn^+p], D2[nn^-] or D3[nn^+n^-], displayed approximately the same rate of increase of light emission with increasing LED current, I_{LED}, or increasing LED power, P_{LED}, independent of geometry. Selected results of this paper are listed in Tables I and II, where the photocurrent of a sensitive photodetector (PD) [13], I_{PD}, is a measure for the light emission as determined with the setup A described in Section II.B.

B. *Emission Measurements*

The emissions were investigated using two different experimental setups as shown in Fig. 3. In setup A, light-emission from the PureB LED being tested is monitored by measuring the light-induced current in a large highly-sensitive photodetector (PD) [13] mounted on the objective of a Cascade Microtech probe-station microscope while the LED was being probed and biased on-wafer. The diode voltage was swept from −0.1 V to −20 V (or −18 V) and simultaneously the PD current was recorded. As these measurements were conducted simultaneously, a direct comparison between features in the *I-V* curve and the PD current was possible. Using the same setup, forward *I-V* curves for sweeps from 0 V to 2.5 V and the concomitant LED emissions were also obtained. All measurements were conducted using a shroud and a foam seal to prevent light pollution around the detector. Before and after every sweep, the dark current was measured. These dark current measurements served as an indicator of the quality of the optical shield and were also a measure of how the ambient light/temperature changed during the day. To extract the I_{PD}

TABLE I. THE SLOPE OF $I_{PD}(I_{LED})$ AND THE SLOPE OF $I_{PD}(P_{LED})$ FOR FORWARD MODE OPERATION. ADAPTED FROM [11]

Diode type	n (atoms-cm^2)	Average $\lvert\Delta I_{PD}/\Delta I_{LED}\rvert$ ($\times 10^{-10}$)	Average $\lvert\Delta I_{PD}/\Delta P_{LED}\rvert$ ($\times 10^{-10}$ V^{-1})
D1[nn^+p^-]	1×10^{12}	88	36
D1[nn^+p^-]	6×10^{12}	96	41
D2[nn^-]	1×10^{12}	860	130
D3[nn^+n^-]	1×10^{12}	170	130

TABLE II. THE SLOPE OF $I_{PD}(I_{LED})$ AND THE SLOPE OF $I_{PD}(P_{LED})$ FOR AVALANCHE MODE OPERATION. ADAPTED FROM [11]

Diode type	n (atoms-cm^2)	Average $\lvert\Delta I_{PD}/\Delta I_{LED}\rvert$ ($\times 10^{-10}$)	Average $\lvert\Delta I_{PD}/\Delta P_{LED}\rvert$ ($\times 10^{-10}$ V^{-1})
D1[nn^+p^-]	1×10^{12}	176	10
D1[nn^+p^-]	6×10^{12}	183	9
D2[nn^-]	1×10^{12}	235	9
D3[nn^+n^-]	1×10^{12}	15	7

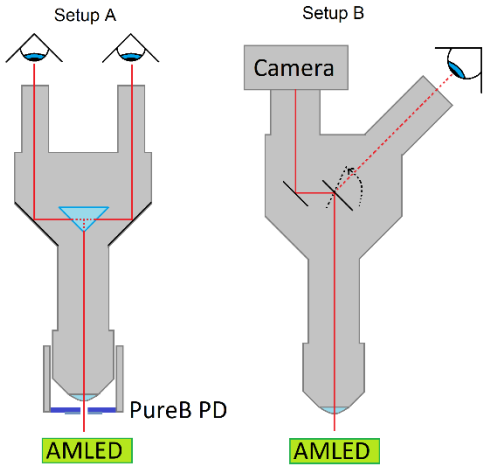

Figure 3. Two setups used for measuring PureB AMLEDs. Setup A (left) is used to obtain quantitative emission data using a highly sensitive detector mounted on a microscope objective. Setup B (right) was used to record images of the emission patterns.

from the PD current, the first four data points close to 0 V biasing were assumed to have been recorded under dark conditions. This was justifiable as the LEDs did not emit light before much higher bias voltages. The mean of these four data points was subtracted from the PD current to obtain the I_{PD}.

Setup B was used to record the emission patterns in AM by using a NIKON digital camera mounted in the optical path of the probe-station microscope, as shown in Fig 3. Images were taken using a 20× magnification and a 20 s exposure time. All electrical measurements were conducted at room temperature, using a Keithley semiconductor parameter analyser equipped with Source-Measurement-Units (SMU) and pre-amplifiers. Using these methods, a large number of PureB devices with varying sizes, geometries, and doping concentrations were investigated.

III. Results and Discussion

In Fig. 4 the reverse *I-V* curves and photocurrents are shown for circular devices of type D1[n$^+$np]. In all the devices, avalanche breakdown occurred close to the breakdown voltage set by the doping level of the n-enhancement region. However, larger devices show an earlier jump in the current level around −7 V. From Fig. 4 it is clear that such jumps are associated with an increase in photocurrent. This was also correlated to the appearance of light emission spots that could be observed with the camera for all the D1[n$^+$np] devices. A selection of these emission patterns are displayed in Fig. 5. Reverse *I-V* curves of the same diodes are shown in Fig. 6 and confirm that the increase in current around −7 V results in light emission spots. Observed current increases are expected to be defect-related avalanching events. This is supported by the reproducibility of both the *I-V* curves and emission patterns. The light emission patterns did not change upon repeated measurements, 9 of which were performed in total.

The behaviour of the 1-µm-diameter diode of Figs. 5 and 6 deviated from that of the larger diodes. Light emission from this small diode is registered by the camera but not by the PD. One explanation for this might be that non-sustained avalanching is occurring near the

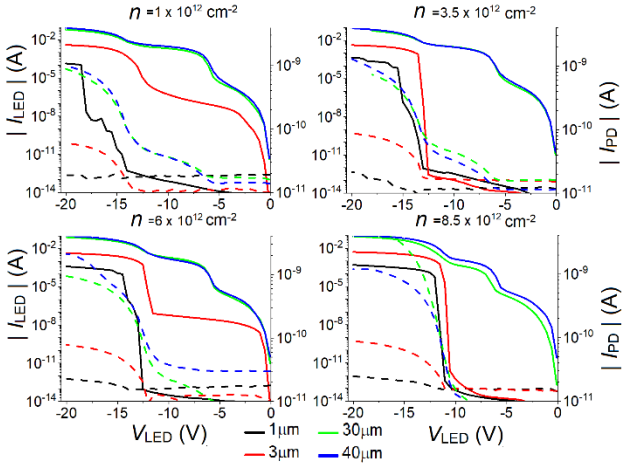

Figure 4. The reverse *I-V* curves around the breakdown voltage (solid) and the detected photocurrent (dashed) at four different doping concentrations for circular D1[n$^+$np] diodes with 4 different sizes.

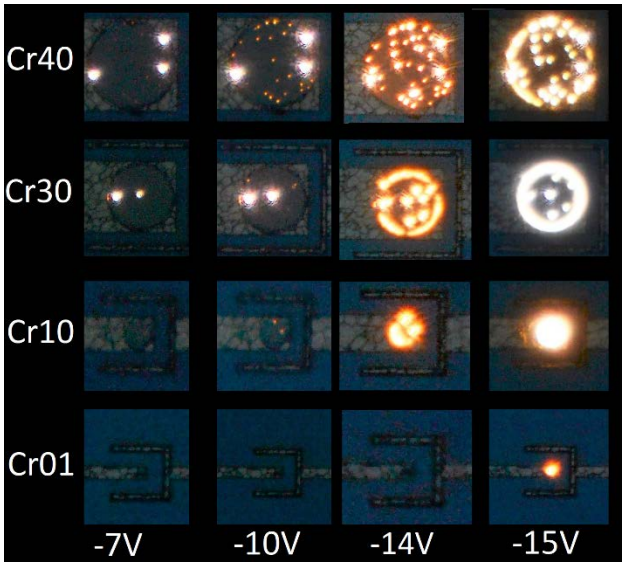

Figure 5. Light emission patterns showing 40-µm, 30-µm, 10-µm and 1-µm-diameter D1[n$^+$np] diodes with n = 10^{12}.cm^{-2}. All images were collected using a 20 second exposure time with brightness corrected to make small features visible.

breakdown voltage which can be seen in Figs. 4 and 6 as irregular *I-V* behaviour just past the V_{br}. Therefore the light emission is not continuous but still detected by the camera due to the long exposure time. From Fig. 4 it is also evident that increasing the doping stabilises the avalanche breakdown and results in a "fully-on" AMLED.

While Figs. 4, 5 and 6 give proof that large circular devices start emitting light at lower voltages than smaller devices where the probability of a defect is smaller, earlier reports [11] have suggested that introducing defects does not increase the emission efficiency. This is supported by Figs. 7 and 9 where the larger devices are seen to emit more light, but without any significant increase in efficiency. Moreover, in Fig. 9 the relationship between I_{PD} and the consumed LED power underlines that neither doping nor geometry have a strong effect on the emission efficiency. Instead there is a strong dependence of the light emission on the LED current both in forward-mode (FM) and avalanche-mode (AM) operation.

All the above measurements where performed on D1[nn$^+$p] devices that had complete diode isolation with

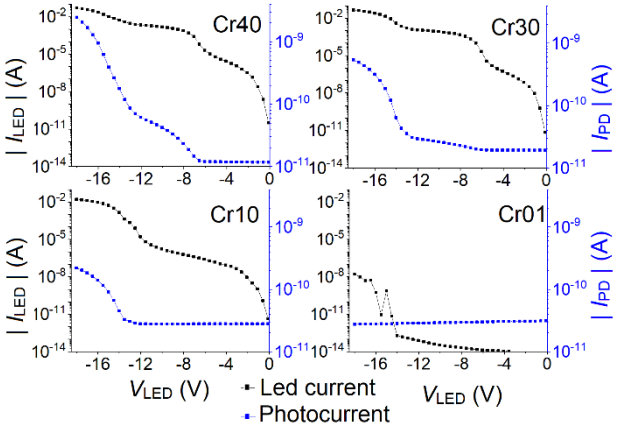

Figure 6. The reverse *I-V* characteristics and detected photocurrents for the specific diodes which were used during the light-emission measurements shown in Fig. 5.

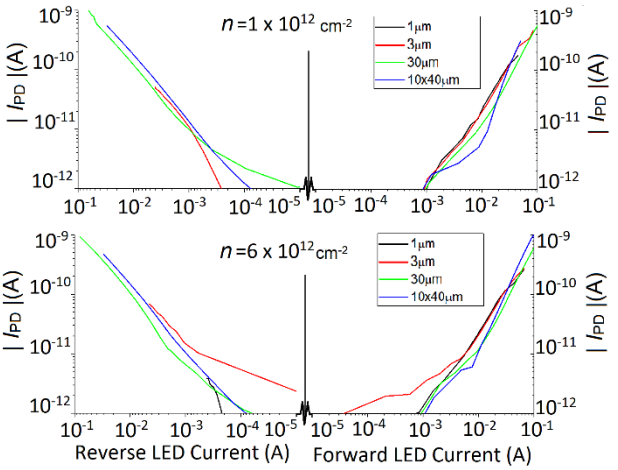

Figure 7. Photocurrent as a function of LED current for 4 D1[nn$^+$p] type diode, 3 with circular geometry with diameters 1 μm, 3 μm and 30 μm, and one with a rectangular area of 10 × 40 μm^2.

buried n$^+$ layer on a p-type wafer. The same measurements were repeated on D2[nn$^-$] and D3[nn$^+$n$^-$] devices that were not isolated but placed on n-type wafers with (D3[nn$^+$n$^-$]) and without (D2[nn$^-$]) a buried layer. An overview of the results of these measurements is shown in Figs. 8 and 10. In Fig. 8 the relation between photocurrent and LED current/power is shown. While this again shows that doping has no strong influence on the light emission, it also shows that D2[nn$^-$] devices with a V_{br} = −14 V are much more efficient in FM than D3[nn$^+$n$^-$] devices with V_{br} = −7V. This is due to the larger spreading of holes injected from the anode into the substrate when the n$^+$-buried layer is omitted.

While it is clear that D2[nn$^-$] diodes in forward emit more light at lower currents than D3[nn$^+$n$^-$] diodes, the *I-V* curves in Fig. 10 show that in reverse D3[nn$^+$n$^-$] devices start emitting light at a lower voltage. Furthermore, the emission pattern of D3[nn$^+$n$^-$] diodes display emission spots comparable to the emission patterns seen in Fig. 5. This supports the earlier proposal that the emission spots are due to defect-related breakdown. In contrast, D2[nn$^-$] diodes exhibit emission rings at the diode perimeter with no spots appearing in the devices. This fits the earlier conclusion that a sharp breakdown at the voltage set by the

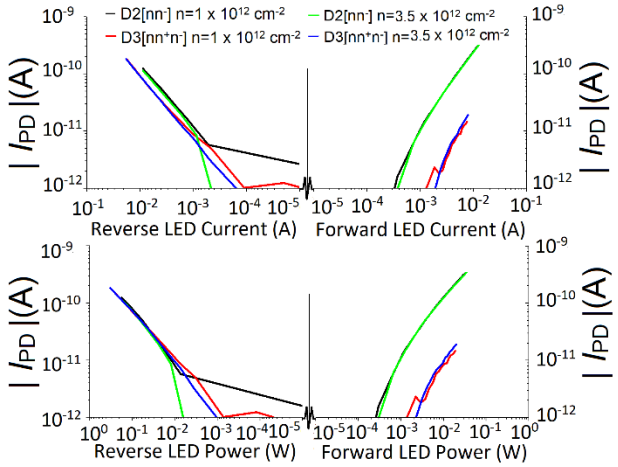

Figure 8. Photocurrent as a function of LED current (top) and consumed LED power (bottom) for circular D2[nn$^-$] and D3[nn$^+$n$^-$] diodes with a diameter of 15 μm.

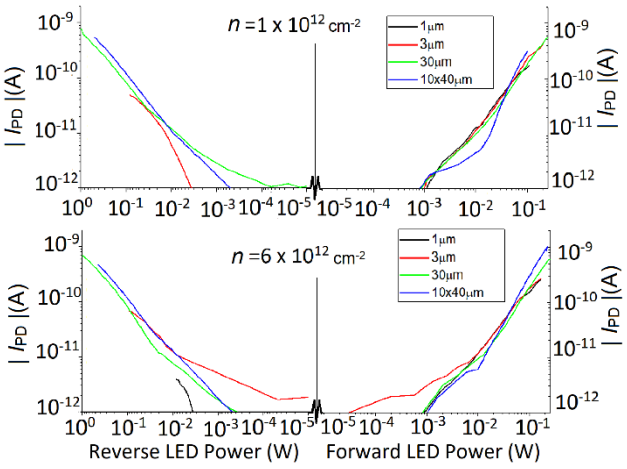

Figure 9. Photocurrent as a function of consumed LED power for 4 D1[nn$^+$p] type diode, 3 with circular geometry with diameters 1 μm, 3 μm and 30 μm, and one with a rectangular area of 10 × 40 μm^2.

enhancement doping will be associated with a emission pattern without spots.

While Fig. 8 does show that the emission efficiency of D2[nn$^-$] devices is higher than that of D3[nn$^+$n$^-$] devices in FM mode, it does not indicate any clear advantage during AM operation. In order to conclusively determine whether or not defect rich devices could be more efficient, the photocurrent versus AMLED power of a D2[nn$^-$] and a D3[nn$^+$n$^-$] device are plotted in Fig. 11. Except for the presence of the buried n$^+$ layer the devices are identical, having the same doping concentration and the same geometry. Narrow rectangular devices with an area defined by gate length, *L*, and gate width, *W*, of 2 μm × 20 μm were used to minimise the area that does not contribute to the emissions. Fig. 11 clearly demonstrates that the D2[nn$^-$] devices with a V_{br} = −14 V are more power efficient during both FM and AM operation. During AM operation the trend is most evident in the low power range up to 50 mW.

The effect of device area on the emission efficiency of rectangular D2[nn$^-$] and D3[nn$^+$n] devices is shown in Fig. 12. Here, the detected LED currents and photocurrents are shown as a function of *L* for two different voltages during

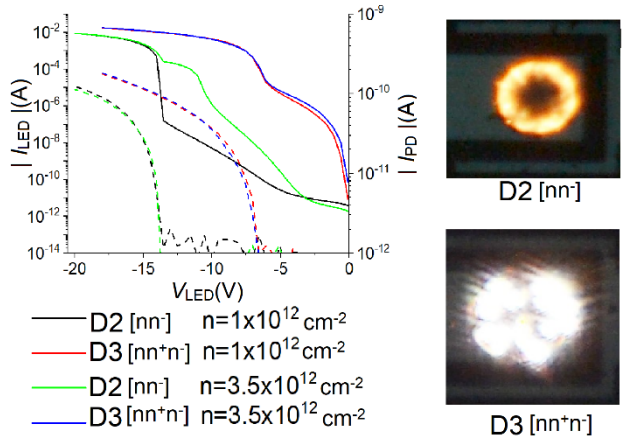

Figure 10. Left: the reverse *I-V* characteristics and detected photocurrents for circular D2[nn$^-$] and D3[nn$^+$n$^-$] diodes showing I_{LED} (solid) and I_{PD}(dashed). Right: Emission patterns of circular D2[nn$^-$] and D3[nn$^+$n$^-$] diodes with a diameter of 15 μm

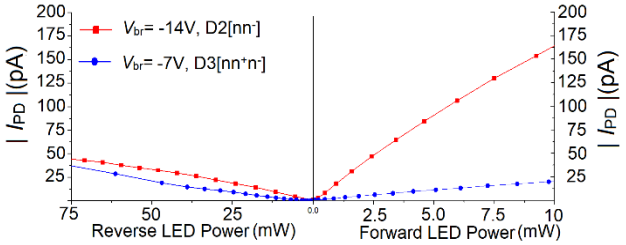

Figure 11. A comparison between D2[nn⁻] and D3[nn⁺n⁻] diodes, showing the photocurrent as a function of consumed LED power. Both diodes had a rectangular geometry of 2 µm × 20 µm.

either AM or FM operation. Again, it shows that D2[nn⁻] devices are far more efficient during FM operation with considerably higher ratio between I_{PD}/I_{LED} than D3[nn⁺n] devices of the same size and voltage. However, both currents show no evident increase with device area since I_{LED} is dominated by the series resistance through the substrate [11]. In reverse the I_{LED} did increase with device area but the rate of increase was significantly attenuated already for 4 µm gate lengths. This could be correlated to the formation of light emission rings for the 14 V devices (D2[nn⁻]) that indicate a strong current crowding at the anode perimeter, which was related to the sheet resistance of the anode region.

The perimeter breakdown could also contribute to increased light emissions above V_{br} set by the n-enhancement implantation but is difficult to examine experimentally. The presence of a second breakdown at the perimeter of a device close to V_{br} is shown by simulations [14]. For the devices with V_{br} = −7 V (D3[nn⁺n]) the current attenuation is equally strong, if not stronger, but can in first instance only be correlated to the appearance of light spots. These spots do increase the amount of light emitted as compared to V_{br} = −14 V devices with the same area but at the cost of more LED current. Moreover, for the narrow devices there is an approximately 20% benefit to using D2[nn⁻] devices. This benefit decreases with increasing device area as the sheet resistance through the anode starts to dominate and bright rings are formed at the anode perimeter. For the D3[nn⁺n] device these rings had a spotted appearance that is not seen for the D2[nn⁻] devices.

IV. Conclusion

The presented PureB diodes when used as AMLEDs displayed stable light-emission at visible wavelengths that could be monitored quantitatively with a PureB photodetector. The emission efficiency did not display any significant dependence on anode area/geometry or the doping of the cathode enhancement region. Furthermore, the similarities between the behaviour of D1[nn⁺p] and D2[nn⁻] devices indicates that the device isolation does not strongly affect the emission efficiency.

The main factors that do influence emission efficiency were identified as defect concentration and series resistance. Both these cause current hogging, the former at the position of the defects and the latter at the perimeter of the device. In both cases, this effect diminishes the chance of reaching voltages over the whole device area that could lead to light emission. Therefore, to make best use of the perimeter current crowding, narrow rectangular devices are

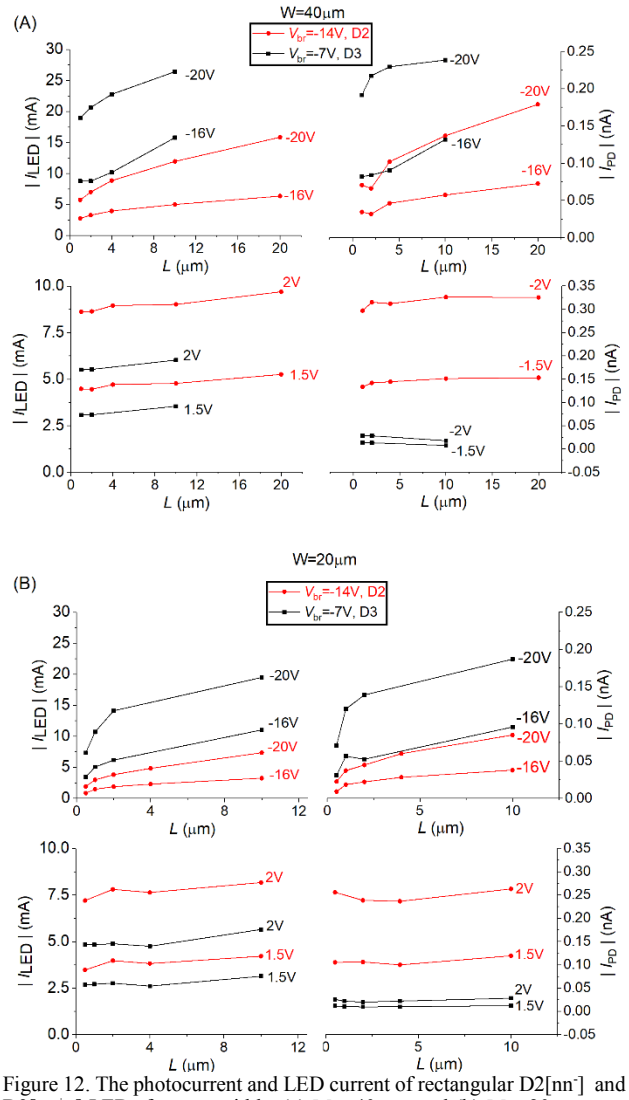

Figure 12. The photocurrent and LED current of rectangular D2[nn⁻] and D3[nn⁺n] LEDs for gate widths (a) W = 40 µm and (b) W = 20 µm as a function of gate length L. All devices had the same doping concentration $n = 1 \times 10^{12}$ cm^{-2}, and were measured at reverse voltages of −16 V or −20 V as well as a forward voltages of 1.5 V or 2 V.

preferable, and defects that cause local current crowding should be avoided. In [11] it was concluded that introducing defects to enhance the light emission was beneficial neither for AM nor FM operation of the diodes. From the present results it becomes clear that by introducing defects there even is a small emission penalty in AM. Therefore, the optimal device design should aim to have an as uniform as possible lateral voltage distribution over the whole light-emitting n-region of the diodes.

For the application to data transmission in on-chip optocouplers, the bit-error-rate was shown to be improved by the presence of defects to provide charge carriers for initiating avalanche events [7]. The conclusion that these extra charge carriers should preferably be supplied by sources surrounding the light-emission area rather than being placed in that area, was made in [11] because this was seen to reduce the spread in light-emission and would lead to more reproducible methods of device fabrication. From the present study it is now clear that there is a benefit for the light-emission efficiency to use defect-free SPAD-

quality diodes both for the function as SPAD detector and as the AMLED.

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PIN-photodiode based active pixel in 0.35 µm high-voltage CMOS for optical coherence tomography

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Abstract - This paper presents an active pixel based on a PIN photodiode for application in Optical Coherence Tomography (OCT), where a high responsivity and low crosstalk is required. The proposed pixel is built on a wafer with a high-resistivity epitaxial silicon layer and optimized for high efficiency at 850 nm, low dark current, low crosstalk, and low noise operation. Advantages of this approach over conventional approaches such as the 3T active pixel in a standard CMOS process and over 4T pinned photodiode active pixel approaches for OCT applications are explained. A test chip was fabricated in 0.35 µm high-voltage CMOS. Three different epitaxial layer thicknesses are investigated. Measured results of the OCT PIN-photodiode pixel are presented.

Keywords - PIN photodiode; active pixel; high resistivity; waveguide coupling; 0.35 µm CMOS; low crosstalk; low noise;

I. INTRODUCTION

From day to day, the number of applications where electronics and photonics are integrated monolithically or in a 3-dimensional manner is increasing. This concept of integration is applied in many applications such as data communications [1], biosensing [2], transmitters [3], LIDAR systems [4] etc. For the spectral-domain optical coherence tomography (OCT) investigated here, an arrayed waveguide grating (AWG) separates the spectrum into 512 waveguides. The wavelength of the used light is determined by the application (ophthalmology) and lies in the near-infrared (NIR) spectral region (800-900 nm). Due to the limited optical power because of eye safety, an optical power on the order of nanowatts is expected per photodiode. Coupling the light effectively out from the waveguides into the photodiodes requires structures that are significantly larger than the used wavelength and this determines the size of the integrated photodetector. The grating coupler at the waveguide's end has a large length. The photodiode, therefore, needs a size of 50 µm×10 µm.

When light penetrates deeper (T_{pen} (850 nm)~25 µm) into the silicon (where the penetration depth is defined as the depth at which incoming radiation is attenuated for the factor of e) than the depth of the photodiode's space-charge region, a high probability of diffusion of photogenerated electrons to the neighboring photodetectors exists. Carrier diffusion occurs for 850 nm light and low or moderately increased supply voltages especially for homogenously doped substrates with usually a doping concentration of 10^{15} cm^{-3}. In applications where low crosstalk is demanded, photodiodes must be fully depleted. Instead of increasing the reverse bias voltage, a deeper depletion region can be achieved by use of a highly resistive (lowly doped) epitaxial (EPI) layer, which is obtained by lowering the doping concentration of acceptors in the EPI layer.

Nowadays most of the commercially available image sensors are CMOS image sensors. Active pixels, which exploit pinned photodiodes are known as very sensitive, low-noise and high conversion gain pixels [5]. It also should be mentioned that the good performance of the conversion gain of active pixel sensors relates to their small pixel area, i.e. to the small capacitance of the photodetector. Furthermore, image sensors are typically optimized for the visible spectrum and the photodetector's responsivity between 800 and 900 nm is low.

In applications, where these longer wavelengths are used, PIN photodiode based photodetectors could have many advantages over widely used conventional pinned photodiode based pixels or simple *p*/*n*-photodiode based pixels in a standard CMOS process. A pinned photodiode (which is practically a double photodiode with two vertically arranged *p*/*n* junctions leading to a high capacitance per µm²) with the large light-sensitive area needed for the OCT sensor would lead to a very long charge transfer time, when full charge transfer to the floating storage node in a 4T pixel is needed. The capacitance of a large-area PIN photodiode per µm² is much smaller than that of a pinned photodiode. The PIN photodiode, therefore, leads to a fast response in waveguide coupled OCT applications. This work presents the implementation of a PIN photodiode based active pixel on a *p*-/*p*+ epitaxial wafer. Its advantages and disadvantages are shown and a good basis for the development of a sensor for OCT is introduced.

II. PIN PHOTODIODE

The PIN photodiode is built of *n*+ (cathode), an intrinsic *p*- type silicon layer and *p*+ substrate (anode). The concept of spectral-domain OCT requires the implementation of up to 512 independent channels, each of them comprising one photodiode. The photodiodes are arranged either in an 1- or 2-dimensional array. To prevent electrical crosstalk between neighboring channels the photodiodes should be separated as far as possible from each other and/or each detector should comprise a guard ring. The PIN

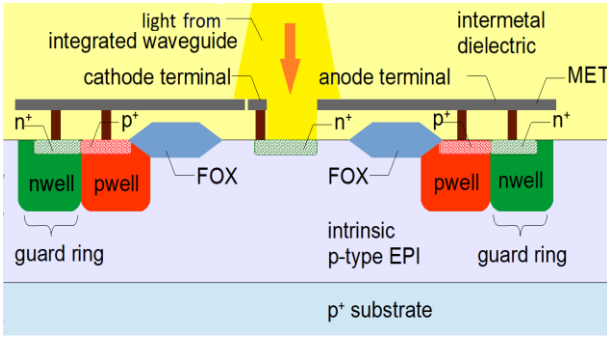

Figure 1. PIN photodiode cross section.

photodiode's cross section is depicted in Fig. 1. The photodiode's active area of 10×50 µm^2 is determined by the grating coupler's size, while the cathode to anode distance (25 µm) and the guard-ring width (15 µm) are chosen in a way to minimize the dark current and the crosstalk. The total pixel area is 290×250 µm^2.

By decreasing the doping concentration of the EPI silicon, the depletion region for the same reverse bias voltage extents deeper into the *p*- EPI. Ideally, all of the intrinsic EPI that is irradiated by incoming light should be depleted. Light that is absorbed within the space-charge region (SCR) will almost instantaneously contribute to the photocurrent due to carrier drift, light that penetrates through the SCR generating carriers in the *p*+ substrate will give a much slower photocurrent contribution due to carrier diffusion and it also raises the chance to give a current signal in one of the neighboring pixels due to 3-dimensional carrier diffusion. To suppress this crosstalk signal each pixel is surrounded by a short-circuited *p*/*n*-junction ring, a so-called "guard ring". The necessity of applying significant reverse biases for a fully depleted diode and the high-resistive EPI-type starting material both require a special isolation concept for the electronic circuits. Therefore we use for the circuit design solely isolated devices in the high-voltage CMOS technology that are isolated by deep *n*-wells.

We have tested three different EPI thicknesses (20, 30, 40 µm) for their spectral responsivity behavior. The measurement results are depicted in Fig. 2. The photodiodes were illuminated with light from a monochromator. The responsivity for 850 nm with 20 µm EPI layer thickness is 0.445 A/W increasing to 0.55 A/W for 40 µm EPI layer thickness, where *SRmax* is the maximal theoretical spectral responsivity of a device with the quantum efficiency of 100%.

If we compare obtained measurement results with the spectral responsivities of the photodiodes in standard CMOS, we see a significant increase of spectral responsivity in the spectral region of 800 to 900 nm. Koklu et al. [6] reports spectral responsivities of *p*+/*n*-well/*p*-sub, *n*-well/*p*-sub and *n*+/*p*-sub photodiodes in a 3T APS at different diffusion areas in standard 0.18 µm CMOS process. Obtained spectral responsivities in the wavelength range of 800 to 900 nm are from 0.02 to 0.35 A/W. These results match measured results obtained by Strle et al. [7] who measured spectral responsivities of *n*+/*p*-sub, *n*+/*p*-well, and *n*-well/*p*-sub photodiodes in 130 nm standard CMOS process.

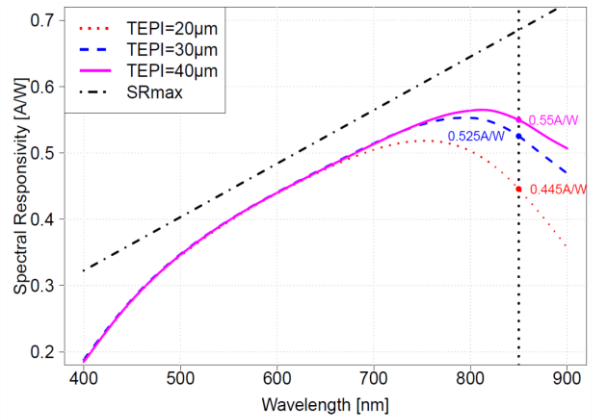

Figure 2. PIN photodiode spectral responsivity measurement results with different EPI layer thicknesses where comparison is made with the maximal theoretical spectral responsivity (*SRmax*).

Another benefit of low doped EPI is seen in cross talk measurements, where in the spectral region from 800 to 900 nm we obtain extremely low cross talk below -60 dB for a photodiode pitch of 140 µm and for all three epitaxial layer thicknesses, which fulfills the requirements of an OCT application. On the other hand we observed an increase of the dark current with increasing EPI thickness, $I_{dark}(TEPI = 20\ \mu m) = 0.556$ pA, $I_{dark}(TEPI = 30\ \mu m) = 1.53$ pA, and $I_{dark}(TEPI = 40\ \mu m) = 3.66$ pA where the reverse bias voltage is -10 V. Therefore, we chose 20 µm EPI thickness wafer as the most optimal starting material for an OCT pixel sensor.

III. PIXEL DESIGN

A. Conventional approaches

1) P/N-photodiode active pixel in a standard CMOS process

In a standard CMOS process photodiodes are usually formed of *n*+/*p*-well or *n*-well/*p*-well. Maximum allowed supply voltages in such processes, where the resistivity of the silicon is about 10 Ωcm [8], can barely deplete such photodiodes, therefore the probability of diffusion of photo-generated electrons to neighboring pixels is high, especially for longer wavelengths, which penetrate deeper into the silicon. Ref. [9] reports crosstalk of almost 25% for 850 nm wavelength, 8 µm thick epitaxial layer and 4 µm photodiode pitch. Due to this fact these pixels usually have high crosstalk and low efficiency for longer wavelengths, therefore this type of pixels doesn't suit well for OCT applications.

2) 4T pinned photodiode active pixel

Another conventional approach is the 4T pinned photodiode pixel. Key benefits of this approach are very low dark current, high conversion gain (only for small pixels), separate charge integration and storage regions, noiseless charge transfer and efficient suppression of reset (*kT/C*) noise, which is the major noise source in 3T pixels [10]. Charge transfer efficiency becomes more and more critical for larger pinned photodiodes when the transfer time dramatically increases. For example for a photodiode size of 40 µm × 40 µm for complete charge transfer 3 µs

to 6 µs are needed [11]. Electrical crosstalk also could be a problem at longer wavelengths. Ref. [12] reports crosstalk of almost 16% at 850 nm (TCAD simulations), while pixel pitch and technology are not mentioned. Even with many advantages, this type of pixel is not a good choice in applications where large photodiodes are required as well as in applications where long wavelengths are used. Since the pinning layer of the pinned photodiode is connected with the *p*-type substrate, negative voltages cannot be applied to the substrate to extend the SCR.

B. PIN photodiode based active pixel

The proposed pixel is based on the 3T architecture. The schematic of the test pixel and a timing diagram are shown in Fig. 3. This pixel consists of a PIN photodiode and three transistors. Transistors M1 and M2 form a source follower (gain less than unity) and the third transistor (M3) is used as a reset transistor. A select transistor was not needed in this pixel test structure.

Prior to integration, the photodiode is reset (RS signal is high for 1 µs). The supply voltage of 2.2 V together with the reset (RS) pulses of 3.3 V makes the pixel working in the hard reset mode ($V_{DD}<V_{G3}-V_{TH3}$), which means fast and complete removal of charges from the photodiode during the reset, where the final photodiode reset voltage fixes at V_{DD}. In this case, 2.2 V is the maximum supply voltage for which hard reset works. Benefits of a hard reset operation are elimination of image lag the and better linearity on one hand, but lower saturation level on the other hand [13], [14]. During the integration, which duration is fixed, the maximal exposure time is set to 190 µs.

The conversion gain of this architecture depends on the photodiode capacitance. Operating conditions are given in Table 1. The anode voltage is chosen in a manner to achieve the best performance of the photodiode (low dark current, low crosstalk, and the smallest possible photodiode capacitance). Load of the pixel is the impedance of the oscilloscope probe (C=20 pF, R=1 MΩ).

Main noise source in such a pixel is the reset (kT/C) noise and its rms noise is $\sqrt{kT/C}$ for hard-reset operation, where k is the Boltzmann constant, T the absolute temperature and C is the photodiode's capacitance. For

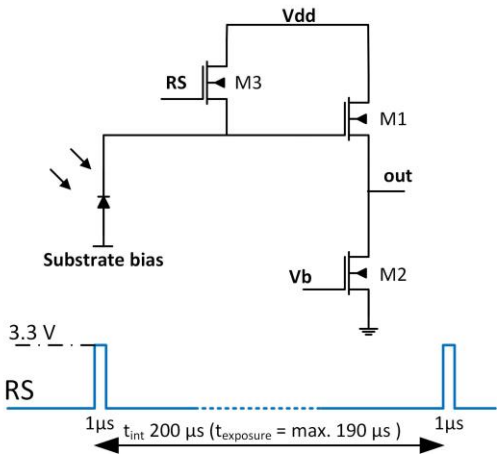

Figure 3. Schematic of test pixel and timing diagram.

Table 1. Pixel operating conditions.

Parameter	Value
V_{DD}	2.2 V
Substrate bias	-10 V
Bias current	3 µA
Load impedance	C=20 pF, R=1 MΩ

implemented photodiode, which has a capacitance of 149.9 fF at -10 V reverse bias, reset noise is 165.6 µV rms. Compared to the other reset possibilities, soft reset and so-called flushed reset [15], this reset operation is noisier but simpler to implement and image lag is eliminated in comparison to soft reset.

This pixel is optimized for low-noise operation. Input referred noise of a source follower amplifier is given by the following equation (flicker and thermal noise only) [16]:

$$\overline{V_{n,in}^2} = 4kT\frac{2}{3}\left(\frac{g_{m2}}{{g_{m1}}^2}+\frac{1}{g_{m1}}\right)+\frac{K}{C_{ox}}\left(\frac{{g_{m2}}^2}{W_2L_2{g_{m1}}^2}+\frac{1}{W_1L_1}\right)\frac{1}{f}$$

where g_m is the transconductance, K is technology parameter, Cox specific gate oxide capacitance, $W_{1,2}$ widths of the transistor gates, $L_{1,2}$ lengths of the transistor gates and f is the frequency. Since the readout circuit is located in a gap of a photodiode guard ring, to minimize crosstalk, values of transistors widths and lengths are chosen to meet minimal design rules.

IV. PIXEL CHARACTERIZATION

A test chip was fabricated in 0.35 µm high-voltage CMOS.

1) Measurement setup

One of the widely used methods for characterization of image sensors is a photon transfer curve (PTC) [17]. To obtain such a curve, mean values at each illumination level are needed. There are two ways of getting image sensor data. The first way is to keep the optical power constant and change the exposure time and the second is to sweep optical power while exposure time is constant. For the measurements, the first method was used. Exposure time was swept from zero (complete dark) to 190 µs, i. e. light pulses with a duration up to 190 µs were used, while integration time was constant (200 µs). Every sample is corrected afterwards for the dark current. Input optical power is chosen in the manner to lead pixel to saturation for an exposure time of 190 µs. Light is coupled to the photodiode via 850 nm single mode optical fiber. Measured optical power at the end of the optical fiber was 2.24 nW. Optical power at the photodiode surface is slightly lower than the power measured at the end of fiber due to the small width of the photodiode of 10 µm (few micrometers gap between the surface and the fiber). Analog output of the test pixel is taken via a probe with an input impedance of R = 1 MΩ and C = 20 pF and sampled by a LeCroy WaveRunner 6200A oscilloscope and further processed by software. Correlated double sampling circuit is not implemented on the chip, but this technique is used in post-processing of pixel data in order to isolate signal and remove FPN (fixed pattern noise). To obtain the PTC, averaging with the factor of 256 was done for each

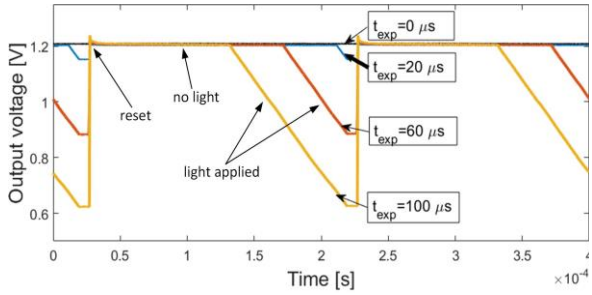

Figure 4. Pixel transient response for 4 different exposure times. After the reset, if there's no light, pixel output is steady. When the light is applied, photo-generated electrons store in the photodiode causing the drop on the output voltage.

exposure time and mean values and standard deviations were calculated. All measurements were made in a dark chamber.

2) Measured results

This section presents measured results of a pixel with 20 µm thick EPI layer, 10×50 µm² photodiode size, 15 µm guard ring width and 25 µm guard ring to cathode distance. Transient response for four different exposure times (0 µs, 20 µs, 60 µs, and 100 µs) is shown in Fig 4. Photon-transfer curve is shown in Fig 5. Measured pixel parameters are presented in Table 2. The pixel operates in a linear region for exposure times up to 180 µs. Conversion gain is expectedly low (1.316 µV/e^-) due to the photodiode capacitance of 149.9 fF. Mean noise is 273.9 µV (201 e^-) and it is calculated as the standard deviation of the pixel output in the dark. For this noise floor, the calculated dynamic range is 71.2 dB. Low conversion gain reflects in a relatively large full-well capacity of 842.7 ke^- which is a figure of merit for the signal-to-noise ratio (SNR). In OCT systems SNR is considered as one of the most important parameters that determine the imaging quality [18]. We measured SNR of 57.3 dB. The linear output voltage swing of the pixel is 1.109 V and it is determined with the photodiode reset voltage (upper boundary) and the saturation of the current mirror (lower boundary). The integral nonlinearity (INL) is 3.37 %.

V. Conclusion

The 3T active pixel is an old approach but in specific imaging applications in combination with a PIN photodiode gives better performance regarding crosstalk than approaches with standard substrates. The unmodified HV CMOS process with high resistive epitaxial layer and isolated electronics gives better results with respect to responsivity than a standard CMOS process. Even usage of a high resistivity epitaxial layer requires large negative substrate voltages for a fully depleted photodiode, which excludes the implementation of a pinned photodiode in waveguide coupled OCT pixels. Since the photodiode for an OCT application is very large in size and has a large capacitance (although the PIN photodiode has a much lower capacitance per µm² than a pinned photodiode), its conversion gain is low compared to known 4T pinned photodiode active pixels with a very small light-sensitive and floating storage node area. But the large photodiode capacitance, on the other hand, minimizes the contribution of reset noise to the total noise. It has been shown that this pixel approach successfully takes all benefits of both PIN photodiode and 3T pixel architecture, which makes it ready for the highly demanding OCT application.

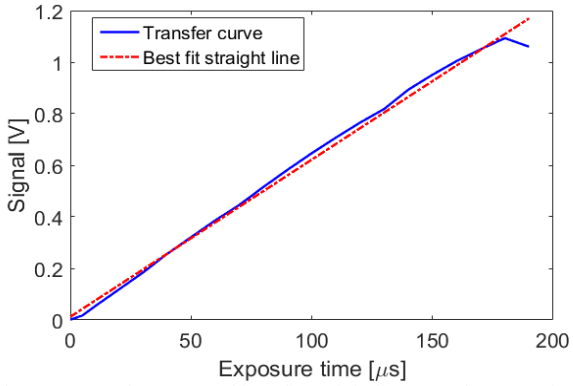

Figure 5. Transfer curve and best fit straight line. In order to get the curve, pixel outputs are taken in equidistant steps for exposure times from 0 µs (complete darkness) to 190 µs (saturation). The pixel output is linear for exposure times up to 180 µs, while for longer exposures it goes to saturation.

Table 2. Measured pixel parameters.

Parameter	**Value**
Pixel size	10×50 µm²
Linear full well capacity	842.7 ke^-
Mean noise (rms)	273.9 µV (201 e^-)
Conversion gain	1.316 µV/e^-
Linear output voltage swing	1.109 V
Integral nonlinearity (INL)	3.37 %
Dynamic range	71.2 dB
Signal-to-noise ratio	57.3 dB

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Formation of thin film Ag/AgCl reference electrode by electrochemical and chemical method

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***Abstract* - The formation and analyses of thin film Ag/AgCl reference electrode by two different methods were studied with aim to extend the lifetime and to determine the potential stability over time. To convert part of thin Ag film into AgCl, chemical formation in FeCl3 of different molarities and electrochemical formation in solution of 3 M NaCl were employed. Optical and SEM analyses of formed Ag/AgCl microstructure revealed that both methods result in uniform distribution of polycrystalline grains with size between 1-3 micrometers. Potential stability measurements were performed by measuring the potential of thin film reference electrode against standard calomel liquid junction electrode. When measuring potential difference in high molarity electrolyte (3 M NaCl), lifetime of thin film electrodes was found to be limited to few hours, though in weak solutions it can be maintained up to several days. Preliminary results showed good potential stability (<1% change per hour). It was shown that additional passivation of AgCl layer by a thin PDMS layer significantly increased the lifetime of the electrode.**

Keywords – thin film reference electrode; Ag/AgCl; chemical and electrochemical formation, potential stability

I. INTRODUCTION

Thin film microelectrodes are very convenient for the realization of miniaturized electrochemical cell. By implementing microfabrication techniques, planar metal electrodes with well defined patterns can be incorporated within microfluidic platform, leading toward micrototal analysis systems. In the miniaturization process toward e.g. biosensors, detecting on the basis of electrochemical response, three electrode configuration is commonly employed. Here, working electrode (WE), where the electrochemical processes are taking place is commonly a thin film Au, covered by e.g. biological samples, counter electrode (CE) is usually made of thin film Pt, while the reference electrode (RE) is usually a thin film Ag converted to Ag/AgCl reference electrode. In many ways, in metrological applications the reference potential of Ag/AgCl electrodes defines the measurement uncertainty [1]. Requirements for reference electrode are to allow high exchange current densities, to be highly nonpolarizable, meaning that its role in electrochemical cell is to provide stable potential during measurements and also to allow for control of WE [2], where all the kinetics occur.

Commonly used laboratory type AgCl reference electrodes have liquid junction, i.e. inner electrolyte fill reservoir and are not convenient for miniaturization. The same confines also the use of another laboratory reference electrode such as standard calomel electrodes (SCE), often used in electrochemistry.

In laboratory environment Ag/AgCl electrode is usually a silver wire with deposited AgCl with various techniques and dipped in fill electrolyte composed of 3.5 M KCl, saturated with AgCl. The conductive path from electrode to bulk electrolyte is via frit glass, which enables only ionic transport to/from reference electrode, without mixing of the filling and bulk electrolyte. Effusion, i.e. time dependent transfer of inner fill electrolyte toward bulk electrolyte solution, which is actually a part of conductive process is a drawback for liquid junction electrodes, since fill electrolyte has to be replenished periodically [3,4]. When miniature electrochemical cell setup is required, the very inconvenient reservoirs for liquid junction, filled with electrolyte or gel is required, which inevitably includes solving of fluidic problems like hermeticity and frequent inner electrolyte replenishment in miniature compartments. Screen printed thick film AgCl electrodes are somewhere in between, are cost effective, exhibit lower accuracy and are mainly used for disposable electrode systems [5].

Solid-state reference thin film electrodes without any internal reference electrolyte are preferable solution when it comes to miniaturization, however, there are still several issues remained unsolved to reach the reliability of previous. Beside the limited lifetime due to very thin AgCl layer, they are susceptible to changing activity of its primary ion, e.g.Cl^- and also to the interference with redox couples present in the bulk electrolyte. [6].

The objective of this study was to compare the two methods of forming thin film Ag/AgCl reference electrode and to determine which are the dominant parameters during formation that affect the electrode lifetime and its potential stability.

II. MATERIALS AND METHODS

The substrate material used in experimental work were thermally oxidized high resistivity (500 ohmcm) Si wafers, four inch in diameter, with dc sputtered Ag/Ni/Ti

thin film layers (1000 nm/350 nm/20 nm). Here, Ti layer acts as adhesive prime layer between SiO_2 and subsequently deposited Ni and Ag layers. Ni buffer layer was implemented according to its beneficial effect on the durability of AgCl electrode presumably due to suppressed Ti and O diffusion toward Ag, causing relatively pore free Ag/AgCl surface as shown by Kim [7]. Finally, wafers were thermally annealed and subsequently diced in 20x7 mm^2 samples.

Prior to use, individual samples were cleaned in 1 M HNO_3 solution for 10 min, thoroughly rinsed by DI water and dried by nitrogen. This was found mandatory in order to commence the process of electrode formation uniformly across the entire Ag electrode surface. Two approaches were utilized in transformation of Ag into AgCl.

With chemical method, samples were chlorinated by vertical dipping to approximately two thirds into prepared $FeCl_3$ solutions of defined molarity (molarity range 50 mM to 1 M) for a certain period of time (5 min to 60 min) and then rinsed thoroughly by DI water and dried with N_2.

Samples for electrochemical formation were cleaned by the same method and then subdued to a procedure of electrochemical oxidation of Ag in an electrolyte solution. During formation, samples were dipped vertically to a defined depth in order to know the exact exposed area to calculate the current density during formation. Selected forming electrolyte in our case was 3 M NaCl solution. The counter electrode used in anodization process was Pt wire coil. The setup is presented in Fig. 1a.Measurement of electric current during formation period was performed indirectly by measuring the voltage drop on resistor, and the current density that actually dictates the electrooxidation of Ag to AgCl was taken as the main parameter of formation. Current densities between 0.1 and 2 mA/cm^2 were adjusted in the preliminary experiments. The formation time was varied between 5 min and 60 min.

Lower current densities would require prolonged formation times to obtain sufficiently thick AgCl layer, while higher current densities proved inappropriate since they produced AgCl prone to rapid reaction with room moisture and further reduction to Ag. After formation, thin film AgCl electrodes were characterized by means of measuring their potential in bulk electrolyte against commercial SCE electrode. Cell potential between the electrodes was measured with Keithley 2700

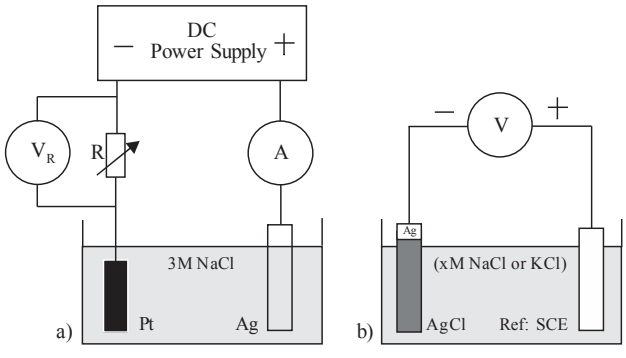

Figure 1. a) electrochemical AgCl forming setup, b) thin film AgCl potential stability measuring setup.

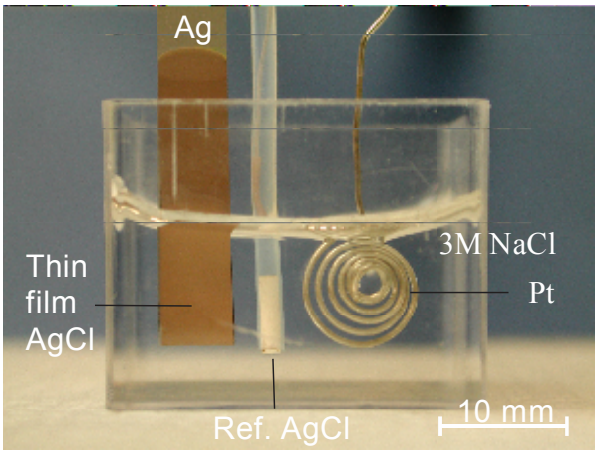

Figure 2. Experimental setup with thin film AgCl, liquid fill SCE and Pt CE in NaCl electrolyte.

multimeter/data acquisition system. The experimental electrochemical cell setup where forming and measuring was performed is shown in Fig. 2.

III. RESULTS AND DISCUSSION

A. Chemical formation

Realization of solid state Ag/AgCl reference electrode involves chemical oxidation of top Ag thin film layer in the presence of chloride ions to form polycrystalline AgCl, but still leaving beneath an electronically conductive Ag part. Ferric chloride $FeCl_3$ was used as a source of chloride ions. The following reaction takes place in the chlorination of Ag:

$$Ag + FeCl_3 \rightarrow AgCl + FeCl_2 \quad (1)$$

To study the properties of AgCl formed under different conditions, samples were prepared by varying the molarity of ferric chloride and by varying the time of soaking in the solution. Beside optical microscopy and SEM characterization of AgCl microstructure, i.e. grain size and its lateral distribution, the most adequate method to evaluate efficiency and appropriateness of formed Ag/AgCl electrode is to directly measure the potential difference and its time variations against commercial reference electrode (Fig. 1b). In our case standard calomel electrode was used as a reference electrode. Generally, reference electrodes in electrochemical cells are performing in a more than decade lower bulk electrolyte concentrations and last therefore longer, however, to determine the lifetime of our thin film electrodes, highly concentrated electrolyte was applied in our case to shorten the measuring time. All potential measurements presented bellow were done in 3 M NaCl bulk electrolyte solution.
Fig. 3 shows the time dependent behaviour of potential of fabricated electrodes vs. SCE electrode for four different molarities of $FeCl_3$ and same forming time. It can be interpreted in terms of increasing the thickness of formed AgCl with increased chloride ion concentration.

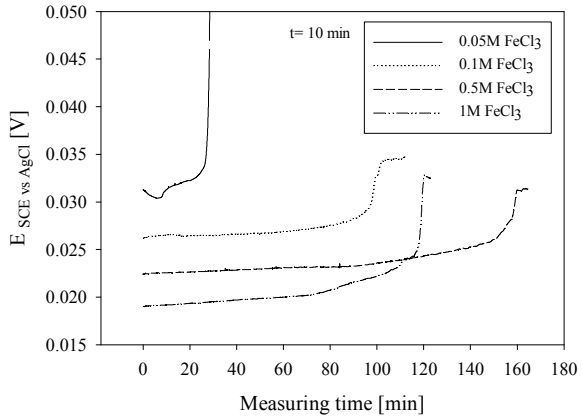

Figure 3. Time stability of potential vs. molarity of $FeCl_3$ during formation.

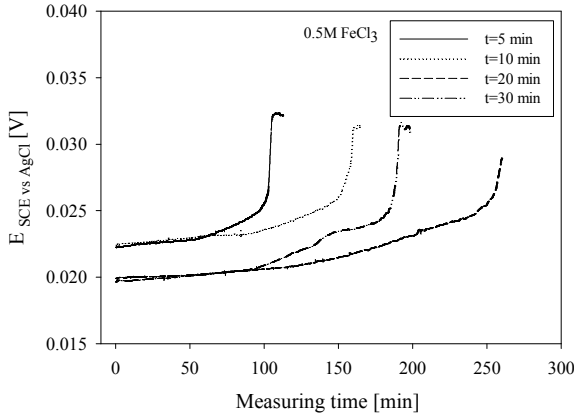

Figure 4. Time stability of potential vs. formation time in 0.5 M $FeCl_3$.

Diluted $FeCl_3$ resulted in slower formation rate and thus in thinner AgCl layer which is consequently dissolved in a shorter period of measurement. The optical inspection could not reveal notable molarity dependent difference of microstructure such as grain size or porosity; therefore it is believed that formed AgCl thickness is mainly responsible for poor lifetime. However, high molarity $FeCl_3$ (1 M) revealed that AgCl growth does not follow proportionally the increase of molarity as was the case between 0.05 M and 0.5 M, which needs further study. As shown, highest lifetime was achieved in 0.5 M $FeCl_3$ and was taken for further experiments to determine formation time dependence on Ag/AgCl electrode lifetime. Results are shown in Fig. 4. The lifetime is increasing proportionally with soaking time between 5 and 20 min, though prolonged time of 30 min showed lower lifetime. The lifetime criterion was defined as the time where the potential exceeded 2 mV differences as compared to initial value. Each potential runaway also corresponds to change of sample colour, i.e. from brownish to silver bright. It should be noted that variations in baseline potential (at t=0) can be attributed to molarity change due to evaporation during prolonged consecutive measurements.

B. Electrochemical formation

Electrochemical formation was performed in 3 M NaCl electrolyte by variation of current density and time of formation according to the setup shown in Fig. 1a. Initial current density in the range between 0.1 and 0.5 mA/cm^2 was adjusted to silver thin film layer for each sample separately and monitored during AgCl formation time.

In Fig.5 it can be observed that current density decreased rapidly during initial period when the reaction starts (20-30%) and only ca. 5-10% during rest 30 min period of formation.

Decrease of current density was gradually after initial drop and most probably corresponds to increase of ionic resistance due to polycrystalline AgCl formation. During AgCl growth, the interface with Ag layer beneath has to be reached by chlorine ions via grain boundaries or formed microchannels [8]. The process of anodization and growth of crystals is in the initial stage very fast and intensive what is typical for diffusion limited processes. Formed samples were evaluated by measuring the potential of electrochemically formed Ag/AgCl vs. SCE reference electrode. Before each measurement, initial stabilization time (5-10 min) is always mandatory in order that electrode wetting process is accomplished. Fig. 6 shows the representative results of measurements by comparing samples formed at 0.2 and 0.5 mA/cm^2. The duration of stable potential is proportional to thickness of formed AgCl, i.e. current density magnitude during formation being the dominant parameter. Three fold increase of lifetime time can be observed at criterion of 2 mV tolerance.

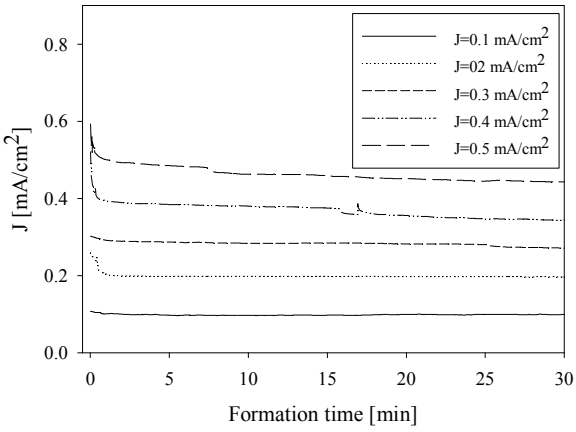

Figure 5. Exchange current density during AgCl formation.

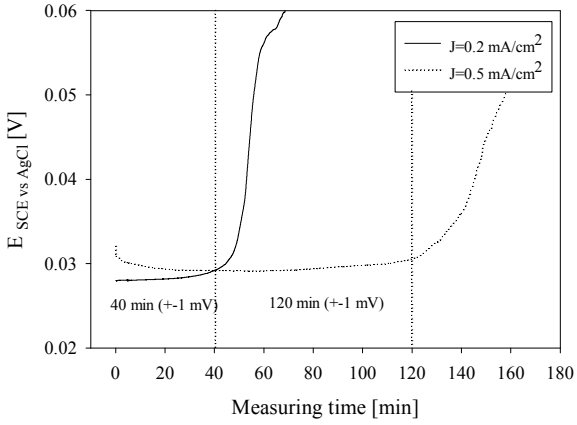

Figure 6. Potential stability of samples formed at 0.2 and 0.5 mA/cm^2.

It should be noted that separate experiments with higher current densities (>1 mA/cm^2) revealed that formed AgCl layer is prone to reaction with moisture, forming acidic product on the surface of the film with pH<2. In contrast, this was not observed after chemical formation of AgCl in $FeCl_3$ even in cases of high molarity (1 M).

Thickness of formed AgCl layer was determined by using Faraday's law modified expression [9], which gives AgCl thickness of 0.8 µm when anodizing at J=0.5 mA/cm^2 for 10 min. Accordingly, this leaves still around 420 nm of electronically conductive Ag layer to remain beneath the AgCl.

C. Role of protective layer

The dissolution of AgCl being directly exposed to high molarity bulk electrolytes is a well known problem in electrochemistry and is even more evident when thin film materials are involved. According to our experimental work, also purely chemical dissolution of thin film AgCl in 3 M NaCl occurs within few hours of immersion, without any other electrode present in the electrolyte. Adding dissolved $Ag^{(+)}$ ions into electrolyte solution somewhat mitigate this effect but might interfere the measurements. There exist various approaches in the literature, how to prevents excessive AgCl dissolution. In general, these approaches suggest to cover the AgCl with additional protective layer or a combination of layers (forming dry ionic bridge), that reduce effectively the AgCl dissolution and at the same time allow free ionic transport to/from reference electrode. Materials such as gel saturated with KCl [6], graphene oxide [10], SAM layers [11] and several others were proposed and applied in different applications, though with various success.

To enhance the durability of AgCl electrodes by means of protective, ion conductive layer, polydimethylsiloxane (PDMS) was applied on formed AgCl surface to obtain a layer cca 100 µm thick. Fig. 7 shows the measured potential vs. SCE reference electrode for the case when incomplete polymerization was performed (PDMS cured at room temperature for 12 hours) and after the sample was additionally cured for 1 h at 80 °C. Due to incomplete polymerization, severe fluctuations of potential resulted, while after completing the PDMS polymerization, the noise has completely vanished and the stable potential was established. Furthermore, the long term measurements for a period of 16 hours is shown in Fig. 8 and compared to sample with bare AgCl, formed under same conditions. Variation less than 0.5 mV was achieved over the 16 h period of measurement in 3M NaCl electrolyte, which is an order of magnitude improvement over bare Ag/AgCl samples shown also in Fig. 3-4 and Fig. 6. PDMS thermal curing to attain sufficient degree of polymerization has to be accomplished to obtain stable behavior. Not only lifetime but as well baseline of potential and variations over period of 16 hours remained within expectations. However, after this period, chemical attack on PDMS and lack of adhesion were optically observed, resulting in potential instability. In contrast to very low lifetime observed in preliminary study in highly concentrated NaCl, we have successfully proved that the application of cover layers extremely increased the life time as shown below.

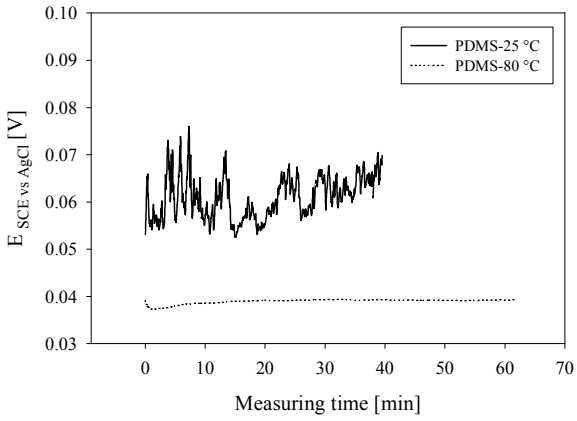

Figure 7. Influence of PDMS curing temperature on stability of potential.

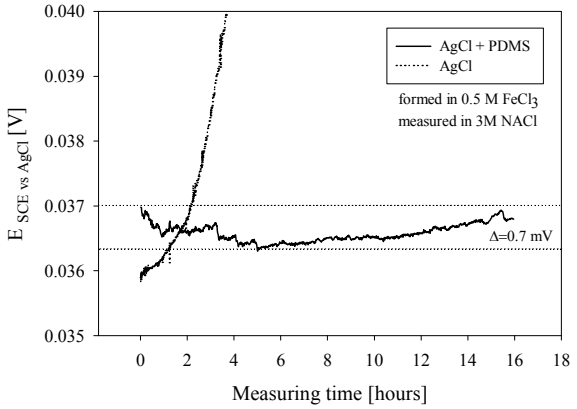

Figure 8. Long term stability of potential between PDMS-passivated AgCl and bare AgCl electrode.

It is well known that the equilibrium potential of the electrode in electrochemical cell is defined by the Nernst equation. Briefly, in our case AgCl electrode is said to exhibit Nernstian behavior when potential decreases by approximately 59 mV per decade of change in chlorine ion concentration at 25 °C [5]. To correlate our electrodes versus theoretical value a potential difference between thin film AgCl and SCE reference at 6 different electrolyte molarities were measured, each over 10 min period (Fig. 9). It is noteworthy that the potential stability is more affected at decreasing electrolyte concentration.

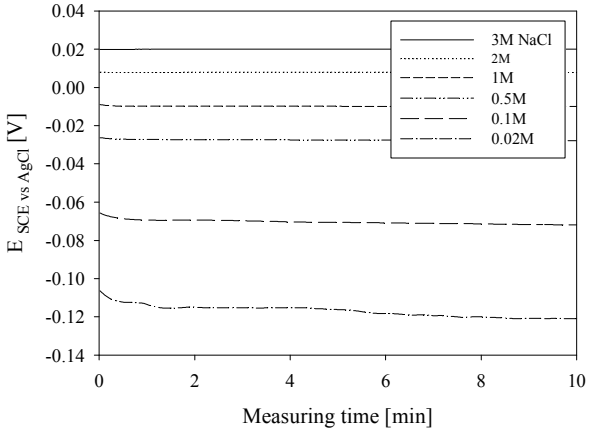

Figure 9. Baseline potential and time stability at various molarities.

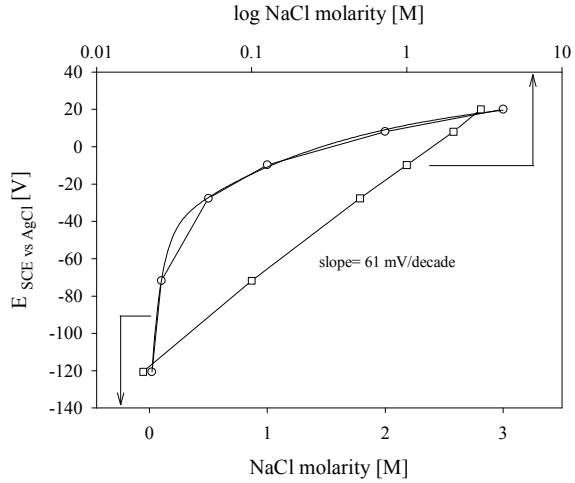

Figure 10. Dependence of potential versus molarity of NaCl electrolyte.

By taking into account values at t=10 min, the plot in Fig. 10 was drawn, which shows the relationship between measured potential and concentration of Cl^- ions.

For our thin film AgCl electrode, Nernstian behavior was confirmed by obtaining a slope of 61 mV/decade as compared to theoretical value of 59 mV/decade of Cl- concentration in bulk electrolyte. Results presented in Fig. 10 are for chemically formed sample (0.5 M $FeCl_3$, t=20 min), but very similar was obtained also for electrochemically formed samples.

D. Comparison between chemically and electrochemically formed AgCl

Optical and SEM analyses of formed Ag/AgCl were performed in order to compare the microstructure of both preparation method and to determine the grain uniformity and grain size. Fig. 11 shows typical SEM micrographs of AgCl microstructure obtained by the presented two methods.

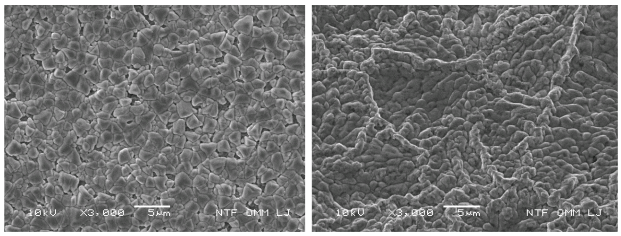

Figure 11. Polycrystalline grains of AgCl formed by chemical and by electrochemical method (3 M NaCl, t=10 min, J=1.5 mA/cm^2).

In contrast to chemically formed samples, AgCl microstructure of electrochemically prepared samples showed more pronounced and nonuniform outward protrusions. This could be due to a large expansion and mechanical stress evolved through electrochemical formation involving higher charge transfer. Both methods generally produce AgCl crystallites via the oxidation reaction of Ag with Cl ions though the process might not be exactly the same. The growth inevitably causes volume expansion during AgCl formation at the interface. The AgCl microstructure (having lattice constant a=5.54 Å), which is actually a salt, is subjected to compressive stress since it is formed on metallic Ag substrate (having lattice constant a=4.079 Å).

Beside the abovementioned surface topography difference, both methods produce comparable porosity of microstructure and crystallites of comparable grains size being between 1 and 3µm. Moreover, by measuring the potential of two typical Ag/AgCl electrodes, prepared by the two methods and shown in Fig. 12, only a minor difference could be observed regarding the time stability or baseline potential (<0.5 mV). Latter could be easily attributed to change of solution molarity or temperature variation. Initial transient, observed in Fig. 12 is due to insufficient stabilization time, i.e. caused by immersion of dry electrodes into the electrolyte. These two samples were without protective PDMS layer.

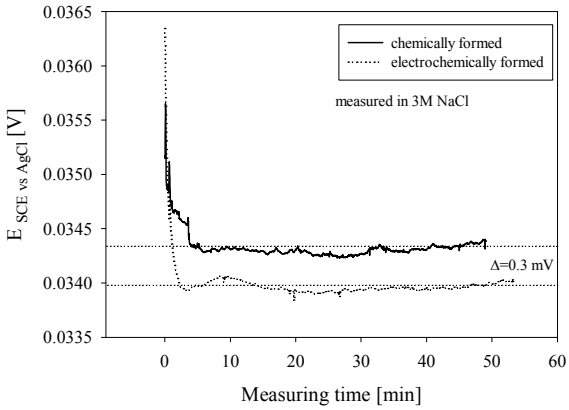

Figure 12. Comparison of chemically and electrochemically formed thin film AgCl reference electrode.

IV. CONCLUSION

Thin film Ag/AgCl reference electrodes were prepared by chemical formation in $FeCl_3$ at different molarities and by electrochemical formation at different current densities in solution of 3 M NaCl with aim to extend the lifetime and improve the potential stability over time.

Optical and SEM analyses of formed Ag/AgCl microstructure revealed that both methods result in uniform distribution of polycrystalline grains with size between 1-3 micrometers. Electrode potential stability against commercial SCE liquid junction electrode showed <1% change per hour. Lifetime of as formed Ag/AgCl thin film electrodes in high molarity electrolyte (3 M NaCl) was found to be limited to a few hours, however, passivation layer of PDMS improved this significantly (>16 hours).

Nernstian behaviour of electrode was confirmed by obtaining a slope of 61 mV/decade as compared to the theoretical value of 59 mV/decade of Cl- concentration in bulk electrolyte. Treatment in ferric chloride was found more convenient and as experiments showed was by no means inferior to electrochemical anodization method regarding the potential stability or electrode lifetime. Baseline potential vs. SCE was independent on the method of preparation, when measured by as-formed Ag/AgCl and also when measured after applying a PDMS passivation on the top of Ag/Cl layer.

ACKNOWLEDGMENT

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Accelerating simulation of nanodevices based on 2D materials by hybrid CPU-GPU parallel computing

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***Abstract*—We describe our new C-based software that combines atomistic quantum transport with the solution of the 2D Poisson's equation for nanodevice simulation. A significant acceleration of about ~100× is demonstrated in comparison to our old Matlab code, by using numerical libraries BLAS and LAPACK, shared-memory parallelization with OpenMP, and GPU acceleration based on CUDA libraries. The new code has enabled the analysis of 10 nm-gate length nanotransistors based on silicene nanoribbons, for which we report electronic, transport and device properties.**

Keywords—atomistic simulation; quantum transport; NEGF; silicene nanoribbon; CUDA; OpenMP

I. INTRODUCTION

Over the past 20 years, many innovations have been introduced into the complementary metal-oxide-semiconductor (CMOS) technology, such as applying strain and using high-k/metal gate stack, in order to meet device requirements for extremely scaled nodes under 45 nm. For the upcoming post-silicon era, two-dimensional (2D) materials could reshape the industry due to their exceptional electronic and charge transport properties [1]–[3]. Since the discovery of graphene [4], more than 50 single-layer materials have been demonstrated [5], [6]. These include monoelemental crystals (X-enes) such as graphene, silicene and germanene, transition metal dichalcogenides (TMDCs) such as MoS_2, etc. In comparison to graphene, silicene [7], [8] could be a better candidate for future electronic applications due to higher compatibility with the existing silicon-based semiconductor industry. Furthermore, its crystal lattice is buckled (see Fig. 1), which should facilitate an easier opening and engineering of the bandgap via the electric field [9], making this material more suitable for digital applications than graphene [10].

The suitability of 2D materials for future nanoelectronic devices, i.e. field-effect transistors (FETs), can be assessed with numerical modeling. Generally, modeling and simulation can support experimental work in the design process since it allows a physical insight into device operation. Moreover, it can reduce the number of trial-and-error iterations, thus reducing the cost of development that is very high at the nanoscale. In order to accurately predict the performance of future nanoscale FETs based on 2D materials, it is necessary to incorporate quantum mechanical effects and atomistic nature of materials into the simulation software. The direct solution of the Schrödinger's equation with open boundary conditions (OBCs) can be obtained with the non-equilibrium Green's function (NEGF) formalism [3], [11], [12]. However, atomistic NEGF simulations are computationally very demanding since they involve numerically intensive matrix operations on large matrices. For realistic sizes, the device consists of thousands of atoms, which demands efficient implementation of the NEGF code [13], [14].

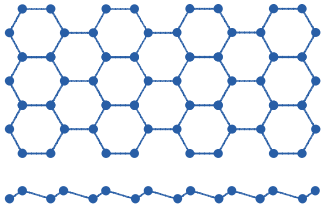

Fig. 1. Top and side view of monolayer silicene crystal lattice. The side view shows that silicene is not flat but periodically buckled.

In this paper, we present the atomistic NEGF simulator in which heterogeneous CPU-GPU computing and parallel code execution is used to significantly accelerate nanoscale FET simulation. This software's capabilities are illustrated by studying the electronic and transport properties of silicene nanoribbons (SNRs), and device characteristics of SNR FETs. This analysis provides physical insight into the feasibility of SNR FETs for future digital/logic applications at ~10 nm gate lengths.

II. THEORY

A. Overview

As illustrated in Fig. 2, the device under study consists of an SNR connected to source and drain contacts (S/D) and two gates (G1/G2). The NEGF part of the code gives charge density and current, while the Poisson equation provides the potential profile in the device. The NEGF-Poisson loop iterates until self-consistence is achieved.

B. Atomistic Hamiltonian

For each SNR, we construct a tight-binding Hamiltonian (H) that accounts for nearest-neighbor interactions:

$$H = \sum_i \varepsilon_i c_i^\dagger c_i + t \sum_{i,j} c_i^\dagger c_j + \text{H.c.}, \qquad (1)$$

where ε_i is the on-site energy, $c_i^\dagger$ (c_i) is the creation (annihilation) operator, while t is the hopping parameter [15]. A 5 nm-wide and 10 nm-long SNR consists of 1536 atoms, i.e. H is an 1536-by-1536 matrix with 2.36 million elements. A 30 nm-long SNR of the same width consists of 4352 atoms and H has 18.9 million elements. Nevertheless, H is very sparse (most elements are zero) which can be utilized to accelerate the computations.

C. NEGF Formalism

The Schrödinger's equations with OBCs is solved directly using the NEGF formalism. The NEGF equations are as follows [12]:

$$\left(E - H - \Sigma_S - \Sigma_D\right) G = I \tag{2}$$

$$\Gamma = \mathrm{i}\left[\Sigma - \Sigma^\dagger\right] \tag{3}$$

$$G^n = G\left[\Gamma_1 f_1 + \Gamma_2 f_2\right] G^\dagger \tag{4}$$

$$T = Tr\left[\Gamma_1 G \Gamma_2 G^\dagger\right] \tag{5}$$

$$I = \frac{2q}{h} \int_{-\infty}^{+\infty} T\left[f_1 - f_2\right] dE \tag{6}$$

where diagonal matrix E contains carrier (injection) energy, G is the retarded Green's function and Σ is the retarded self-energy that accounts for OBCs in S/D contacts. Charge density matrix (electron correlation) G^n depends on G, broadening matrices Γ and Fermi functions f for the two contacts. T is the transmission between contacts that also determines the current I via the Landauer's equation. Position- and energy-dependence in (2)-(6) is omitted for simplicity.

D. 2D Poisson's Equation

Electrostatic potential profile caused by the applied bias and charge distribution is found by solving a two-dimensional Poisson's equation (2D PE):

$$\nabla\left[\varepsilon(\mathbf{r}) \nabla U(\mathbf{r})\right] = q\rho(\mathbf{r}) \tag{7}$$

where ε is the spatially-dependent dielectric constant, U is the potential and ρ is the net charge density distribution (depends on doping profile and carrier densities). The 2D PE is solved using finite differences method, applying Dirichlet BCs at gates and Neumann BCs elsewhere.

III. Implementation

A. Hardware

All simulations were done on a single heterogeneous workstation with a 6-core processor (Intel i5-8400, 2.80 GHz to 4 GHz), 16 GB RAM (Kingston DDR4, 2400MHz), and Nvidia Titan Xp GPU (30 streaming multiprocessors (SMs), 3840 cores, 12 GB GDDR5X, 1.4 GHz). In double precision, processor performance is about 26 GFLOPS, while Titan performance is about 380 GFLOPS.

B. Numerical Libraries and Parallel Computing

The simulation software is implemented in C, a general purpose language in contrast to Matlab, and uses several numerical libraries for both CPU and GPU computation. BLAS (from Basic Linear Algebra Subprograms) contains low-level routines for operations such as vector/matrix addition, multiplication, etc. [16]–[18]. LAPACK (from Linear Algebra Package) provides routines for solving linear systems of equations, eigenvalue problems, matrix factorizations, etc. [19]. In this work, we use OpenBLAS, an open-source BLAS/LAPACK implementation with some general optimizations [20]. For GPU programming, we use CUDA (Compute Unified Device Architecture), a parallel computing platform and API model for Nvidia GPUs. Numerical libraries used for GPU acceleration include cuBLAS (a CUDA C implementation of BLAS), cuSPARSE (mostly BLAS-like functions for sparse matrices) and cuSOLVER (LAPACK-like routines for sparse and dense matrices) [21], [22]. In order to use GPU computational resources, the host application must transfer data to and from the GPU memory space, which could lead to performance decrease due to bandwidth and latency limitations. Regarding parallel execution on the CPU, we either set OpenBLAS to use multi-threading (`pthreads`) or we parallelize compute-intensive parts of the code using OpenMP (Open Multi-Processing) which is an API for shared-memory multi-processing [23], [24]. As for the GPU, CUDA libraries internally optimize the parallel execution by setting appropriate grid and thread block sizes across the 30 SMs in Titan Xp GPU. The code we developed in C/CUDA is compared to Matlab implementation. Matlab is a package and domain specific language, highly optimized for vector/matrix algebra, which internally employs numerical libraries such as BLAS, LAPACK, etc. and has a built-in multithreading.

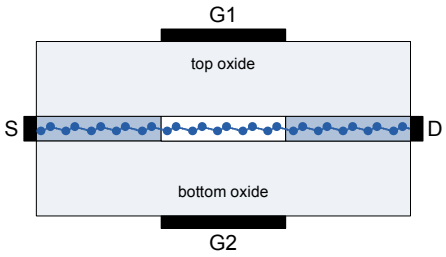

Fig. 2. Illustration of the double-gate silicene FET. This device structure is solved by the 2D Poisson's equation, as described in the text.

C. Dealing with Compute-Intensive Steps

Contact self-energy matrices Σ_S and Σ_D in (2) are obtained by the Sancho-Rubio method [25]. The procedure involves complex matrix addition and multiplication in double precision with BLAS routines `zgeadd` and `zgemm`. In CPU-only version of the code, the retarded Green's function G in (2) is obtained by inversion, using LAPACK routines `zgetrf` and `zgetri`. Similarly, in CUDA version, G is found by solving a linear system AX = B (with B = I) using cuSOLVER routines `Zgetrf` and `Zgetrs`. Transmission in (5) is calculated using `zgemm`/`Zgemm` in both versions. Finally, in the case of sparse CUDA version, the transmission is found using `Zcsrmm`. In all of the above steps several format conversions are necessary since BLAS, LAPACK and CUDA store complex matrices in different formats, which adds time to simulation. Acceleration is possible by

setting maximum number of `pthreads` in OpenBLAS, or by OpenMP parallelization. The NEGF equations must be solved for many energy points (e.g. 500−1000) in the chosen spectrum in order to capture fine changes, e.g. singularities in density of states. Therefore, OpenMP is a natural choice to divide the workload between cores.

The discretized 2D Poisson's equation (7) is in the form Ax = b, where A is a real matrix in double precision. It is solved using LAPACK `dgetrf` and `dgetrs` routines in CPU-only version, cuSOLVER routines `Dgetrf` and `Dgetrs` in dense CUDA version, and cuSOLVER routine `SpDcsrlsvqr` in the sparse CUDA version. In sparse versions of the code, reformat into compressed sparse row (CSR) is necessary, which requires calls to several subroutines from the cuSPARSE library. Acceleration on GPU, i.e. dividing workload between SMs, is handled internally.

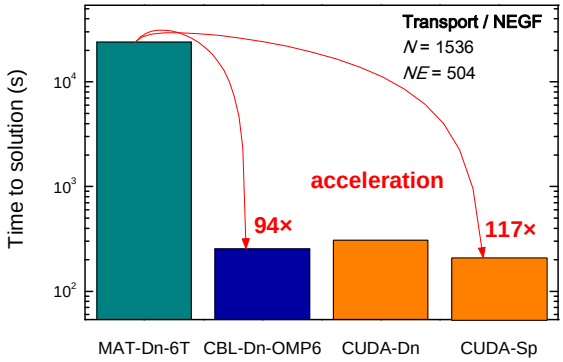

Fig. 3. Comparison of time-to-solution for different code implementations of the NEGF solver. Device under study is a 5 nm-by-10 nm silicene nanoribbon, with 1536 atoms. The reported results are obtained by solving the NEGF equations over 504 energy points.

IV. Analysis of Time-to-Solution

A. Accelerating NEGF Transport Computation

NEGF code implementations (Matlab, C and C-CUDA) are tested under the same conditions, i.e. for the simulation of a 5 nm-wide and 10 nm-long SNR with $N = 1536$ atoms, with an energy spectrum with $NE = 504$ energy points. Relatively small structure ($N = 1536$) is chosen due to large NE in order to keep time-to-solution manageable, especially for the Matlab version. Time-to-solution for NEGF transport is reported in Fig. 3 for four different implementations. Dense Matlab (MAT-Dn-6T) and dense C+BLAS+LAPACK (CBL-Dn-OMP6) versions are multithreaded over 6 cores. Matlab code is parallelized using `spmd` from the Parallel Computing Toolbox, while the C version is parallelized with OpenMP. In both versions, the energy spectrum with NE points is divided between the 6 cores. Parallelization in the dense (CUDA-Dn) and sparse (CUDA-Sp) implementations in Fig. 3 are done internally. Duration is measured by `tic/toc` commands in Matlab, while `clock_gettime` function is used in C versions.

The time-to-solution obtained using MAT-Dn-6T is approx. 24,000 s, while dense C and CUDA versions finish in 255 s and 307 s, respectively. The acceleration compared to Matlab equals 94× and 78× for dense C and CUDA code, respectively. An additional speed-up is offered by the sparse CUDA version, which takes only 206 s to calculate the transmission of an SNR with 1536 atoms over 504 energy points. In this case, the acceleration obtained in comparison to Matlab is 117×. The sparse CUDA implementation takes approx. 410 ms per energy point, out of which roughly two-thirds are taken by reformatting two N-by-N matrices into CUDA double complex format. This reformat is needed because part of the host code is based on BLAS/LAPACK. Nevertheless, when the issue of reformatting into CUDA format is resolved in future work, the CUDA-Sp version in Fig. 3 could have a time-to-solution of approx. 70 s, which would present an acceleration of 3.6× and 343× in comparison to dense C and Matlab solutions, respectively.

B. Accelerating Poisson Electrostatics Computation

Different implementations of our 2D PE solver are tested on the same device structure: double gate Si FET with 10 nm-long source and drain regions, and 10 nm channel length; channel thickness is 5 nm; SiO_2 thickness is set to 2 nm. The PE is discretized on a rectangular mesh with $\Delta x = \Delta y = 0.1$ nm, leading to 300 points in y-direction and 92 points in x-direction. Coefficient matrix in (7) is of the size $N = 27{,}600$, i.e. more than 760 million elements in double precision (8 bytes) so it takes more

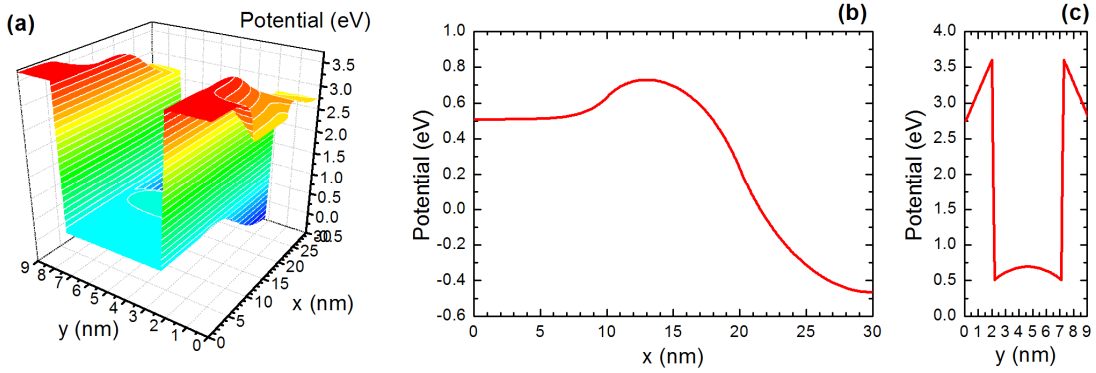

Fig. 4. An example output from the 2D Poisson's equation solver. The structure is a double-gate Si FET with overall length of 30 nm and thickness of 9 nm. $N_{S/D} = 10^{20}$ cm^{-3} and inversion carrier concentration is constant (for simplicity) in the channel. $V_{G1} = V_{G2} = 1$ V.

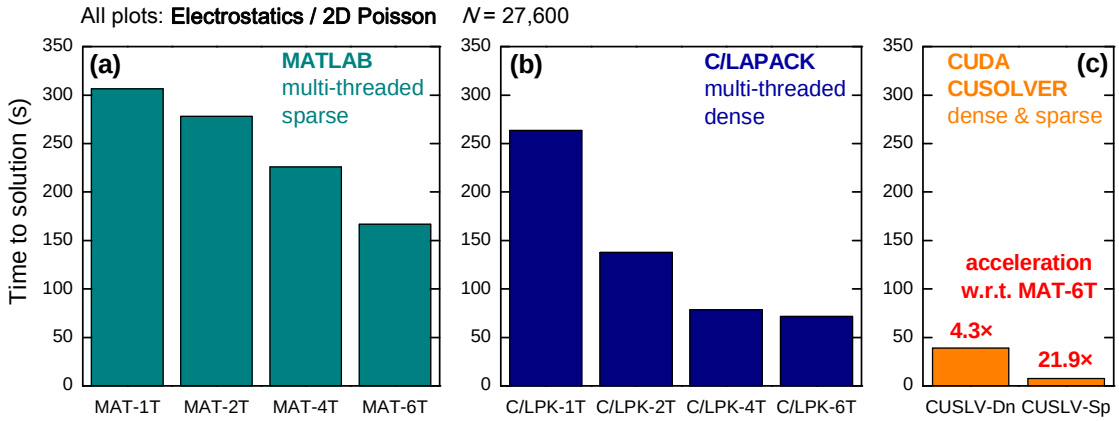

Fig. 5. Comparison of time-to-solution for different code implementations of the 2D Poisson's equation solver. The simulated structure is the same for all cases, as described in the text. N = 27,600.

than 5.6 GB of memory. An example of the solution for $V_{G1} = V_{G2} = 1$ V is given in Fig. 4.

Figure 5 shows time-to-solution for the 2D Poisson's equation for (a) Matlab, (b) C-LAPACK and (c) C-CUDA implementations. For the Matlab implementation, we used sparse matrix storage and `mldivide` to solve Ax = b, which should provide the fastest possible Matlab solution. In addition, the number of internal threads is increased from 1 to 6 (MAT-1T to MAT-6T in Fig. 5a) to assess performance improvement with parallelization. C implementation using LAPACK is also multithreaded (C/LPK-1T to C/LPK-6T in Fig. 5b) with internal `pthreads` but deals with dense matrices. The time-to-solution for the CUDA implementation using cuSOLVER is shown in Fig. 5c for the dense and sparse implementation (CUSLV-Dn and CUSLV-Sp, respectively). In order to solve the 2D PE with N = 27,600, MAT-1T version runs 306 s, while MAT-6T is done in 167 s. C/LPK-1T version finishes in 264 s, while C/LPK-6T gives the result in 72 s. Therefore, C/LAPACK version offers faster simulation (2.3× for 6T) and better scaling (3.7× acceleration over 6 cores compared to 1.8× in Matlab). The same problem is solved much faster within the CUDA framework, as it takes only 39 s and 7.6 s for the dense and sparse version, respectively. In comparison to the fastest sparse Matlab solution (MAT-6T), CUSLV-Sp version accelerates the simulation by almost 22×.

C. *Estimating Time-to-Solution for I-V Characteristics*

In order to obtain current-voltage characteristics, bias on the gate (V_G) and drain (V_D) electrodes has to be swept across different voltages. For each bias combination (V_G, V_D), roughly ten NEGF-Poisson iterations are needed to achieve self-consistency. Figure 6 reports time-to-solution for one NEGF-Poisson iteration. The sparse C-CUDA implementation offers 113× shorter time than the sparse Matlab version.

We can estimate that it would take approx. 5.93 hrs to calculate a single transfer characteristic even with sparse C-CUDA code (10 bias points, 10 iterations per bias point assumed). Nevertheless, this simulation duration pales in

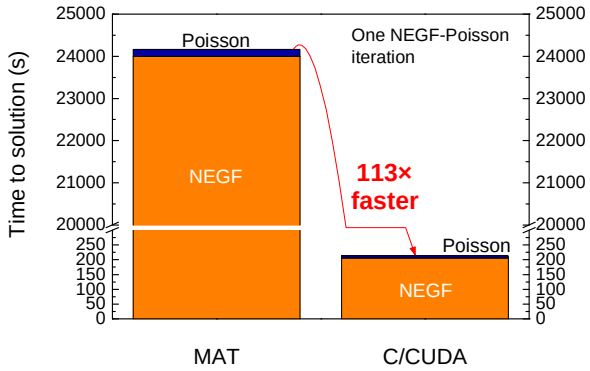

Fig. 6. Comparison of time-to-solution for one NEGF-Poisson iteration for the sparse Matlab and sparse C-CUDA implementation. The CUDA version offers 113× acceleration.

comparison with the Matlab case, where the same simulation would take approx. 27.8 days.

V. Properties of Silicene Nanoribbon FETs

In this section, we analyze several electronic, transport and device properties of SNR-based FETs. The SNR length is L = 30 nm (channel and S/D extensions are 10 nm long), while the nanoribbon width (W) is varied from ~1 to ~4.4 nm. All SNRs belong to the same 3m family (i.e. number of dimer lines along the width is divisible by three), for the sake of consistency. An additional reason is that the 3m family offers the smallest effective transport mass, which should benefit device performance [26].

Figure 7 reports the transmission and density of states (DOS) for 0.96, 2.10, 3.25 and 4.39 nm-wide SNRs. As shown in Fig. 7a, the transmission is a series of step functions, depending on the number of conducting channels or modes. Narrower SNRs exhibit a larger bandgap and a lower transmission at a given energy than wider nanoribbons. The DOS results in Fig. 7b again illustrate the increasing bandgap when W decreases. In addition, wider SNRs have higher DOS, indicating the possibility of an increased amount of inversion charge at the same voltage when compared to narrower SNRs. The energy gaps from Fig. 7a and b are identical, which means that the band- and transport-gap are the same, i.e. there are

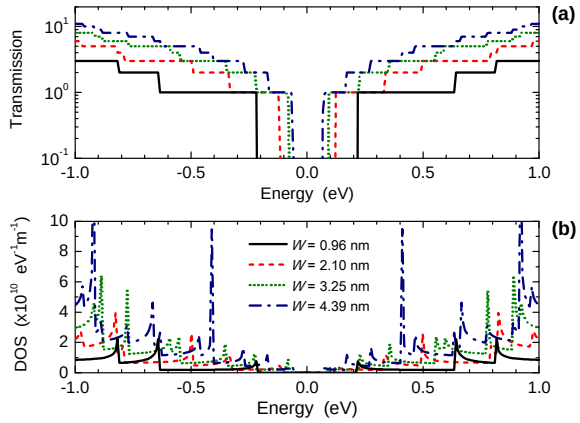

Fig. 7. Comparison of (a) transmission and (b) density of states (DOS) for silicene nanoribbons of different widths. L = 30 nm.

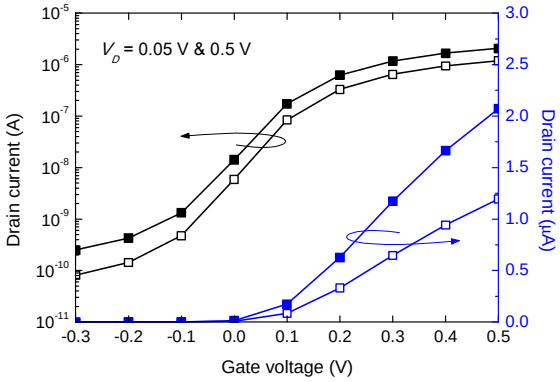

Fig. 9. Transfer characteristics of a 0.96 nm-wide and 30 nm-long SNR FET for V_D of 0.05 and 0.5 V. Channel/gate and S/D regions are each 10 nm long.

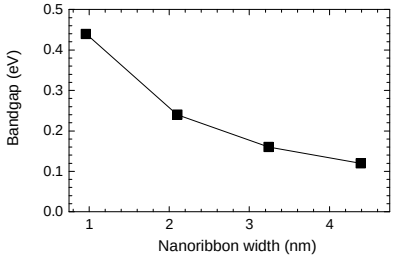

Fig. 8. Bandgap vs. silicene nanoribbon width. Extracted from the transmission data at $T(E)$ = 0.1.

no localized states inside the gap that do not contribute to transport.

As shown in Fig. 8, the bandgap increases from 0.12, over 0.16 and 0.24, to 0.44 eV when nanoribbon width scales down. Among the analyzed SNRs, it seems that only the narrowest one (W = 0.96 nm) could be a feasible transistor channel because other bandgap values are too small. Therefore, device characteristics are analyzed only for the 0.96 nm-wide and 30 nm-long SNR FET. Figure 9 reports transfer characteristics in log and lin scales, obtained for drain voltages of V_D = 0.05 V and 0.5 V. The gate voltage is swept from V_G = −0.3V to 0.5 V. From the results in Fig. 9 it is clear that the device suffers greatly from short-channel effects. Namely, subthreshold swing extracted for V_D = 0.5 V equals S = 85 mV/dec while the drain current at V_G = 0.5 V is greatly influenced by V_D; it increases from 1.2 to 2.1 μA when V_D changes from 0.05 to 0.5 V, indicating poor saturation behavior. At the same time, off-state current (at V_G = 0 V, V_D = 0.5 V) is ~15 μA/μm. The only redeeming property is the high current drivability, i.e. on-state current (at V_G = V_D = 0.5 V) that equals 2.2 mA/μm when SNR width is taken into account, which is close to the required level given by ITRS [27]. Other parameters do not meet ITRS requirements, especially the off-state current which is 146× higher than recommended.

In order to clarify SNR FET characteristic, in Fig. 10 we plot energy- and position-resolved (a) local density of states (LDOS), (b) electron density (ND) and (c) electron current density (CD), for the case of V_G = 0.5 V and V_D = 0.05 V. The LDOS shows the distribution of allowed states within the NEGF formalism, illustrating wave-like injection, reflection and transmission. The ND reports spatial and energy distribution of electrons in the device,

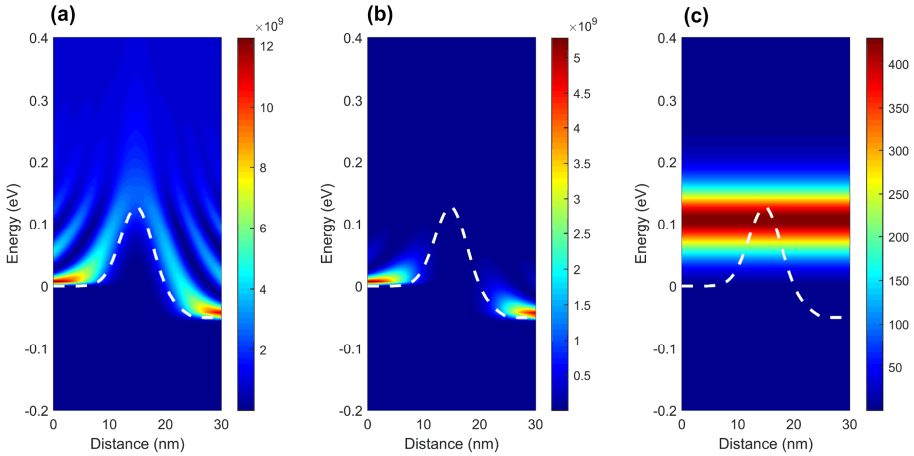

Fig. 10. Position- and energy-resolved (a) local density of states, (b) carrier density and (c) current density for electrons only. V_G = 0.5 V and V_D = 0.05 V. Current density plot shows direct tunneling through the barrier, which is also obtained for V_D = 0.5 V (not shown).

when Fermi functions in S/D are taken into account. Finally, the CD in Fig. 10c shows at which energies the current flow is the strongest. Clearly, even at high bias the majority of electrons tunnel directly through the barrier, in contrast to findings in [28]. The same is observed for $V_D = 0.5$ V (not shown in Fig. 10). The reported direct tunneling observed in this device with a 10 nm-long channel is caused by the low effective mass that equals only ~$0.1m_0$ (m_0 is electron rest mass) for the 0.96 nm-wide silicene nanoribbon. Therefore, low-effective-mass SNR FETs do not seem to be a feasible solution for the extremely scaled CMOS technology nodes, at least for digital/logic applications. Other SNR types and geometries together with other potential application areas will be the topic of future work.

VI. Conlusion

We have presented a C-based simulation software that combines atomistic non-equilibrium Green's function (NEGF) formalism (for transport) with the 2D Poisson equation solver (for electrostatics). By using efficient numerical libraries, sparse matrix representations and hybrid CPU-GPU parallel programming in CUDA, we have significantly accelerated the time-to-solution in comparison to our old Matlab code. The obtained accelerations are up to 117× and 22× for the NEGF and Poisson module, respectively. This allows full device simulations, consisting of thousands of atoms, in the matter of hours on a single hybrid workstation. The capabilities of the simulation software are illustrated by analyzing 30 nm-long silicene nanoribbons of various widths in the range from ~1 to 4.4 nm, both in terms of their electronic/transport material properties and FET device characteristics. We have shown that low-effective-mass SNR FETs are not a feasible solution for digital/logic applications in the future due to strong direct source-to-drain tunneling, both in the off- and on-state.

Acknowledgment

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Voltage-to-Frequency Converter for Ultra-Low-Voltage Applications

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***Abstract*—The paper is focused on the design and analysis of a Voltage-to-Frequency Converter (VFC) that was implemented in 130 nm CMOS technology. The proposed VFC was designed using the bulk-driven technique and can reliably work with the power supply voltage of 0.4 V. Since its basic building block is a Fully Differential Difference Amplifier (FDDA), the proposed VFC has a differential output. Therefore, the high output frequency dynamic range (Δf_{OUT} 3.45 kHz for the input range of 0-10 mV) as well as high sensitivity (348.8 Hz/mV) were obtained. The presented VFC can be used in complex ultra-low-voltage systems, where it would provide on-chip current consumption measurement.**

I. Introduction

Towards increasing battery life of today's portable devices, the development of integrated circuits (ICs) is mainly based on the the ultra-low-voltage (ULV) and low-power (LP) design techniques and approaches. Nanoscale CMOS technologies bring opportunity to design ICs with ultra-low value of the supply voltage, and in this way, also the current consumption of digital ICs can be decreased. On the other hand, the power consumption of analog ICs usually depends on required signal-to-noise (SNR), and therefore, it does not decrease by scaling down the supply voltage. Moreover, the ultra-low value of the supply voltage also reduces the dynamic range (DR) of analog ICs. To overcome these drawbacks of ULV ICs, new design techniques, e.g. bulk-driven approach [1]–[4] and novel topologies of analog ICs have be to introduced.

One of the basic issue in complex mixed-signal Systems-on-Chip (SoC) is to ensure the synergy between the analog and digital supply voltage domains, especially in the case of the interface between the analog and digital parts. In the conventional mixed-signal ICs, the analog signal is usually digitized at the hand of analog-to-digital converter (ADC). However, in some cases, this is not the appropriate solution from the power consumption point of view. The simpler and low-cost approach is to convert the analog signal using the quasi-digital converter such as VFC [5]–[9]. Generally, the VFC is a voltage-controlled oscillator, which frequency is linearly proportional to the control (input) voltage. The output signal is equivalent to a serial digital signal that can be directly connected to the microprocessor for further processing. With the proper design, it is possible to obtain the performance of a conventional ADC. Since the VFC has a single (serial) output, disadvantage could be a relatively long conversion time. However, due to its quite simple topology, it can be a better solution for analog-to-digital conversion in many control and measurement electronic systems integrated on the chip than the ADC approach [9].

In this paper, the design of a ULV VFC based on the differential topology is presented, and its main parameters are analyzed. In Section II, the proposed VFC is described. Achieved results obtained by simulation are presented in Section III. In the last section, the achieved results are discussed.

II. Proposed Voltage-to-Frequncy Converter

The general block diagram of the proposed VFC is shown in Fig. 1. The designed VFC is based on the charge-balance approach. Firstly, the input voltage is converted into current and then, transformed into pulses using the current integrator and control circuit. The VFC has a differential input and output and therefore, its main advantage is the high dynamic range and sensitivity with respect to the conventional single-ended topology.

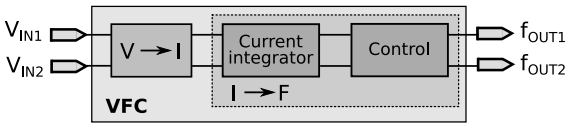

Fig. 1. General block diagram of the proposed VFC

Detail schematic diagram of the proposed ULV VFC circuit is depicted in Fig. 2. The circuit was designed in 130 nm CMOS technology and can reliably operate at the supply voltage of 0.4 V. As can be observed in Fig. 2, the proposed VFC consists of three main parts: gain stage, voltage-to-current (V-I) conversion stage and current-to-frequency (I-F) conversion stage. Considering the differential topology, devices in the both branches of the proposed VFC are the same. Passive devices (resistors and capacitors) have the same values while the transistors have the same size (channel width and length).

The first (gain) stage was used to set the appropriate voltage gain, on which the VFC's sensitivity depends. The slope of the VFC transfer characteristic can be changed by varying the gain. The gain stage is formed by a pseudo FDDA (PFDDA) based on the rail-to-rail bulk-driven input stage, which is

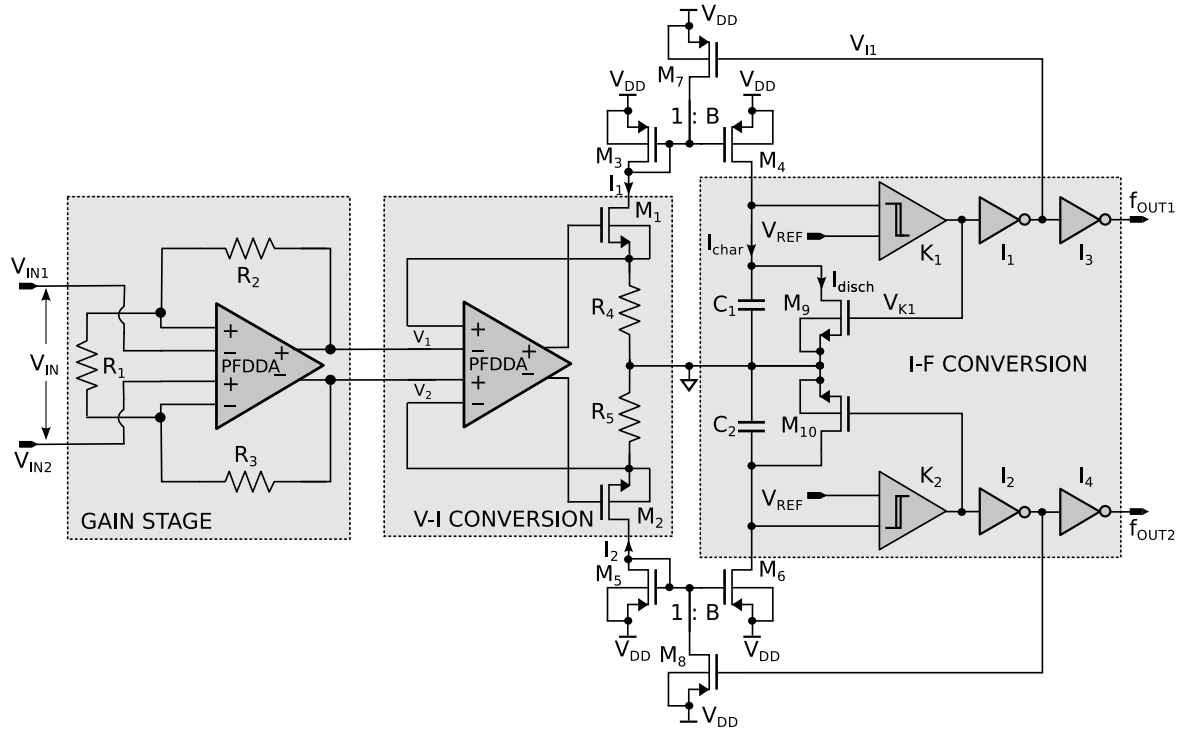

Fig. 2. Schematic diagram of the proposed VFC

presented in [10] and the feedback network consisting of resistors R_1-R_3. To avoid the loading effect, in our case, the values of 10 kΩ, 100 kΩ and 100 kΩ for resistors R_1, R_1 and R_3 were chosen, respectively. The output resistance of the PFDDA is in order of kΩ but still low enough for neglecting the loading effect. The differential gain of the first stage can be expressed as follows

$$A_{CL} = \frac{A_{OL}}{1 + A_{OL}\beta} = \frac{A_{OL}}{1 + A_{OL}\dfrac{R_1}{2R_2}}, \tag{1}$$

where A_{OL} is an open-loop gain of the PFDDA and $R_2 = R_3$. If $A_{OL} >> \beta$ the differential gain of the first stage can be given by

$$A_{CL} = \frac{1}{\beta} = \frac{2R_2}{R_1} \tag{2}$$

Since the PFDDA presented in [10] was used, Eq.2 cannot be considered in the design phase because the relation $A_{OL} >> \beta$ is not satisfied in this case. The open-loop gain is not sufficiently large to be neglected in Eq 1. Additionally, it is important to note that open-loop gain of the PFDDA (A_{OL}) can vary with the input common-mode voltage (V_{COMM}), which might provide an additional gain variation of the gain stage. For this purpose, we investigate the dependence of the open-loop gain A_{OL} on the input common-mode voltage of the PFDDA (in Section III).

In order to ensure conversion of voltage to current, the V-I conversion stage was employed in the proposed VFC (Fig. 2). This block generates an output current which is proportional to the input voltage. Because of the differential structure of VFC, for the simplicity point of view, the further description will be presented for the single output. Transistor M_1 driven by the PFDDA and resistor R_4 connected to the negative feedback loop form the high linear voltage-controlled current source [9], [11]. Since the PFDDA together with transistor M_1 represent a voltage follower, the output current I_1 is directly proportional to the voltage V_1. If we neglect the input offset voltage of the PFDDA (V_{offset}), the output current I_1 of the V-I conversion stage can be expressed as follows

$$I_1 = \frac{V_1 + V_{offset}}{R_4} \approx \frac{V_1}{R_4} \tag{3}$$

The last block of the proposed VFC is a I-F conversion stage. The output current from the V-I conversion stage is firstly integrated and then transformed into the pulses using control circuitry. Current I_1 is mirrored using the current mirror formed by transistors M_3 and M_4. In order to minimize the current consumption of the VFC, the current through transistor M_4 (I_{char}) is lower then I_1 and can be expressed as

$$I_{char} = I_1 B \approx \frac{V_1}{R_4} B, \tag{4}$$

where $B = 1/6$ is the current mirror (transistors M_3 and M_4) ratio.

The timing diagram of the VFC's operation principle is shown in Fig. 3. In the charging phase, charging current I_{char} flows into capacitor C_1. In this phase, transistors M_7 and M_9 are turned off. The voltage across capacitor C_1 is sensed

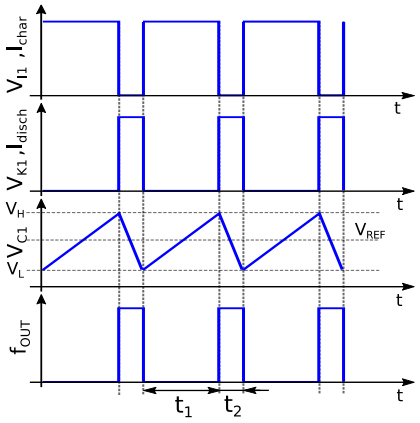

Fig. 3. Timing diagram of the charging and discharging phase

by comparator K_1 with the hysteresis and compared to the reference voltage V_{REF}. The reference voltage was supplied externally (off-chip) and was set to 200 mV. High (V_H) and low (V_L) values of the comparator threshold voltage were set to $V_{REF}\pm$100 mV. If the voltage drop across capacitor C_1 is higher than V_H, the comparator changes its output state from log 0 to log 1 (generates a pulse at the output) and turns transistor M_9 on. In this moment, capacitor C_1 starts to discharge through transistor M_9. If we consider that turn-on resistance of M_9 is $R_{ON,M9}$, the discharge current $I_{dischar}$ can be defined as follows

$$I_{dischar} = \frac{(V_H - V_L)}{R_{ON,M9}} = \frac{\Delta V}{R_{ON,M9}}, \tag{5}$$

At the beginning of the discharging phase, transistor M_7 turns off the current mirror in order to prevent the charging current to flow. The discharging phase is finished when the voltage across the capacitor drops below the low threshold voltage V_L. Then the comparator changes the state and starts the charging phase.

The output frequency of the proposed VFC is indirectly proportional to sum of the charge time (t_1) and discharge time (t_2) can be expressed as follows

$$f_{OUT1} = \frac{1}{t_1 + t_2} \tag{6}$$

The charge and discharge times t_1, t_2 can be expressed according to Eq. 7 and Eq. 8

$$t_1 = \frac{\Delta V C_1}{I_{char}} = \frac{\Delta V C_1 R_4}{V_1 B} = nC_1R_4 \tag{7}$$

$$t_2 = \frac{\Delta V C_1}{I_{dischar}} = C_1 R_{ON,M9}, \tag{8}$$

where $R_{ON,M9}$ is the turn-on resistance of the discharging transistor M_9. The output frequency expression for the proposed VFC obtained by inserting Eq. 7 and Eq. 8 into Eq. 6 is given as

$$f_{OUT1} = \frac{1}{\frac{\Delta V R_4 C_1}{V_1 B} + R_{ON,M9} C_1} \tag{9}$$

and simplified as

$$f_{OUT1} = \frac{1}{C_1(nR_4 + R_{ONM9})} \tag{10}$$

It can be observed that the output frequency depends on the time constants of charge nC_1R_4 and discharge $C_1R_{ON,M9}$ phase.

III. Achieved Results

In this section, achieved results of the proposed VFC for the supply voltage of 0.4 V are presented. The results were obtained from Corner and Monte Carlo (MC) analyses, where the process variations as well as mismatch of devices were taken into account. The particular corners for transistors are: $TPTN$ – both PMOS and NMOS for typical process variation; $FPSN$ – fast PMOS and slow NMOS; $SPFN$ – slow PMOS and fast NMOS; $FPFN$ – fast PMOS and fast NMOS; $SPSN$ – slow PMOS and slow NMOS. The temperature range from -20°C to 85°C was considered in all simulations.

As already mentioned in the previous section, the open-loop gain of the PFDDA can be influenced by the input-common voltage. Therefore, we investigate the dependence of the open-loop gain of the PFDDA on the input common-mode voltage, and the obtained results are depicted in Fig. 4. It can be observed that, in the typical case, deviation of the open-loop gain is 4.27 dB in the range of the input common-mode voltage from 0 V to 0.4 V. However, in the worst case (FPFN, res:max, cap:max, T=85°C), the gain will decreases to the value of about 40 dB that can influence the gain of the VFC's gain stage. Since the proposed VFC might be used for the high-side current consumption measurement, all results were obtained for the input-common voltage of about 0.4 V.

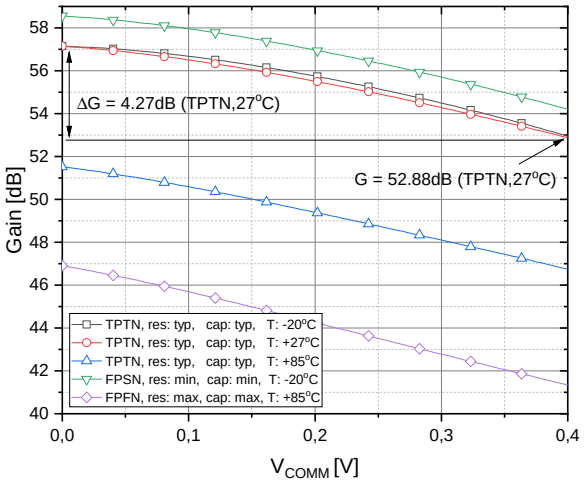

Fig. 4. Dependence of the PFDDA gain on input common-mode voltage

The most important feature of the VFC is its transfer characteristics which defines the dependence of the output frequency on the input voltage. In Fig. 5, the transfer characteristics for both outputs as well as for the differential output are shown. Sensitivity of the first output is 137.7 Hz/mV, while the second output has slightly higher sensitivity of 211 Hz/mV. This is mainly caused by the different common-mode voltage at the inputs and outputs of the V-I conversion block (in simulations, one input was fixed and the second one was varied), which brings behavior of the proposed differential VFC into asymmetry. If the input terminals are swapped, the transfer characteristics will be also inverted. One can observe that the differential output has higher sensitivity (348.8 Hz/mV) and the frequency range from 33 Hz to 3.4 kHz which is an advantage of the proposed differential VFC. The nonlinearity (NL) is defined by Eq. 11 as the maximum relative error between ideal (depicted as straight line in Fig. 5) and real characteristics in the investigated input voltage range from 0 V to 10 mV. NL of the first and second output is 3.13% and 8.69%, respectively. However, if the differential output Δf_{OUT} is used, the nonlinearity about 2% in the typical case.

$$NL[\%] = max\left\{\frac{f_{real} - f_{ideal}}{f_{ideal}}\right\} 100 \qquad (11)$$

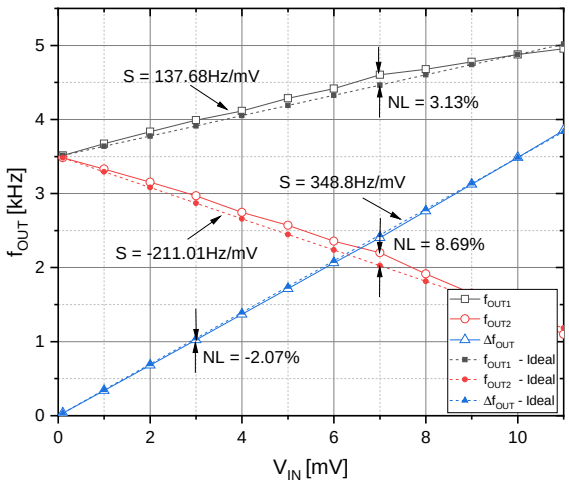

Fig. 5. VFC differential output frequency vs. input voltage

In order to analyze the sensitivity of the proposed VFC, the dependence of the differential output frequency Δf_{OUT} on the input voltage for different process corners and temperature was investigated. From Fig. 6, one can be observe that, in the typical case, the sensitivity of the proposed VFC is 348.8 Hz/mV. In the best case (FPSN, res: min, cap:min, T=−20°C), the sensitivity is 515.8 Hz/mV but the higher nonlinearity can be observed. On the other hand, the nonlinearity is low in the worst case (FPFN, res: max, cap:max, T=85°C), where the sensitivity drops to the value of 110 Hz/mV.

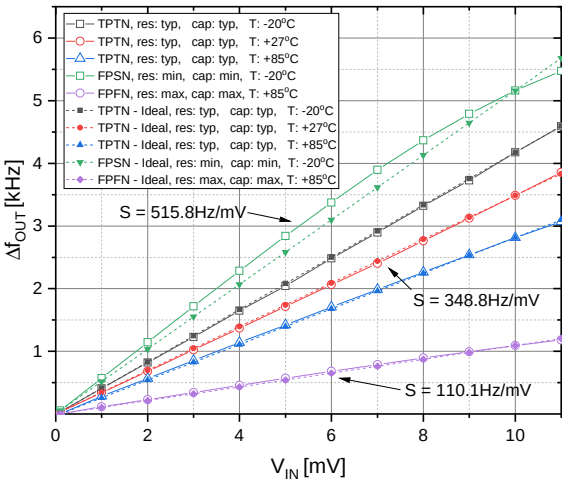

Fig. 6. VFC output frequency vs. input voltage for different process corners

From the power consumption point of view, the proposed VFC does not achieve satisfactory results. In the worst case, the power consumption is 786 μW, while in the best case, the value of 53.7 μW can be observed. The high power consumption is mainly caused by the PFDDA, which in worst case, has power consumption of 385 μW [10]. It means that the gain stage together with the V-I conversion stage of VFC represent 97% of the total power consumption. However, considering the complexity of the PFDDA, such a value might be still acceptable. It is important to note that the presented power consumption was obtained for the worst and best process corners from the output frequency point of view. If we consider the power consumption in the best case (SNSP, res:max, cap:max, T=−20°C), it will be only 17.71 μW, while the worst case will not change.

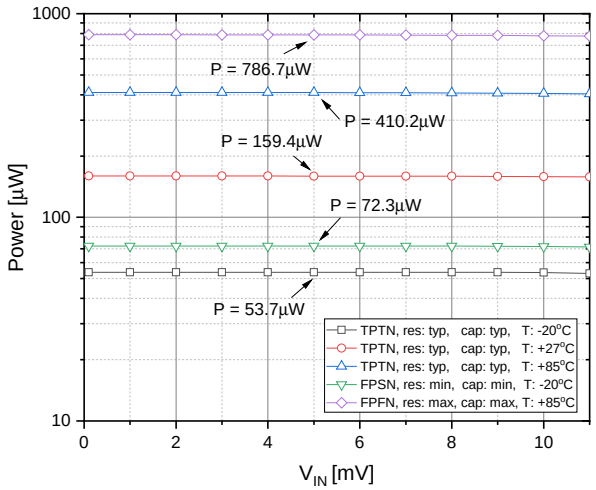

Fig. 7. VFC power consumption vs. input voltage for different process corners

The value of differential frequency Δf_{OUT} for the input voltage of 5 mV obtained from MC analysis is shown in Fig. 8. In this case, mismatch of $\pm 3\sigma$ as well as process variation of

all devices were taken into account. The mean value of Δf_{OUT} of 1.55 kHz was obtained with the standard deviation of 1 kHz. Based on the preformed MC analysis we can conclude that a relatively high variation of the output frequency was observed, which can be caused by passive devices used in the proposed VFC.

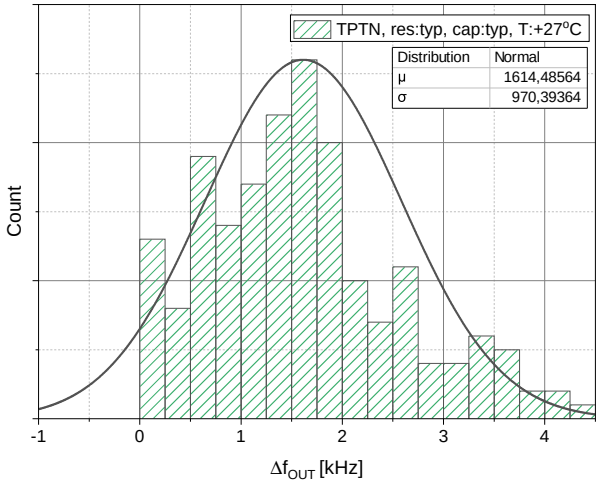

Fig. 8. MC analysis of Δf_{OUT}

For this purpose, we investigated and analyzed the sensitivity of the proposed VFC on the process variations using the Corner analysis. Results obtained from the Corner analysis are shown in Fig. 9, where the output frequency is normalized to the maximum output frequency in the particular transistor process corner. One can be observe that the output frequency is mainly sensitive to passive device used in the designed VFC. The higher influence has been reported for capacitor C_1, where the deviation of the output frequency is up to 20% (with the change between the minimum and the maximum value of capacitor). In the case of resistors, the variation of about 14% in the output frequency can be observed. These variations in the output frequency correspond with the relative changes of the resistor (from -24% to 13%) and capacitor (from -17% to 13%) in the corner simulations. In order to compensate the process variations, some calibration methods or compensation techniques have to be employed [12].

The main parameters of the proposed VFC are summarized in Table I, where all process corners and the temperature range from -20°C to 85°C are considered.

TABLE I
MAIN PARAMETERS OF THE PROPOSED VFC

Parameter	Min	Typ	Max
Input Range [mV]	-	0 - 10	-
Frequency Range [kHz]	0.003 - 1.09	0.033 - 3.48	0.056 - 5.16
Frequency Span [kHz]	1.089	3.45	5.106
Sensitivity [Hz/mV]	110.1	348.8	515.8
Nonlinearity [%]	-	-2.7	-
Offset Error [Hz]	1.3	33.2	52.2
Total Power [μW]	17.71	78.4	788.4

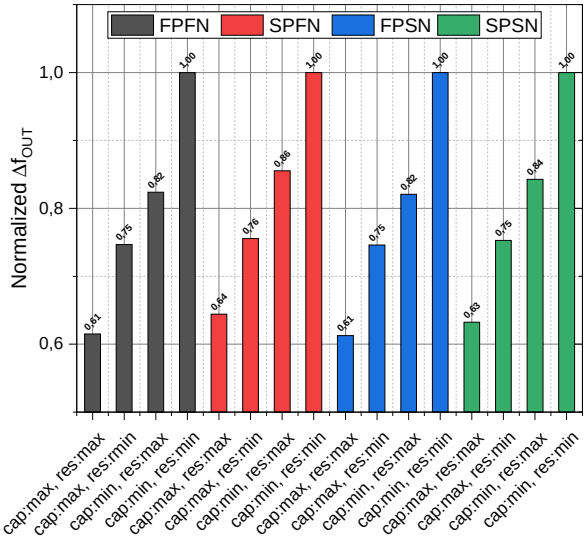

Fig. 9. Normalized Δf_{OUT} for different process corners

The comparison on the proposed VFC to other works is presented in Table II. Based on our knowledge, there are no similar works published where such a low value of the supply voltage was used. Therefore, the presented comparison might not be fully relevant. In order to compare the nonlinearity of the proposed VFC to other works, the nonlinearity definition presented in [11] was used. However, in the case of [13], 1-R^2 nonlinearity definition was introduced in Table II.

TABLE II
COMPARISON OF THE VGA TO OTHER WORKS

Parameter	[13]	[14]	**This work**
Process	180 nm	65 nm	130 nm
Supply Voltage	1.2 V	1.2 V	0.4 V
Total Power [mW]	0.08	0.168	0.078
Temperature Range [°C]	-40 to 120	-30 to 80	-20 to 85
Input range	0-1.2V	30 nA-60 μA	0-10 mV
Frequency range [Hz]	0.1M-1M	1.3k-2.49M	0.033-3.48M
Sensitivity	750kHz/V	41.5Hz/nA	348.8Hkz/V
Nonlinearity [%]	0.009	$\pm$ 0.6	0.59
Sim./Meas.	Meas.	Meas.	Sim. (PVT)

From the Table I and Table II can be observed that the proposed VFC has good linearity in a wide output frequency range that is mainly cased by the differential topology. The maximum offset error is about 52 Hz which represents only 1% of the full frequency range of VFC. The disadvantage of the proposed VFC is its relatively high power consumption mainly caused by PFDDA, which was designed as basic a building block for differential signal processing. Therefore, the power consumption can be reduced by a proper design of the gain and V-I conversion stages.

The microphotography of the designed VFC is shown in

Fig. 10. The VFC occupies chip area of $0.227\,\mathrm{mm}^2$ with dimensions of $863\,\mu\mathrm{m} \times 263\,\mu\mathrm{m}$. The gain stage was placed on the left side, while the V-I conversion stage together with the I-F conversion stage was placed in the middle of the layout. The considerable layout area is occupied by capacitors C_1 and C_2, which were placed on the right side of the layout. Proper layout techniques were employed in order to achieve good matching of the bulk-driven MOS transistors as well as all passive devices (resistors and capacitors).

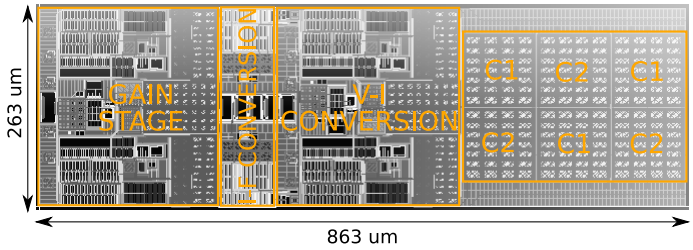

Fig. 10. Microphotography of the proposed VFC

IV. Conclusion

The differential low-voltage VFC, based on the PFDDA topology and designed in 130 nm CMOS technology, was presented. As demonstrated, the designed VFC can be used in low-voltage applications, where the supply voltage of less than 0.4 V, high dynamic range and high linearity are required. Since the proposed VFC has a rail-to-rail input voltage range, it can be used for the high-side or low-side on-chip current measurement. The future work will be focused on the design of calibration circuity and measurement of the designed VFC.

Acknowledgment

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Design of Sense Amplifiers for Non-Volatile Memory

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***Abstract*—In this paper, four sense amplifiers using different architectures are designed and manufactured in 180 nm technology and compared in terms of speed, area and precision. First two amplifiers are latch-based, the third is current-sampling-based and the fourth architecture combines the current conveyor with the comparator. The results show that the minimal sensing time is equal to: 4.32 ns, 6.01 ns, 7.33 ns and 13.22 ns for the first, second, third and fourth amplifier, respectively. The achieved precision is equal to: 7.6 μA, 7.9 μA, 6.7 μA and 18.4 μA, having the areas of the circuit equal to: 156.54 μm^2, 212.18 μm^2, 2147.44 μm^2 and 3755.65 μm^2, respectively. The manufactured samples were verified experimentally.**

***Index Terms*—non-volatile memory, sense amplifiers, integrated circuit design, layout design, chip measurements, 180 nm CMOS technology**

I. Introduction

The development of the integrated circuit technology mostly assumes the scaling of the devices, together with the lower supply voltage. This also applies to the devices used in non-volatile memories (NVM). Subsequently, the read current of non-volatile memory devices is decreasing as the circuits are implemented in smaller technology nodes. Also, the bitline offset and process variations present an additional challenge for the design of the read circuit, especially the sense amplifier. Additionally, the difference in cell currents gets smaller with time.

Several solutions, considering the trend and problems mentioned before, have been proposed to sense small difference in values between cell current and reference current [2], [3], [4]. In this work, some of the proposed architectures are further explored, modified for the Twin-bit cell [8], [1] and compared in terms of precision, speed and area. In [2] latch type sense amplifier is proposed, in [3] a fully differential sense amplifier is explored, while in [4] a current sampling based sense amplifier is presented.

This paper is organized as follows. In Section II four different sense amplifier architectures are presented. Section III exhibits the analysis and quantitative comparison of the amplifier performances. In Section IV the implementation and experimental results are shown. Final conclusions are given in Section V.

II. Sense Amplifier Architectures

A. First Version of the Sense Amplifier

The first architecture of the sense amplifier is shown in Fig. 1. This circuit is latch-based sense amplifier, similar to the one described in [2]. The latch consists of two inverters (M_{1-4}, M_{2-5}). The rest of the circuit are: two switches for the precharge of bitlines (M_{6-7}), precharge equalization transistor (M_8), sense enable transistor (M_3) and two switches for input currents (M_{9-10}). The operation read is performed in three phases using the control signals: precharge ($PRCHR$), input current enable ($DVLP$) and sense enable (SE). The first phase, namely the precharge phase, begins with the falling edge of the signal $PRCHR$. At the same time, the signal $DVLP$ goes high. Low value of the signal $PRCHR$ ensures that the bitlines precharge to a high value, the power supply voltage V_{DD}. The duration of this phase depends mostly on the parasitic capacitance of the bitlines (C_{bl}), which value can be only approximated. Therefore, it is required that this phase lasts long enough so that the outputs get precharged to V_{DD}

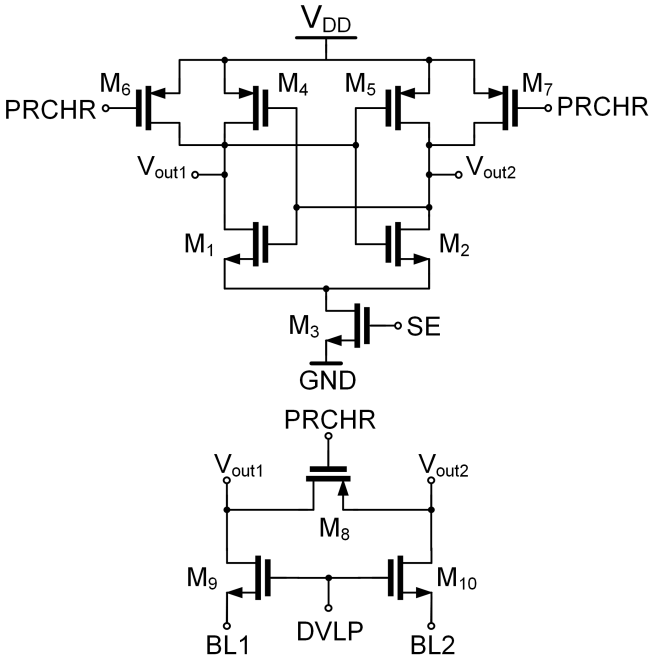


Fig. 1. Schematic of the first version of the sense amplifier.

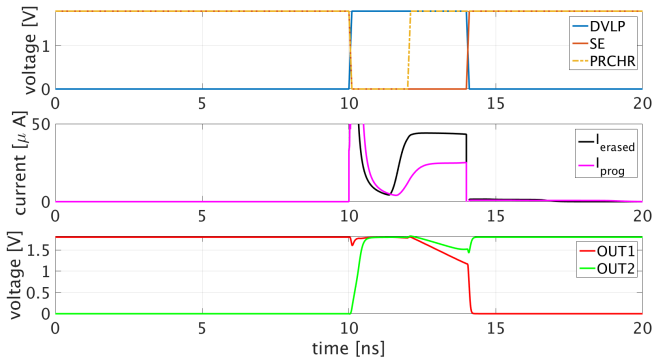


Fig. 2. The detailed results of the first version of the sense amplifier, showing the control signals, input currents and output voltages vs. time.

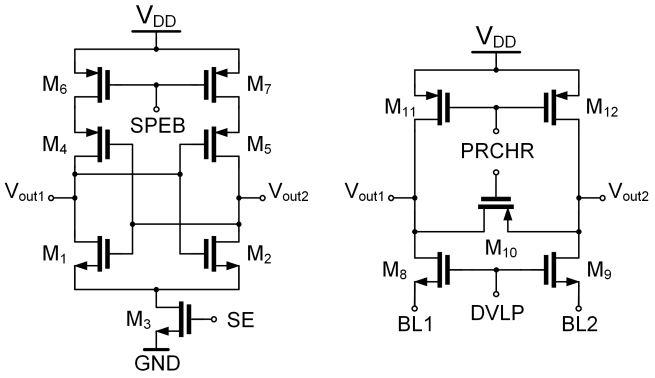


Fig. 3. Schematic of the second version of the sense amplifier.

independently of exact value of C_{bl}. The currents I_{erased} and I_{prog} start to flow. I_{erased} and I_{prog} represent the currents from erased and programmed cells, respectively. The second phase, namely the develop phase, starts with the rising edge of $PRCHR$. The outputs start to discharge and the difference between them develops. When the difference develops to a value 0.3 V, the third phase starts. This value is chosen so that the next phase starts as soon as possible, taking care that correct values are read out regardless of the process corner variations. Therefore, with the difference in outputs approaching the value 0.3 V, the value of $DVLP$ falls to logical '0' and SE rises to logical '1'. This represents the beginning of the sensing phase, which should last until the outputs V_{OUT2} and V_{OUT1} settle to 1.8 V and 0 V, respectively. Basic calculations provided the approximate values of the sufficient length of the control signals. These values were optimized later with respect to the timing, area and process variations. Assuming that the bitline capacitance C_{bl} and precharge transistors (M_{6-7}) can be approximated by an RC circuit, the total precharge time is equal to:

$$t_{PRCHR} = 5R_{avg}C_{bl} = \\ = 5\frac{1}{K_p(\frac{W}{L})_p(V_{DD} - |V_{thp}| - \frac{V_{DS}}{2})}C_{bl}. \quad (1)$$

During the develop phase, the bitline capacitance is discharging. In order to estimate the develop time, t_{DVLP}, the constant discharge currents are assumed. Therefore, the time t_{DVLP} is equal to the following expression:

$$t_{DVLP} = C_{bl}\frac{\Delta V_{OUT}}{\Delta I} = C_{bl}\frac{0.3V}{I_{erased} - I_{prog}}. \quad (2)$$

The complete results of the transient analysis, together with the timing of the control signals, are shown in Fig. 2.

B. Second Version of the Sense Amplifier

The second architecture [9] of the sense amplifier is shown in Fig. 3. This architecture, like the first circuit, exploits two inverters (M_{1-4}, M_{2-5}), two switches for the precharge of bitlines (M_{11-12}), bitline voltage equalization transistor (M_{10}), sense enable transistor (M_3) and two switches for the input currents (M_{8-9}). Two remaining transistors (M_{6-7}) operate as a switch and also prevent current leakage, which is important for the worst power case combined with high temperature. Also, all three read operation phases are equivalent to the ones described in the previous paragraph. The results of the transient analysis are shown in Fig. 4. Although the results are very similar to the results of the previous amplifier, this amplifier has about five times smaller leakage current.

C. Third Version of the Sense Amplifier

The third version of the sense amplifier is presented in Fig. 5, and it was proposed in [4]. The main motivation for the architecture was to design a sense amplifier with better offset tolerance, simultaneously avoiding slow read speeds and wrong readings [4]. The circuit operates in three phases. The first phase is called current sampling. During this phase, all four switches (Fig. 5) are closed, M_4 and M_5 are diode-connected and capacitors are charging. A simple calculation shows that the circuit is independent of threshold voltage variations to the first order. The following equation is valid with assumptions that transistors are in saturation:

$$I_{prchr} = K_p(\frac{W}{L})_p(V_{DD} - V_{G0} - V_{thp1,2})^2, \quad (3)$$

where V_{G0} is the gate voltage and I_{prchr} is the precharge

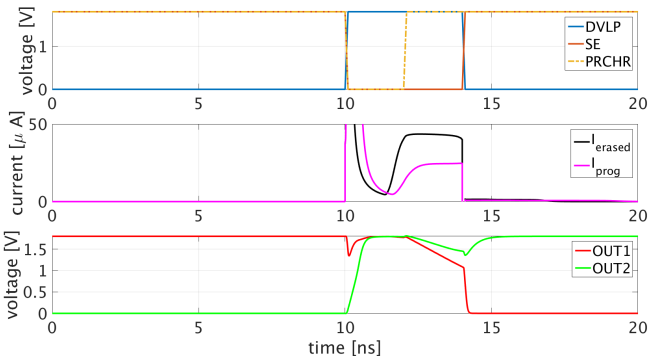


Fig. 4. The detailed results of the second version of the sense amplifier, showing the control signals, input currents and output voltages vs. time. The signal $SPEB$ is identical to the signal SE.

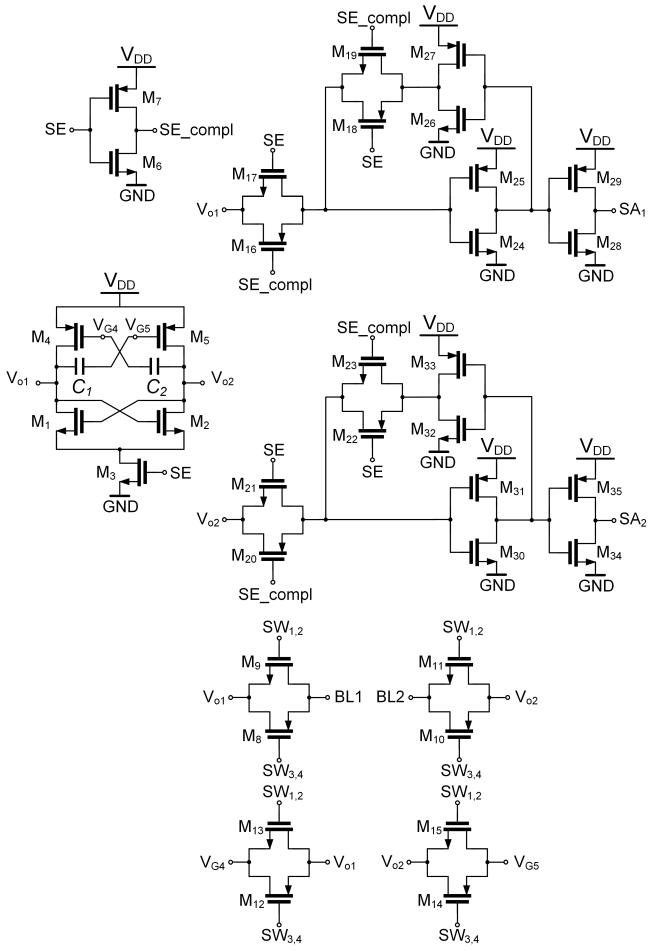


Fig. 5. Schematic of the third version of the sense amplifier.

current of the transistors M_4 and M_5. Just after the precharging is completed, all four switches open and the following is valid:

$$I_{erased} = K_p(\frac{W}{L})_p(V_{DD} - V_{G1} - V_{thp1})^2, \tag{4}$$

$$V_{capacitor} = V_{out2} - V_{G1} = V_{DD} - V_{G0}. \tag{5}$$

Equation (4) is similar to the (3) and it is valid because the voltage on the capacitor cannot change immediately. Also, this applies to the other transistor, by the symmetry of the circuit (with the different indices). Combining (3)-(5), it follows that:

$$I_{prchr} = K_p(\frac{W}{L})_p(V_{out2} - V_{G1} - V_{thp1})^2, \tag{6}$$

$$\begin{aligned} V_{G1} &= V_{DD} - V_{thp1} - \sqrt{\frac{I_{erased}}{K_p(\frac{W}{L})_p}} = \\ &= V_{out2} - V_{thp1} - \sqrt{\frac{I_{prchr}}{K_p(\frac{W}{L})_p}}. \end{aligned} \tag{7}$$

Finally, the expression for the output voltage is:

$$V_{out2} = V_{DD} + \sqrt{\frac{I_{prchr}}{K_p(\frac{W}{L})_p}} - \sqrt{\frac{I_{erased}}{K_p(\frac{W}{L})_p}}. \tag{8}$$

As the (8) does not contain any threshold voltage value, the effect of mismatch in threshold voltages is not critical in the first approximation.

The second phase, called the current-ratio amplification phase [4], starts after the switches open. It should last long enough so that the outputs can separate and that their difference can be sensed later on. This current amplification can be seen as a development of differences of outputs. The sensing process starts when the nMOS latch (M_1 and M_2) gets enabled by raising the signal SE. All this is shown in Fig. 6, which shows the transient simulation results of the circuit.

D. Fourth Version of the Sense Amplifier

The fourth version of the sense amplifier is presented in Fig. 7. The amplifier consists of two parts, namely the current conveyor [5] and the comparator. The ports X, Y and Z marked in Fig. 7a represent the ports of the conveyor. The comparator is analogue latch-based with two (differential) outputs, each of which is connected to the output buffer (two inverters). The whole read operation is done in four phases: two phases for the current conveyor and two for the comparator, all realized using two control signals, $PRCHR$ and SE. At the beginning, the $PRCHR$ signal is going to '0' so that the drains of M_3, M_6 can be discharged and drains of M_4 and M_7 charged to V_{DD}. During the next phase, which is coming immediately after precharging, the signal SE is high, enabling input currents to flow through M_1 and M_2. The signals $PRCHR_dly$ and SE_dly are the control signals for the comparator. They were achieved by delaying the signals $PRCHR$ and SE, as shown in Fig. 7b. Not only that the number of the input signals is reduced, but also better mutual tracking of control signals in case of mismatch is achieved. The lengths of the phases, as well as the number of delay lines, are set up in a way that precharging of the comparator starts during the sense phase of the conveyor. That is, the time $t_{se} \approx t_{delay_line}$. The value of 10 ns was chosen as a compromise between the speed and the

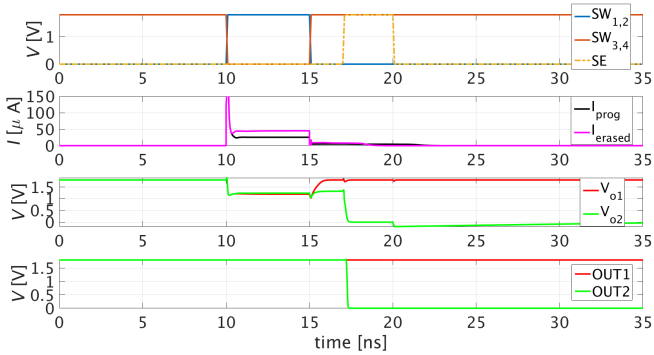
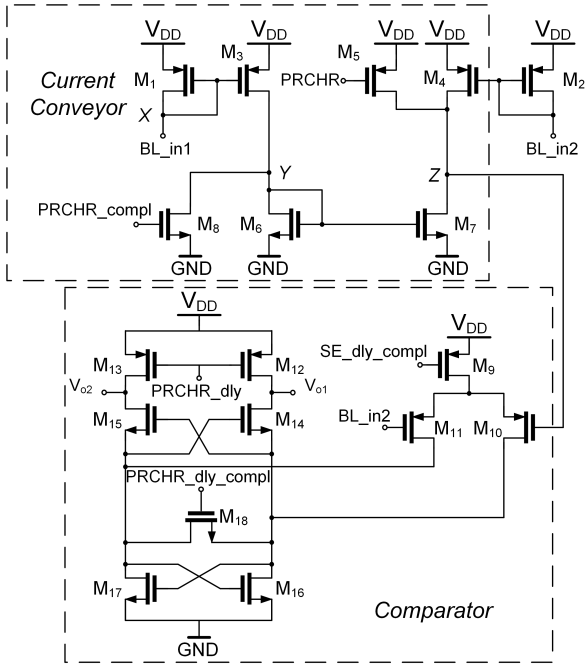
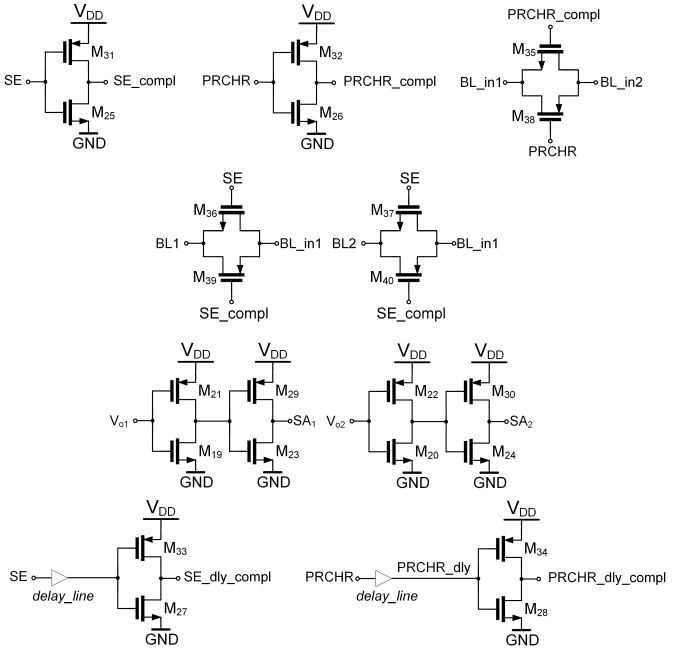


Fig. 6. The detailed results of the third version of the sense amplifier, showing the control signals, input currents and output voltages vs. time.



(a) A current conveyor and a comparator.



(b) Control, input and output signals.

Fig. 7. Schematic of the fourth version of the sense amplifier.

precision. During Monte Carlo simulations, it was observed that the voltages at the input of the comparator become small with the mismatch and wrong readout can happen. When the sense phase ends, precharging of comparator ends and the final sensing starts. Complete results of the transient simulations are given in Fig. 8.

III. Analysis and Comparison

For each of the amplifiers, three most important aspects were taken into account. They are the speed, the area and the precision of the amplifiers. The speed is related to the minimal period. The period is measured from the beginning of the first phase (rising or falling edge of $PRCHR$) until the outputs

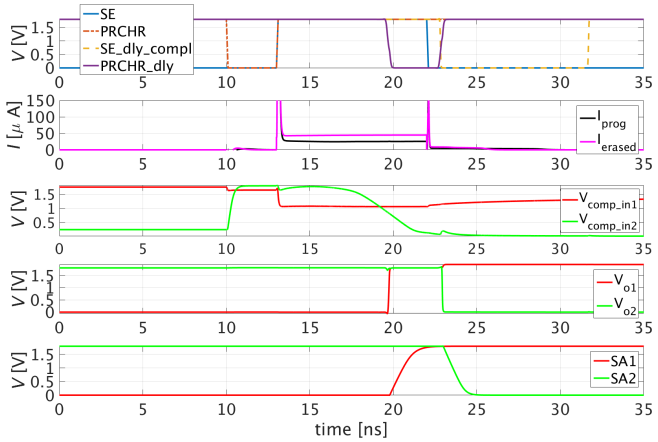


Fig. 8. The detailed results of the fourth version of the sense amplifier, showing the control signals, input currents and output voltages vs. time.

are settled to the correct values (within 0.1%). It is marked as a T_P in Table I. In Table I the area and the precision of each amplifier are listed, as well as the leakage current. The precision $(\Delta I)_{min}$ is defined as a minimal difference in input currents that can set the outputs to the correct values. All this is presented in Table I. The minimal difference in currents was obtained using the Monte Carlo simulations. Number of points was 200, and the required yield for all cases was 100%. Additionally, the leakage currents for all amplifiers is given in Table I as a I_{leak}. Leakage current is measured as a total current consumption of the amplifier in off state, for the case of worst power and temperature of 125°C. For all testbenches, the nominal values of currents were I_{erased} = 45 μA and I_{prog} = 25 μA, the power supply voltage V_{DD} was equal to 1.8 V, and the parasitic capacitance of the bitlines C_{bl} was equal to 100 fF. Also, PVT variation analysis was performed, as well as the parasitic extraction analysis.

IV. Implementation and Experimental Results

All four amplifiers were manufactured in the TSMC 180 nm technology and integrated on the same test chip, as shown in Fig. 9.

TABLE I. The detailed results of the simulations for different sense amplifiers.

#	T_P [ns]	$Area$ [μm^2]	$(\Delta I)_{min}$ [μA]	I_{leak} [nA]
1	4.32	156.54	7.6	82
2	6.01	212.18	7.9	18
3	7.33	2147.44	6.7	382
4	13.22	3755.65	18.4	237

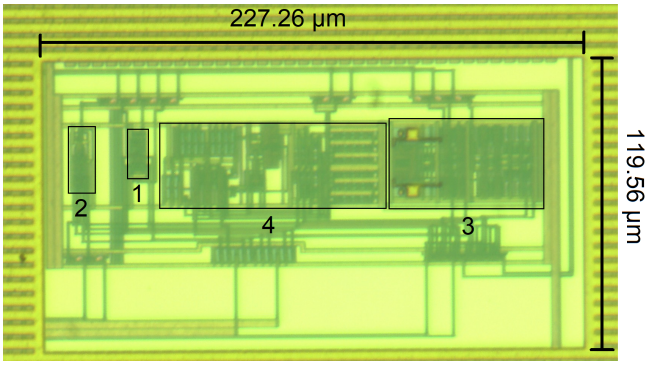


Fig. 9. The die micro-photograph of the sense amplifier test chip. All four amplifiers were integrated on the same chip, and the amplifiers were selected one at a time during testing. Each amplifier is marked and labeled with the corresponding number.

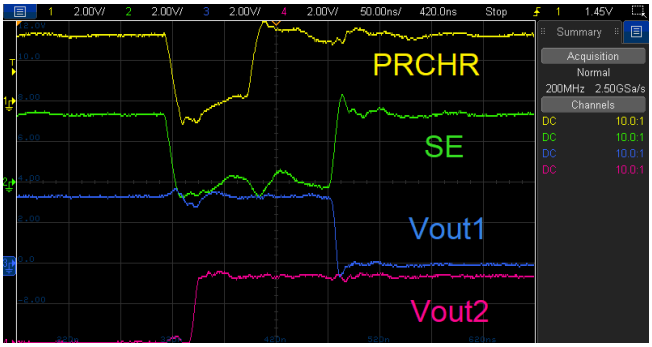


Fig. 10. Results of the measurement of the first amplifier for I_{erased} = 1 μA and I_{prog} = 0 μA.

The maximum possible frequency of the digital signals was smaller than that used in simulations. That is, the shortest duration of the pulse was 80 ns, which is considerably longer than the pulses in the simulation. Moreover, simulations showed that longer develop time should provide better precision of the circuits. Therefore, it was reasonable to apply lower input currents - more precisely, the difference of 1 μA in input currents was applied. The experimental results are shown in Figs. 10-13 as a screen captures from the oscilloscope. They confirm the proper operation of all four amplifiers, as the outputs are set to the correct values. Although the duration of the operation is not comparable with the timings from the simulations, it is possible to distinguish operating phases of the circuits, namely the moments when the outputs get precharged and the change of the output signal values after the sensing starts. The precharge of the outputs in Fig. 12 is not visible, as the outputs are separated from the rest of the circuit with the output buffers.

V. Conclusions

This paper presents the difference between several approaches in sense amplifier design. There are three criteria for the design comparison - the precision, the speed and the area. Regarding the timing, it can be seen that the first and the second amplifier are faster than the third and the fourth. The area is, as expected, growing in size with the higher

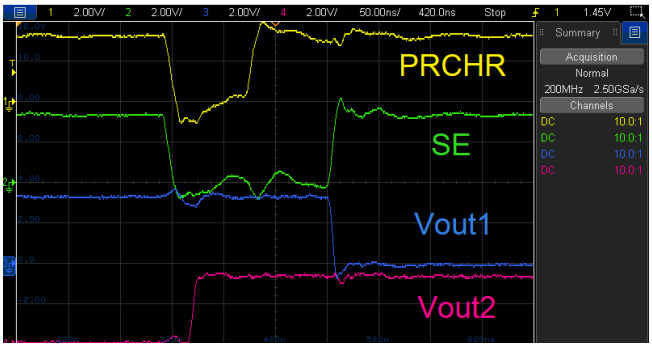


Fig. 11. Results of the measurement of the second amplifier for I_{erased} = 1 μA and I_{prog} = 0 μA.

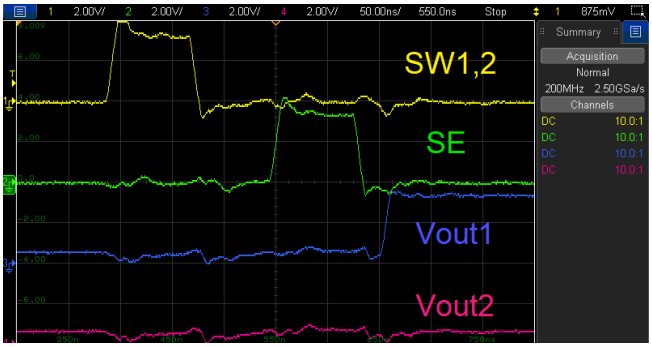


Fig. 12. Results of the measurement of the third amplifier for I_{erased} = 1 μA and I_{prog} = 0 μA.

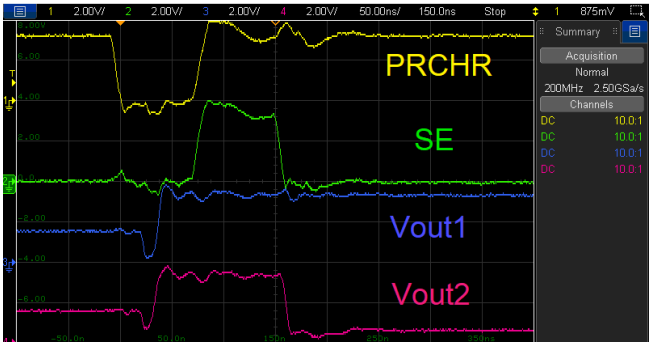


Fig. 13. Results of the measurement of the fourth amplifier for I_{erased} = 1 μA and I_{prog} = 0 μA.

complexity of the circuit. However, it was expected that the precision could be trade off for the speed and the area of the circuit. The results of the PVT variation analysis showed that the variations of the period was small across corners for the third amplifier. That proves that this architecture is suitable for the cases when the offset should be minimized. Finally, the operation of the amplifiers is verified on silicon, exhibiting the behavior predicted by the simulations.

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Design Methodology of an On–Chip Inductor in 180 nm CMOS Technology

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***Abstract*—This paper presents the design methodology for an on–chip inductor in 180 nm CMOS technology, intended for a fully integrated LC oscillator. The design method uses the model based on the physical interpretation of the inductor, and optimizes the design with respect to the Q–factor. Resulting from the optimization procedure, the inductor is designed for the on–chip LC resonator, having the nominal inductance value of L_S=2.62 nH and Q–factor of 5.42 at 1 GHz. Finally, the designed inductor is verified by the EM simulations, and the results are compared to the physical model used for the optimization.**

***Index Terms*—LC resonator, on–chip inductor, electromagnetic simulations, Q–factor**

I. Introduction

The need for the full–scale integration of the clock generation circuits has emerged over the last decade, resulting from the cost and size reduction requirements [1]. Crystal oscillators, although featured with the best performance in terms of noise and precision, do not have the possibility of integration. The high–performance full on–chip quartz alternatives are available in the form of LC and MEMS resonators. Nevertheless, their use remains limited because of several factors. To begin with, both solutions have the inherent problem with the excessive power consumption. Furthermore, MEMS resonators require a special and rather expensive process, significantly increasing the production cost. In the end, the critical element of the on–chip LC resonator is the inductor, having problems with large area, low Q–factor, and limited inductance values, unavoidably limiting the resonant frequency to the ∼GHz range.

Together with the investigation of the mentioned problems related to the inductor design, this work presents the design methodology and the optimization procedure for such an inductor. Different coil layout topologies and methods for the coil inductance approximation are considered, with the special focus on the Q–factor optimization. In the end, the traditional methods are considered in order to provide the algorithm for a time–efficient inductor design with the inductance value as an input parameter and physical dimensions as the output parameters (shape, size, line width, spacing).

This work is organized as follows. In Section II a typical LC oscillator architecture is presented. In Section III the design of the inductor is discussed. In Section IV the simulation results of the designed inductor are shown for the physical model and 3–D electromagnetic simulations. In Section V the conclusions are given.

II. Conventional LC Oscillator Architecture

A commonly used LC oscillator core architecture is shown in Fig. 1 [1], consisting of the negative resistance circuit and the LC resonator, with the design parameters shown in Table I. In order to maximize the effective transconductance g_m, the negative resistance circuit [2] used to sustain the oscillations (compensating the energy loss in the resonator) comprises both nMOS and pMOS cross–coupled pair. The model of an inductor and capacitor with series resistances is used for the LC resonator tank. According to [1], the resonant frequency of the LC tank can be expressed as:

$$f_R = \frac{1}{2\pi\sqrt{LC}}\sqrt{\frac{1-R_L^2\frac{C}{L}}{1-R_C^2\frac{C}{L}}}. \quad (1)$$

Inserting the design values into (1), the value of the resonant frequency is f_R=1 GHz. As a result of parasitic capacitances loading the V_{OUT1} and V_{OUT2} nodes, the simulation provides somewhat lower frequency, namely $f_R = 937.4$ MHz.

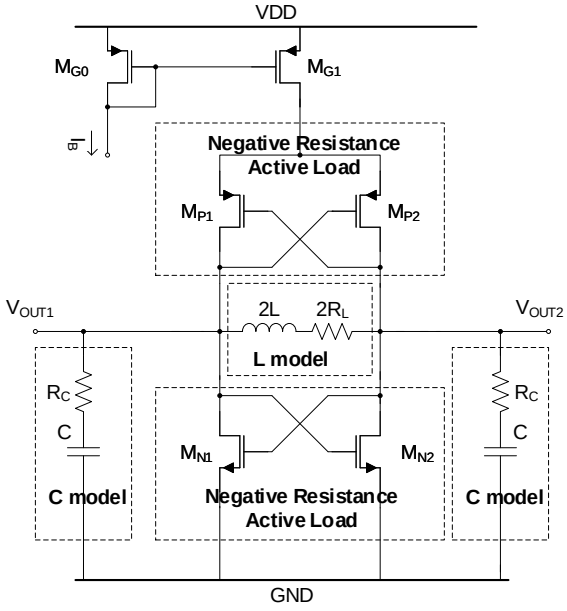


Fig. 1. Schematic of the LC oscillator core comprising the negative resistance load and the model of the LC resonating tank.

TABLE I
DESIGN PARAMETERS OF THE OSCILLATOR CORE.

Parameter	Value
$(w/l)_{MN1,2}$	100μm/0.2μm
$(w/l)_{MP1,2}$	200μm/0.2μm
$(w/l)_{MG0,1}$	800μm/0.2μm
$2L$	2.58nH
$2R_L$	3Ω
C	20pF
R_C	80mΩ

The simulation results showing the frequency variation vs. temperature for the designed core are presented in Fig. 2, performed for different corners and the temperature range from -40°C to 125°C. The worst case temperature coefficient of $\pm$6.8ppm/°C originates entirely from the CMOS variations, provided the ideal R/L/C elements in the resonating tank.

III. INDUCTOR DESIGN

A. Design Considerations

The differential inductor is considered for the implementation, since it typically provides up to two times higher Q–factor compared to the non–differential structure [3]. Furthermore, in order to reduce the ohmic losses, it is beneficial to realize the inductor in thicker metal layers. In this work, the designed inductor is realized in the top three metal layers within the layer stack–up shown in Fig. 3.

The typical topologies of on–chip inductors are rectangular, octagonal, hexagonal or round, shown in Fig. 4, each having its benefits and disadvantages. The round inductor provides a higher Q–factor compared to the rectangle inductor at the price of increased area, meaning that both the hexagonal and octagonal inductor are compromises between the rectangular and round topologies. The octagonal inductor was chosen for the implementation.

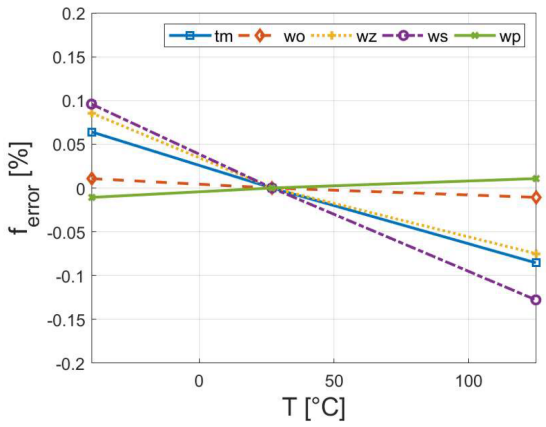


Fig. 2. Frequency error vs. temperature, shown for different process corners, simulated with the bias current of I_B=10 mA (-40°C $\leq T \leq$125°C).

B. Inductance Calculation

In the beginning, the values that describe the inductor layout (shown in Fig. 4) are introduced: d_{in} is the inner diameter, d_{out} is the outer diameter, w is the line width, and s is the spacing between lines. Furthermore, n represents the number of turns, while the two other variables introduced for the simplification reasons, namely the average diameter d_{avg} and the fill ratio ρ, are defined as:

$$d_{avg} = \frac{d_{out} + d_{in}}{2}, \tag{2}$$

$$\rho = \frac{d_{out} - d_{in}}{d_{out} + d_{in}}. \tag{3}$$

Once the structure is defined, the values for the design parameters need to be determined as well. There are several ways to calculate the inductance quickly with a sufficient accuracy. The method called the Expression based on Current Sheet Approximation [4] is used in the following analysis, and is based on the approximation of the sides of the spirals by symmetrical current sheets of equivalent current densities. Using this method, the inductance can be expressed as:

$$L_S = \frac{\mu n^2 d_{avg} c_1}{2} \left(ln\frac{c_2}{\rho} + c_3\rho + c_4\rho^2 \right), \tag{4}$$

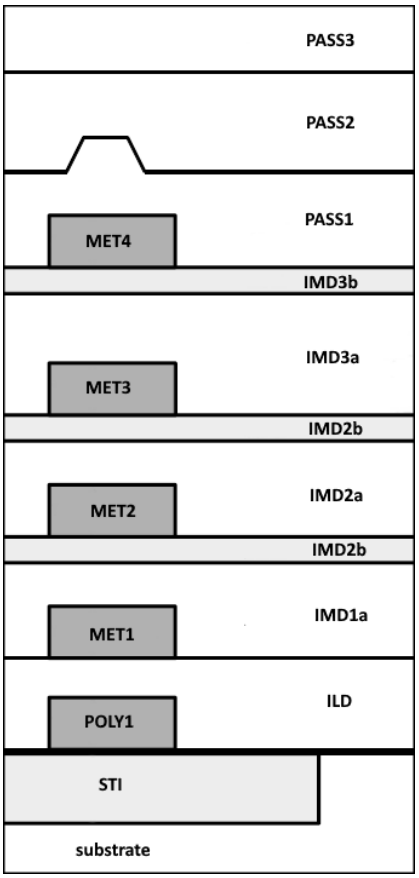


Fig. 3. Wafer cross–section [4].

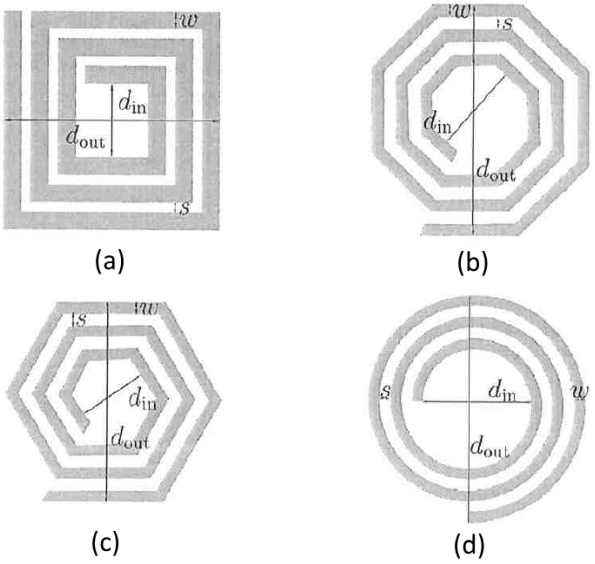


Fig. 4. On–chip inductor structures: (a) rectangular, (b) octagonal, (c) hexagonal, (d) round. [4]

where μ is the magnetic permeability, while the constants c_1, c_2, c_3 and c_4 are defined by the used shape, listed in Table II [4]. The method is especially accurate for $s \leq w$.

C. Lumped Elements Model

In order to calculate the inductor parameters and optimize the structure with respect to the Q–factor, the losses need to be taken into account. For this reason, the lumped elements inductor model shown in Fig. 5 is introduced [4], where L_S is the inductance, R_S is the series resistance, C_L is approximated as the parallel–plate capacitance between the spiral and the center–tap underpass, C_{OX} is the capacitance between the spiral and substrate, C_{SI} is the parasitic substrate capacitance, and R_{SI} is the parasitic substrate resistivity. The expressions for the calculation of the parameters are [4]:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}, \tag{5}$$

$$R_S = \frac{\rho l}{w\delta(1-e^{-t/\delta})}, \tag{6}$$

$$C_L = nw^2\frac{\epsilon_{OX}}{t_{OX}}, \tag{7}$$

$$C_{OX} = \frac{1}{2}lw\frac{\epsilon_{OX}}{t_{OX}}, \tag{8}$$

TABLE II
COEFFICIENTS FOR CURRENT SHEET EXPRESSION [4].

Shape	c_1	c_2	c_3	c_4
square	1.27	2.07	0.18	0.13
octagon	1.07	2.29	0.00	0.19
circle	1.00	2.46	0.00	0.20

$$C_{SI} = \frac{1}{2}lwC_{SUB}, \tag{9}$$

$$R_{SI} = \frac{2}{lwG_{SUB}}. \tag{10}$$

The first parameter is the skin depth δ needed for the calculation of R_S, while ω is the radial frequency, μ is the magnetic permeability, and σ is the conductivity. For the R_S calculation, ρ is the resistivity $(1/\sigma)$, l is the inductor length, w is the metal width, and t is the metal thickness. For the C_L calculation, n is the number of the spiral turns, ϵ_{OX} is the oxide dielectric permittivity, and t_{OX} is the oxide thickness. For C_{OX} calculation no new parameters are introduced. For C_{SI} and R_{SI} calculation C_{SUB} and G_{SUB} are needed. Unlike the previous parameters that are either typical or rather easily obtainable within a certain technology, these are technology parameters that are hard to approximate. Usually they are obtained after performed measurements by fitting various values in the model simulations on the measured results.

D. Q–Factor Calculation

The Q–factor of the inductor is the single most important parameter for the on–chip LC oscillator design. Most of the time having the value below $Q_L < 10$, the coil is responsible for the biggest portion of the energy losses inside the resonator. The Q–factor is defined as [5]:

$$Q = \omega\frac{W_m + W_e}{P_{dis}} = \frac{\mathrm{Im}(Z)}{\mathrm{Re}(Z)}, \tag{11}$$

where ω is the frequency, W_m is the stored magnetic energy, W_e the stored electrical energy and P_{dis} is the power loss. The inductor impedance Z can be calculated using the lumped elements model from Fig. 5, namely:

$$Z = \frac{V}{I} = \left[\frac{1}{2}\frac{j\omega C_{OX}(1+j\omega R_{SI}C_{SI})}{1+j\omega R_{SI}C_{SI}(C_{SI}+C_{OX})} + j\omega C_L + \frac{1}{R_S + j\omega L_S}\right]^{-1}. \tag{12}$$

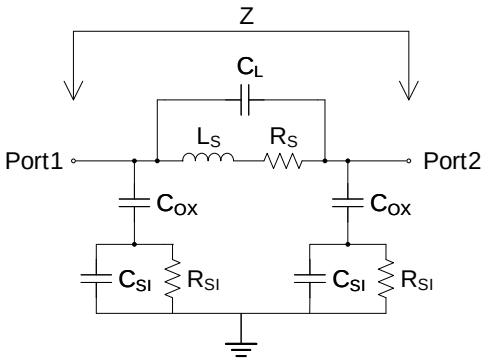


Fig. 5. Lumped elements inductor model [4].

E. Coil Optimization Algorithm

The optimization procedure based on (2)–(12) was implemented in MATLAB using the following algorithm:

- The desired inductance, resonant frequency, and relative error are specified.
- Typical values of the inner diameter, outer diameter, spacing, width and number of turns are varied through multiple loops with respect to technology rules and inserted into (4).
- If the obtained inductance is within the error limit, the corresponding parameters are saved.
- All the inductors and their parameters are again loop–tested through the Q–factor formula previously also derived by the algorithm.
- The inductor and its parameters are replaced every time a new inductor with a better Q–factor is found.
- After the algorithm has tested all possible design values, the outputs are the parameters of an inductor with the highest obtained Q–factor.

The range of the variables used in the algorithm is shown in Table III, together with the results of the optimization procedure for the input parameters of L_S=2.5 nH for the series inductance, f_R=1 GHz for the resonant frequency, and relative error of 5%. The inductor layout is shown in Fig. 6.

TABLE III
VARIABLES USED IN THE COIL OPTIMIZATION ALGORITHM.

	d_{in} [μm]	d_{out} [μm]	w [μm]	s [μm]	n
min value	100	100	2	2	1
max value	350	350	25	9	7
step	1	1	1	1	2
Design value	146	304	25	2	3

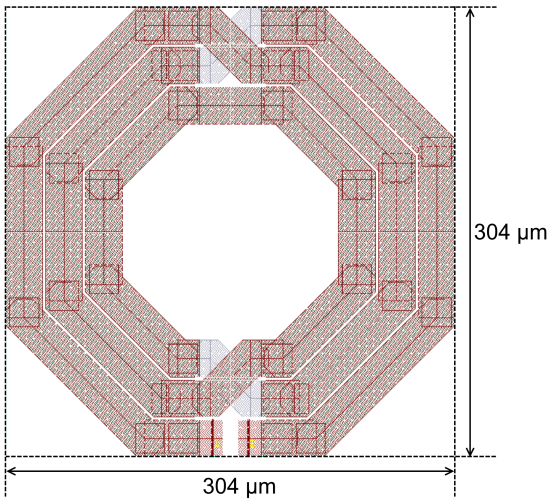


Fig. 6. Layout of the designed inductor, realized in single–layer and three–layer implementations, having the nominal inductance value of 2.5 nH at the target resonant frequency of 1 GHz. The lines intertwined at each turn of the spiral. Multiple vias are placed at each angle point.

IV. Simulation Results

The designed inductor was simulated using two different approaches. The first approach is based on the lumped elements model (LEM) shown in Fig. 5, while the other approach is based on electromagnetic (EM) simulations in HFSS. In order to investigate the influence of the series resistance, two different implementations of the inductor are considered, namely the single–layer and three–layer implementations, realized in a top metal layer and three top metal layers, respectively. Other than using different number of metal layers, the two inductors are identical. The summary of the simulations is shown in Table IV, while the details are discussed in the following text.

A. Lumped Elements Model Simulation Results

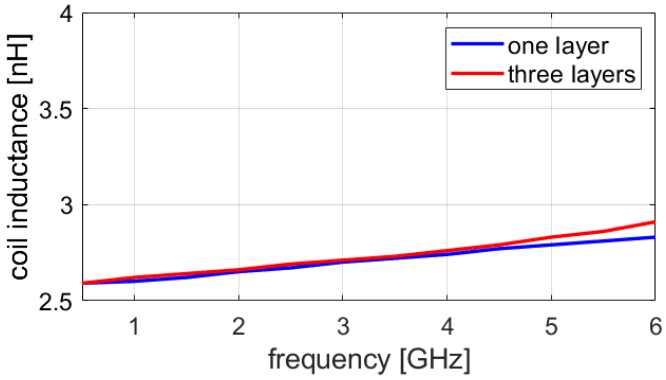
The lumped elements model simulations performed for the designed inductor are shown in Fig. 7, showing the inductance and Q–factor variation with frequency. At the target frequency of 1 GHz, the single–layer inductor has the series inductance of 2.60 nH, while the three–layer inductor has the inductance of 2.62 nH. Seen from the figure, it is apparent that the inductive character of the structure is growing, more so for the three–layer inductor. Furthermore, the simulated Q–factors of the designed inductor at the target frequency of 1 GHz are 4.11 for the one–layer inductor and 6.94 for the three–layer inductor. According to the model, significant improvement is achieved for the three–layer inductor as a result of lowering the series resistance. Finally, the maximum Q–factor is observed around 3 GHz and 2 GHz for the single–layer and three–layer inductor, having the peak values of 8.32 and 9.72, respectively. At higher frequencies, the Q–factor becomes deteriorated as a result of the increase of the ohmic losses, originating from the skin-effect and substrate energy loss.

B. Electromagnetic Simulations Results

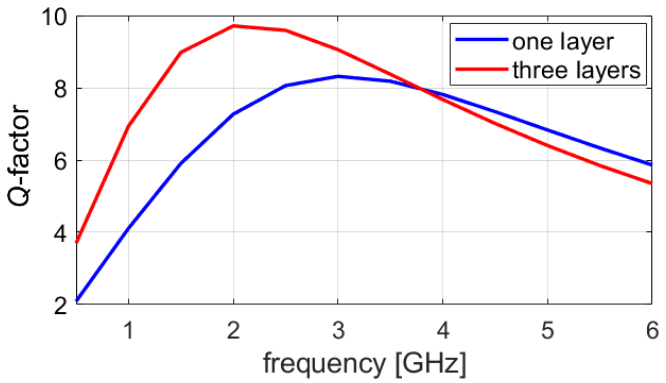
The electromagnetic simulations performed by HFSS for the designed inductor are shown in Fig. 8, showing the inductance and Q–factor variation with frequency. According to the simulations, at the targed frequency of 1 GHz the inductor has the inductance value of 2.70 nH and 2.62 nH for the single–layer and three-layer implementation, respectively. Furthermore, the simulated Q–factor values at the target frequency of 1 GHz are 4.09 and 5.42 for the single–layer and three-layer implementation, respectively. Finally, the maximum value of the Q–factor is observed around 2.5 GHz and 2 GHz for the single–layer and three–layer inductor, having the peak values of 5.42 and 6.69, respectively.

TABLE IV
SIMULATION RESULTS OF THE DESIGNED INDUCTOR USING LUMPED ELEMENTS MODEL AND ELECTROMAGNETIC SIMULATIONS.

Design Value @1GHz	**Single-Layer**		**Three-Layer**	
	LEM	**EM**	**LEM**	**EM**
L_S	2.60nH	2.70nH	2.62nH	2.62nH
Q	4.11	4.09	6.94	5.42

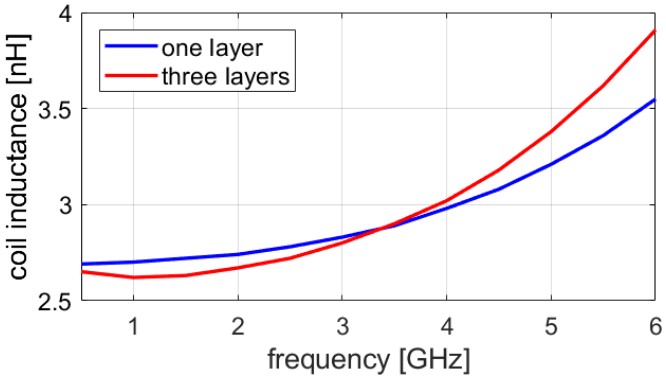


(a)

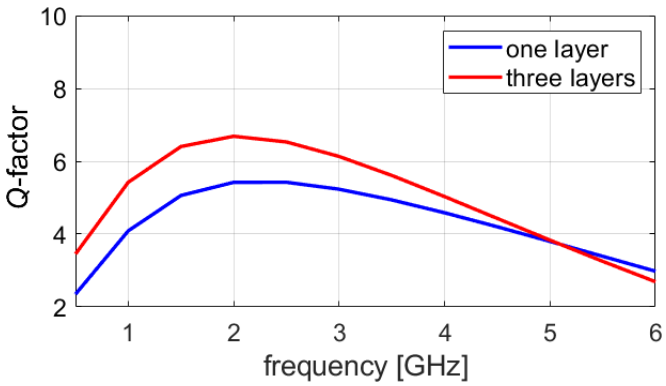


(b)

Fig. 7. Lumped elements model simulations: (a) coil inductance vs. frequency (b) Q–factor vs. frequency.



(a)



(b)

Fig. 8. Electromagnetic simulations: (a) inductance vs. frequency (b) Q–factor vs. frequency.

C. Results Comparison

When comparing the lumped elements model simulation (Fig. 7) with the electromagnetic simulation results (Fig. 8), considerable correspondence is observed for the series inductance value within the frequency range from 0.5 GHz to 3 GHz. This confirms the effectives of the algorithm presented in Section III for a time–efficient estimation of the inductance value at the beginning of the design phase. On the other hand, a discrepancy between the two models is observed in terms of the absolute value of the Q–factor. Possible causes include the influence of the vias and sub–optimal placement, together with the uncertainty of the current distribution in different layers. Nevertheless, the detailed investigation of this discrepancy surpasses the intended scope of the research and should be investigated in a separate occasion.

V. Conclusion

In this work, the design and optimization procedure of an on-chip inductor is investigated. If intended for the full on–chip LC oscillator, the inherently low Q–factor of the on-chip inductor presents a serious limitation, being responsible for the majority of the power loss inside the resonator. For this reason, the differential structure was adopted, providing $\sim$2x higher Q–factor compared to the non-differential structure. As a compromise between multiple inductor geometries that primarily differ in area efficiency and Q–factor value, the octagonal geometry is chosen. Furthermore, in order to reduce the parasitic resistances, the inductor is realized in top three metal layers. Next, the algorithm is proposed based on the lumped elements model for the fast calculation of the inductor design parameters having the highest Q–factor at the specified frequency. The algorithm is used for the design of the test-case inductor optimized for the resonant frequency of 1 GHz, having the nominal inductance value of 2.62 nH and Q–factor of 5.42. The inductor has three turns, its inner and outer diameter being 146 μm and 304 μm wide. The electromagnetic simulations have shown good correspondence with the lumped elements model in terms of the series inductance value, while some discrepancy is observed with respect to the absolute value of the Q–factor.

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Balanced RF Power Amplifier Design in Horizontal Current Bipolar Transistor (HCBT) Technology

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***Abstract* - The paper presents a balanced RF power amplifier designed by using Horizontal Current Bipolar Transistors (HCBT). The near-50-Ω large-signal input and output impedances of HCBT are exploited to achieve wideband operation. Matching and bias networks are designed in microstrip technology and the optimization is performed using electromagnetic simulator. Signal splitting and combining is achieved by microstrip double-box branchline hybrid couplers, which are optimized for wide bandwidth and high return loss. Bias lines are implemented as quarter-wavelength short-circuited shunt stubs, which provide short circuit for even harmonics and open circuit for the fundamental frequency over the entire operating bandwidth. The amplifier is implemented on a low-cost 1-mm-thick FR4 substrate. At 1-dB compression point, the amplifier exhibits 21.4 dBm output power and 10.4 dB gain in the frequency range from 1.8 GHz to 2.5 GHz, with input and output return losses higher than 20 dB while using pure-silicon HCBT technology.**

Keywords - Horizontal Current Bipolar Transistor (HCBT), Wireless communication, Power amplifiers, Balanced power amplifiers

I. INTRODUCTION

Despite recent shift towards millimeter-wave frequency range, the majority of wireless communication still takes place in the sub-6 GHz range. Emerging communication standards demand multiband radio frequency (RF) transceivers which can cover multiple frequency bands in order to reduce the cost incurred by RF circuitry. As the final stage of the transmitter, RF power amplifier (PA) should have bandwidth wide enough to amplify signals in multiple bands with low distortion and high efficiency.

The optimal characteristics of the PA, such as efficiency and linearity, are usually maintained in narrow frequency band whereas the bandwidth can be increased by using advanced transistor technologies or by employing configurations of multiple single-stage PAs, such as balanced PA, which exhibit excellent input and output return loss [1]. A balanced PA consists of two PAs connected in parallel, doubling the output power of a single-stage PA. Additionally, to split the input signal and combine the output signals, a 3-dB coupler with 90° phase shift between the through and coupled ports is used [2]. As a result, the input and output reflections of each PA in the balanced configuration are cancelled by the input and output coupler, respectively. Thus, input and output return losses can be high even if PAs present high reflection coefficients to the couplers. Therefore, the bandwidth of the balanced amplifier is mainly determined by the characteristics of the input and output coupler [2]. Additionally, the reliability is increased, since the balanced PA continues to operate with limited performance if one stage fails.

In order to achieve both high power and gain, high-performance devices must be employed, such as SiGe HBTs, III-V HEMTs or advanced down-scaled MOSFETs, resulting in high cost of implementation. In this paper, a low-cost Horizontal Current Bipolar Transistor (HCBT) technology is used in the implementation of the balanced PA for the first time. The adopted design methodology relies on empirical data gathered using load-pull setup and is presented in Section II. In Section III, the measurement results are presented verifying the design methodology.

This work has been fully supported by Croatian Science Foundation under the project IP-2018-01-5296.

II. DESIGN METHODOLODY

A. Horizontal Current Bipolar Transistor (HCBT)

HCBT is a state-of-the-art low-cost silicon bipolar transistor technology integrated with 180 nm CMOS by adding minimal process complexity [3-4]. Due to a very compact structure and optimized doping profiles, HCBT outperforms all other silicon lateral transistors and can be used as a low-cost, high-performance alternative to conventional BiCMOS technologies. The optimized HCBT has a peak cut-off frequency (f_T) and maximum frequency of oscillations (f_{max}) of 51 and 61 GHz, respectively, whereas the $f_T BV_{CEO}$ product equals 173 GHz·V, which is among the highest-performance Si BJTs. High-performance RF circuits are already demonstrated using HCBT technology, such as down-converting mixers and divide-by-2 static frequency dividers [5]. In this paper, discrete HCBTs packaged in industry-standard, 4-pin SOT343 package are employed in PA design.

B. Power splitting

The signal is equally split (3-dB) at the input whereas the amplified signals are combined at the output of the balanced amplifier. For that purpose, a branchline hybrid coupler is designed in microstrip technology at the center frequency of 2.4 GHz. In its basic form, a branchline coupler consists of four transmission lines and has high

return loss at the design frequency, but it is very narrowband [2]. Therefore, a balanced amplifier utilizing such a coupler would also be narrowband. To increase the bandwidth of the amplifier, a double-box branchline coupler is designed [6] (Fig. 1a). The coupler has four ports, with port 1 being the input port, port 2 through port, port 3 coupled port, and port 4 isolated port. The design equations for the coupler are given by:

$$Z_2 = (1+\sqrt{2})Z_1, \quad (1)$$

$$Z_3 = \sqrt{2}\cdot Z_1. \quad (2)$$

Therefore, characteristic impedance Z_1 is a design parameter which defines characteristic impedances Z_2 and Z_3. According to (1) and (2), selecting the default value of 50 Ω for Z_1, sets Z_2 to 120.7 Ω and Z_3 to 70.7 Ω. Microstrip lines with such a high characteristic impedance are very narrow, considering the substrate used for the design. Both coupler and amplifier are fabricated on a low-cost 1-mm-thick FR-4 laminate, which has the dielectric constant and dielectric loss of ε_r = 4.3 and tanδ = 0.02, respectively. Implemented on this laminate, the 120.7 Ω microstrip line would have a small width of around 9 mil, which can result in variation of impedances of the two fabricated Z_2 lines of the coupler. To increase the width of the high impedance Z_2 lines, a lower value of Z_1 is needed.

The functionality of the coupler is verified by simulations employing ideal transmission lines and microstrip line models, which use the parameters of the substrate. The performance of the coupler is then optimized using electromagnetic (EM) finite element method (FEM) simulator in Advanced Design System (ADS). The final layout of the coupler is shown in Fig. 1b. Optimization resulted in Z_1 = 38 Ω, the value which further increases the bandwidth of the double-box branchline coupler and relaxes the width constraint of the high impedance lines at the same time. At each port, a 50-Ω line (w_1 = 76 mil, l_1 = 200 mil) is added to enable the interface with coaxial connectors. The coupler is optimized by tweaking the widths of Z_2 and Z_3 lines to achieve the highest return loss while maintaining equal 3-dB power split between through and coupled ports. The best performance is achieved for w_3 = 13.9 mil and w_4 = 93.3 mil. The coupler is fabricated on a separate PCB in order to measure the performance and compare the results with EM simulation.

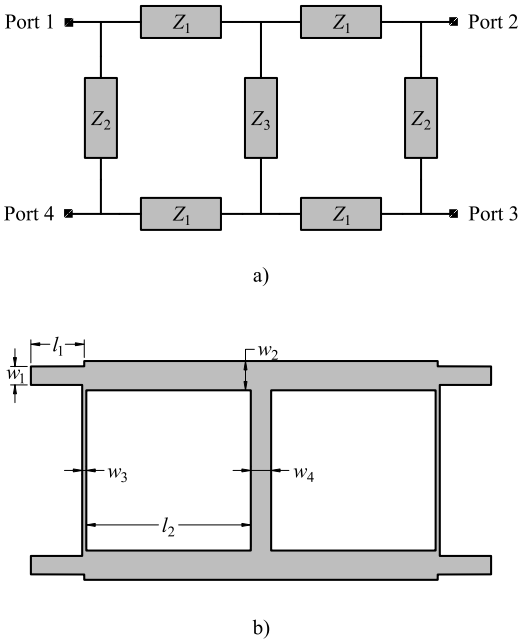

Figure 1. Double-box branchline hybrid coupler a) schematic with ideal transmission lines and b) layout (w_1 = 76 mil, w_2 = 117.4 mil, w_3= 13.9 mil, w_4 = 93.3 mil, l_1 = 200 mil, and l_2 = 678.6 mil).

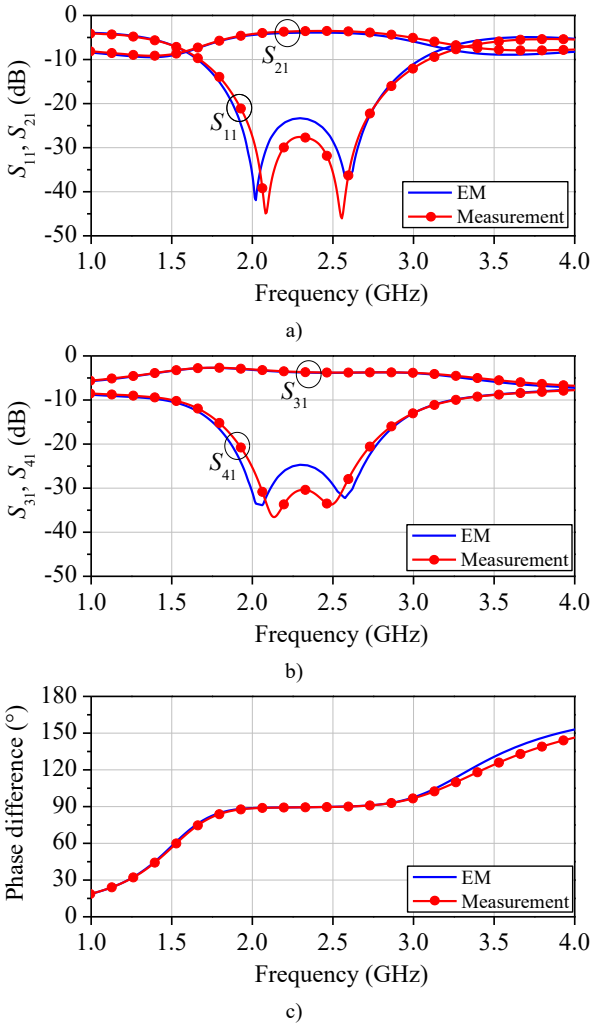

Figure 2. Measurements and EM simulation results of hybrid coupler. a) S_{11} and S_{21}, b) S_{31} and S_{41}, and c) phase difference ($\angle S_{21}$ - $\angle S_{31}$).

Measurements are compared with EM simulation in Fig. 2. The *S*-parameters of the coupler are measured by using a two-port vector network analyzer (VNA), thus, the two ports not being measured are terminated by 50 Ω. At 2.4 GHz, measured S_{11}, S_{21}, S_{31}, and S_{41} are -28.2 dB, - 3.52 dB, -3.73 dB, and -31.7 dB, respectively, whereas the phase difference between through port 2 and coupled port 3 is 89.55°. Input return loss, RL = -20log($|S_{11}|$) dB, is higher than 20 dB in the 800 MHz bandwidth from 1.9 to 2.7 GHz. Amplitude imbalance of port 2 and 3 is +/-0.6 dB and +/-0.45 dB, respectively, whereas phase imbalance is +/-3.4°. Overall, the coupler exhibits very high input return loss around 2.4 GHz and small amplitude and phase imbalance over the 800 MHz bandwidth.

C. Optimal matching impedances

In order to extract maximum output power with maximum available gain out of the HCBT devices, the transistors in both amplifiers of the balanced configuration are matched for maximum output power and maximum gain at the output and input, respectively. To that end, large-signal input and output impedances are found using calibrated load-pull setup employing automated mechanical impedance tuners.

As a first step in the load-pull process, the bias is defined for both amplifiers based on DC measurements and maximum voltage and current ratings of the HCBT. The DC measurements and measured load-pull data for the HCBT used in the current design are previously reported in [7]. The data also compares the performance of the HCBT in three different classes of PA operation, namely, Class A, Class AB, and Class B. The best performance is achieved in Class AB with I_C = 20 mA and V_{CE} = 2.87 V, wherein output power at the 1-dB compression point, collector efficiency, and gain of 18.6 dBm, 46%, and 10 dB are measured, respectively [7]. Thus, both PAs in the balanced configuration are biased the DC collector-emitter voltage of 2.87 V. Since the device is successfully operated at a higher collector current of 50 mA, the HCBTs in the balanced PA are biased at I_C = 50 mA to achieve maximum output power available from the device. Once the bias is defined, load-pull and source-pull are performed to find out optimal input and output impedances at 2.4 GHz:

$$Z_S = 39.9 + j7.7\ \Omega, \qquad Z_L = 32.4 - j8.2\ \Omega. \tag{3}$$

The reflection coefficients associated with the impedances from (3) are 0.14 and 0.24 for Z_S and Z_L, respectively. Therefore, the impedances are close to the system impedance of 50 Ω and a wideband match is possible using basic two-element matching networks.

D. Input and output matching network

Input matching network (IMN) and output matching network (OMN) are designed in microstrip technology utilizing open-circuited shunt stubs and series stubs. Both IMN and OMN are optimized first using ideal transmission lines and the performance is then fine-tuned in the EM simulator. The networks are the same for both PAs in the balanced configuration.

The layout of the IMN is shown in Fig. 3a. The network comprises 100-Ω open-circuited shunt stub (w_3, l_3) followed by a 60-Ω series stub (w_2, l_2). The signal is fed from port 2 or 3 of the input hybrid coupler to port 1 of the IMN over a small trace of 50 Ω line (w_1, l_1) which is used to solder the input decoupling capacitor. The EM simulation results are shown in Fig. 3b for port 2 impedance defined as a complex-conjugate of Z_S. Since the optimum input impedance of the used HCBT is very close to 50 Ω, a wideband match is achieved with return loss higher than 20 dB in the frequency range from 1.6 GHz to 3 GHz. The insertion loss is 0.1 dB at 2.4 GHz and increases to 0.2 dB at 3 GHz. The layout of the OMN is shown in Fig. 4a. The network comprises 44-Ω series stub (w_8, l_6) followed by the 60-Ω open-circuited shunt stub (w_{10}, l_8). The EM simulation results are shown in Fig. 4b for port 1 impedance

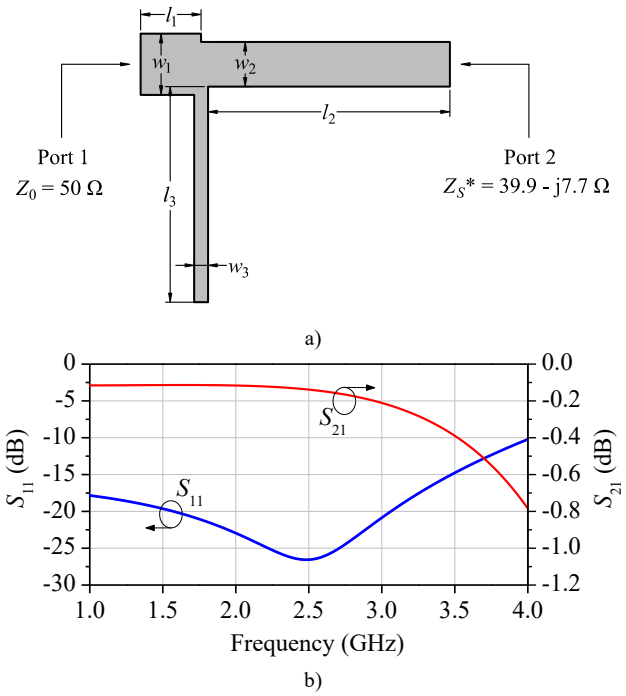

Figure 3. Input matching network a) layout (w_1 = 76 mil, l_1 = 75 mil, w_2 = 55.4 mil, l_2 = 299 mil, w_3 = 17.16 mil, and l_3 = 267 mil) and b) EM simulation results.

defined as a complex-conjugate of Z_L. Return loss is higher than 20 dB in the frequency range from 1.65 GHz to 3 GHz. In the frequency range from 1.6 GHz to 3 GHz insertion loss is lower than 0.2 dB.

E. Bias network

The bias network should present high impedance to the input and output of the transistor over the bandwidth of the PA while incurring minimal loss at DC. Both base and

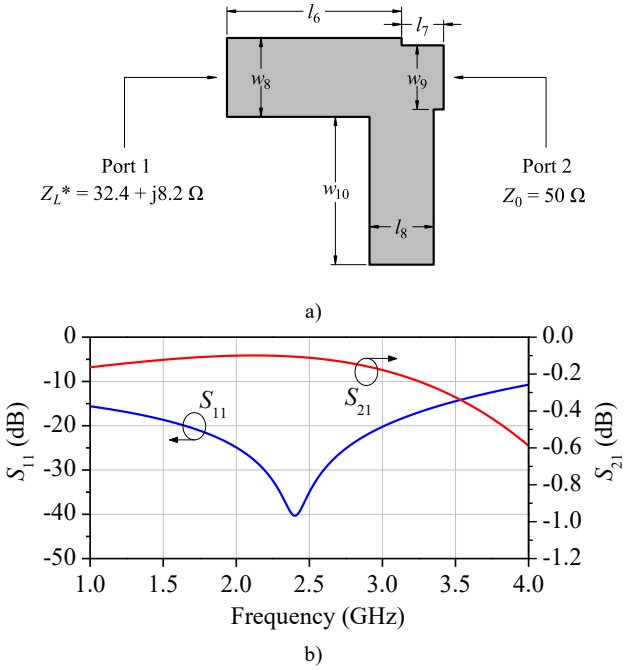

Figure 4. Output matching network a) layout (l_6 = 208 mil, l_7 = 50 mil, w_8 = 94 mil, l_8 = 76.3 mil, w_9 = 76 mil, and w_{10} = 176 mil) and b) EM simulation results.

collector bias are implemented with a short-circuited quarter-wavelength ($\lambda/4$) transmission line. Ideal $\lambda/4$ transmission line provides infinite impedance at the fundamental frequency and short circuit at even harmonics [2]. Therefore, the bias microstrip line is designed at the center frequency of 2.4 GHz. Firstly, the characteristic impedance of the line is selected to be as high as possible, since the bandwidth of the $\lambda/4$ microstrip line is larger for high-impedance lines [1]. The impedance chosen is 110 Ω, setting the width of the line at 13 mils. The length of such $\lambda/4$ microstrip line turns out to be 720 mil for the used substrate. To achieve more compact layout, the line is meandered, and the final layout is optimized using EM simulations (Fig. 5a). The line is 850 mil long, but the length of the layout (w_{12}) is reduced to 230 mil. The results of the EM simulation are shown in Fig. 5b wherein the bias line is simulated in shunt configuration (Fig. 5b, inset). The capacitor C = 10 pF is utilized near the self-resonant frequency to provide low impedance at 2.4 GHz. From 1.6 GHz to 3 GHz, S_{21} is higher than -0.17 dB and equals -0.05 dB at 2.4 GHz. The minimum at 470 MHz is caused by the resonance of the equivalent inductance of the bias line, equaling 11 nH, and the 10-pF capacitor.

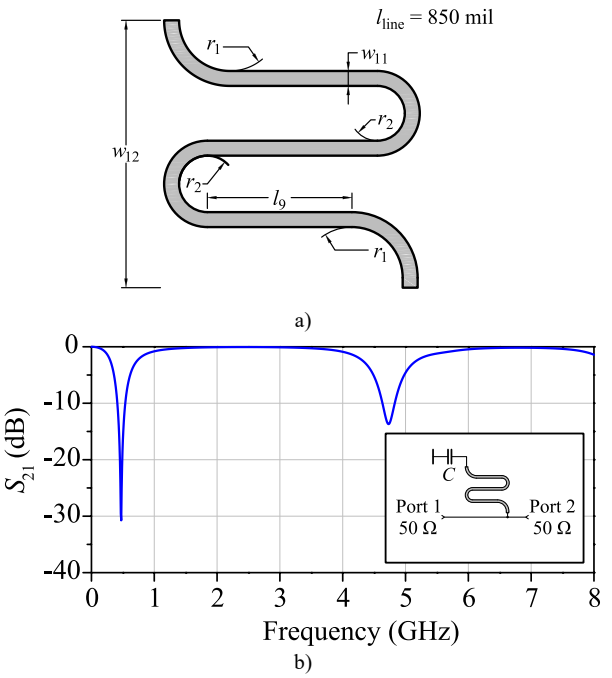

Figure 5. Bias network a) layout (w_{11} = 13 mil, l_9 = 146 mil, w_{12} = 230 mil, r_1 = 68 mil, and r_2 = 49 mil) and b) EM simulation results. Inset in b) shows simulation setup.

F. Balanced PA

The schematic and printed circuit board (PCB) of the balanced PA in HCBT technology are shown in Fig. 6. The PA uses two previously designed double-box branchline hybrid couplers for power splitting and combining. Input signal is applied at port 4 of the input coupler and the output signal is taken at port 2 of the output coupler. Unused ports

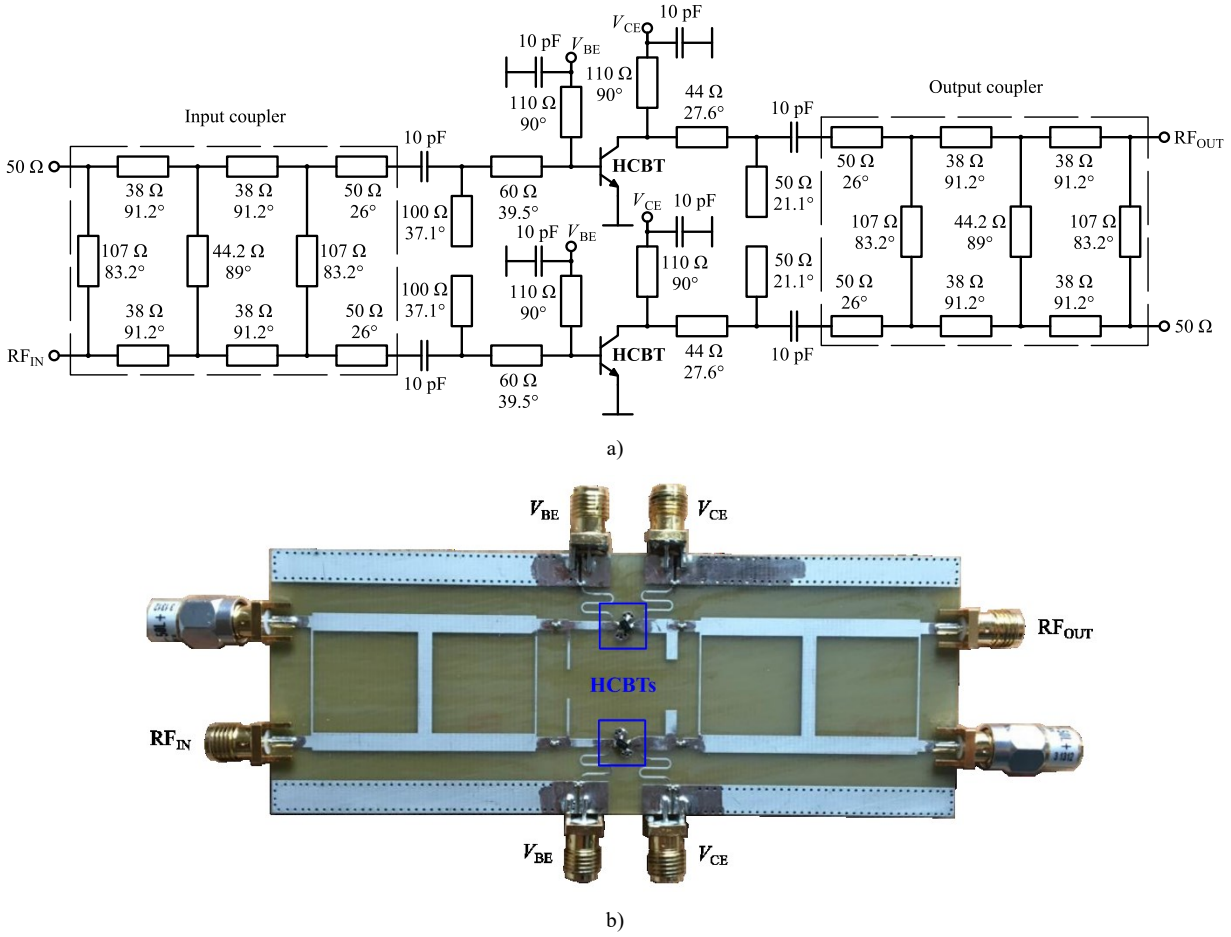

Figure 6. Balanced PA a) schematic and b) PCB. The coaxial SMA connectors are soldered at all four RF ports and four bias ports. Unused RF ports are terminated by 50 Ω.

(port 1 of the input coupler and port 3 of the output coupler) are terminated by coaxial 50 Ω (Fig. 6b). Both emitter pins of the HCBT devices are grounded with multiple plated through-hole vias to lower the inductance of the emitter. The capacitor used to provide RF short for the proper operation of $\lambda/4$ short-circuited stub does not provide bypass for low frequency components, which can cause instabilities since the transistors have high gain at low frequencies. To ensure that low frequency components do not cause instabilities, both base and collector bias is applied through wideband coaxial bias tees (200 kHz – 12 GHz) with 50 Ω at the RF port. In this way, the bias tee provides a 50 Ω termination for low-frequency components thus enhancing the stability of the PA. The operation in the passband, i.e. around 2.4 GHz, is not disturbed by adding the bias tees since the $\lambda/4$ line presents an open circuit to those frequencies, as shown in Fig. 5b.

III. MEASUREMENT RESULTS

A. Small-signal measurements

Measured S-parameters of the balanced PA are shown in Fig. 7. At 2.4 GHz, the PA exhibits small-signal gain S_{21} of 10.5 dB with high input and output return loss of 30.6 dB and 37 dB, respectively. Reverse isolation is higher than 18.7 dB up to 8 GHz. The bandwidth of the PA is mainly limited by the bandwidth of the couplers, thus, the PA exhibits 800 MHz bandwidth since the input and output return losses are higher than 20 dB in the frequency range from 1.9 GHz to 2.7 GHz. In the band, the small-signal gain is higher than 9 dB. Also shown in the figure is the stability factor K which is larger than 1 from DC to 8 GHz.

B. Large-signal measurements

The large-signal performance of the PA at 2.4 GHz is shown in Fig. 8. At 1-dB compression point (P1dB), the output power and transducer gain are 21.5 dBm and 10.6 dB, respectively, which is an increase in output power of 2.8 dB compared to load-pull measurements of the single HCBT [7] (Fig. 8a). Collector efficiency is 44% at P1dB and reaches maximum of 52% at the output power of 23.1 dBm, which is an increase of 7.4% compared to single HCBT. Since the output power of the balanced PA is twice the output power of single HCBT, balanced PA has efficiency peak at around 3 dB higher output power.

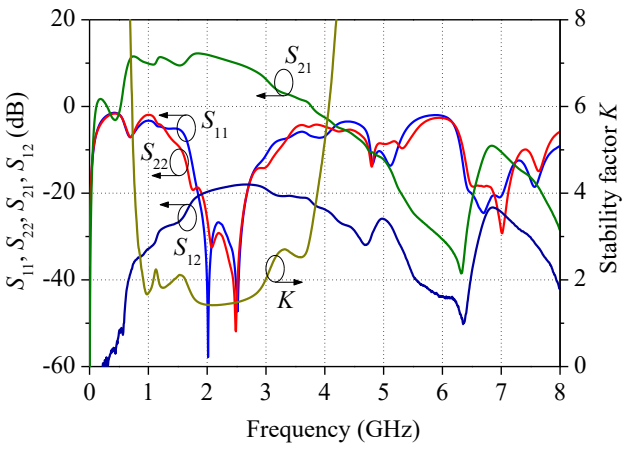

Figure 7. Measured S-parameters of the balanced PA in the frequency range from 0 to 8 GHz.

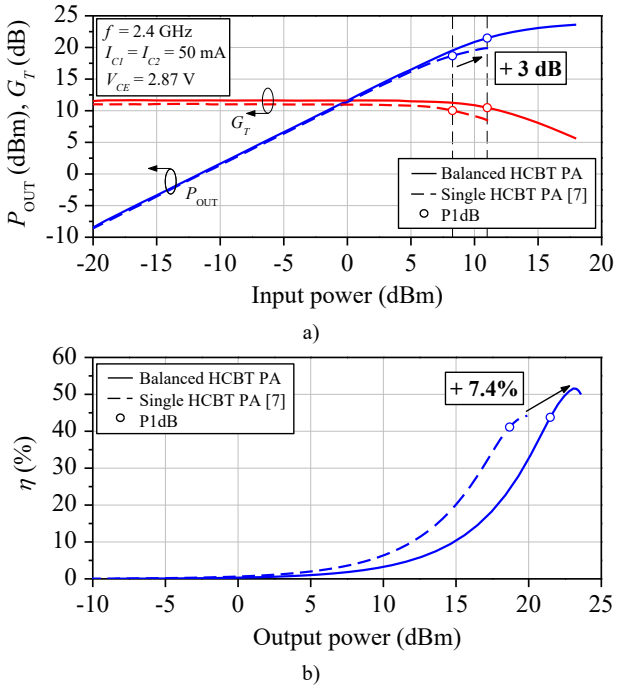

Figure 8. Measured a) output power P_{OUT}, transducer gain G_T and b) collector efficiency η for $I_{C1} = I_{C2}$ = 50 mA and V_{CE} = 2.87 V at 2.4 GHz. Measurements are compred to HCBT load-pull results from [7].

Frequency dependence of large-signal parameters is shown in Fig. 9. In the frequency range from 1.8 GHz to 2.5 GHz, output power and gain are 21.4+/-0.18 dBm and 10.4+/-0.15 dB, respectively, with minimum collector efficiency of 36% at 2.1 GHz going up to 45% at 2.3 GHz. Since the PA is designed at 2.4 GHz, the best performance is achieved around 2.4 GHz whereas the characteristics deteriorate outside the passband due to bandwidth limitation of input and output couplers.

In case one of the PAs in a balanced configuration fails, the balanced PA continues to operate with limited performance. More precisely, the gain of the balanced PA becomes 6 dB lower in case one PA fails [1]. In order to verify this behavior, the performance of HCBT balanced PA with one stage is measured. The failed condition is achieved by turning off one amplifier and biasing the other so that only one is on at the time. The small-signal and

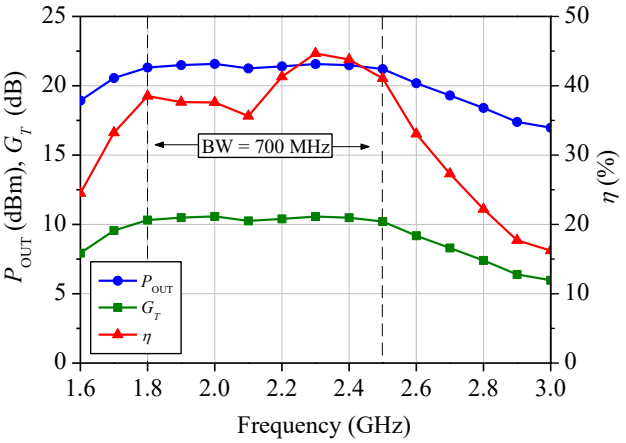

Figure 9. Measured a) output power P_{OUT}, transducer gain G_T and b) collector efficiency η for I_C = 50 mA and V_{CE} = 2.87 V from 1.6 to 3 GHz.

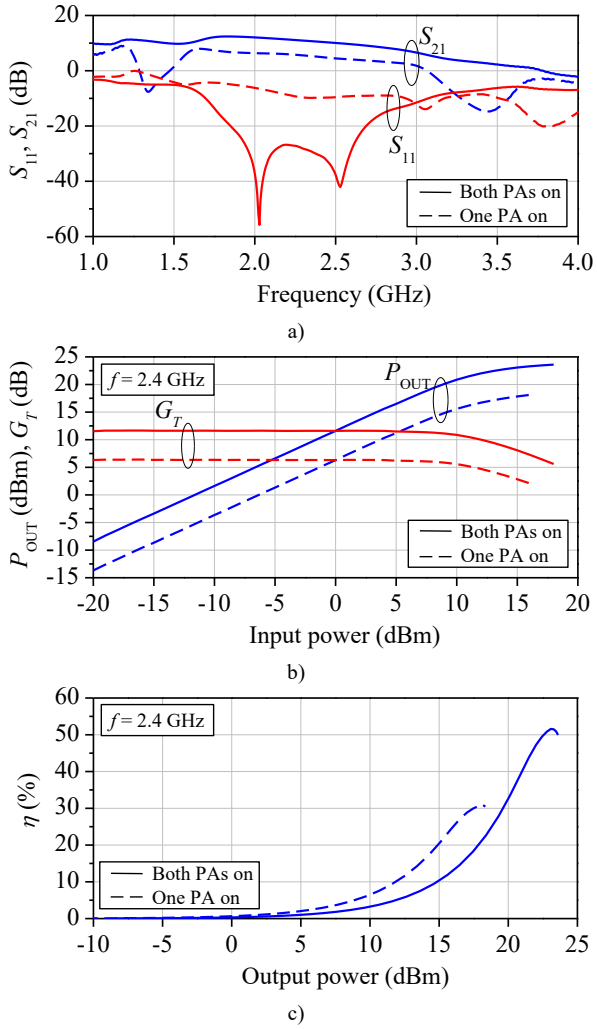

Figure 10. Measured performance of the balanced PA with one stage turned off. a) S_{11} and S_{21}, b) output power P_{OUT} and transducer gain G_T, and c) collector efficiency η for $I_{C1} = I_{C2} = 50$ mA and $V_{CE} = 2.87$ V.

large-signal performance is shown in Fig. 10. As expected, S_{21} decreased for around 5.5 dB in the frequency range from 1.8 GHz to 2.5 GHz (Fig. 10a). Input return loss decreased to around 10 dB since the turned-off PA presents high impedance to the input coupler. Output power and gain are also decreased by 5.5 dB over the entire input power range (Fig. 10b). Collector efficiency curve resembles the characteristics of single-transistor PA shown in Fig. 8b, but since the half of the input power is now reflected to the couplers and dissipated in 50-Ω load, the efficiency is much lower. Nevertheless, with one stage turned off, HCBT balanced PA maintains functionality with 6 dB lower gain and output power, but with higher efficiency at lower output powers.

The performance of the balanced PA is compared to two other PAs implemented in advanced transistor technologies (Tab. 1). Even though HCBT PA operates at lower output power, it achieves minimum collector efficiency of 35.6% with input and output return loss higher than 20 dB for the similar bandwidth.

TABLE 1. PERFORMANCE COMPARISON BETWEEN THIS WORK AND POWER AMPLIFIERS IMPLEMENTED IN OTHER TECHNOLOGIES

Ref.	**[8]**	**[9]**	**This work**
Bandwidth (GHz)	1.8 – 2.8	1.8 – 2.4	1.8 – 2.5
P1dB (dBm)	28	27.2	21.4
Collector/Drain Efficiency, Power Added Efficiency (%)	7.5 (PAE)	28 (DE)	> 35.6 (CE)
Input *RL*, Output *RL* (dB)	10	< 15	> 20
Technology	GaAs HBT	CMOS SOS	HCBT

IV. Conclusion

The balanced PA is designed at the frequency of 2.4 GHz using high-performance, pure-silicon Horizontal Current Bipolar Transistor (HCBT) technology. The design is based on measured load-pull data of the HCBTs employed in the PA. Matching and bias networks are designed in microstrip technology on a FR4 substrate. The HCBT balanced PA provides 21.4+/-0.18 dBm of output power and 10.4+/-0.15 dB over the bandwidth of 700 MHz, from 1.8 GHz to 2.5 GHz. The bandwidth of the PA is determined by wideband input and output branchline couplers which ensure return losses higher than 20 dB in the passband.

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Constant-resistance filters with diplexer architecture for S-band applications

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***Abstract*—Constant-resistance filters are a class of absorptive filters that ideally present no reflection to the incoming signal of any frequency while their transfer function can be designed to exhibit low-pass, high-pass or band-pass characteristics. There is a variety of architectures employed to accomplish this function and such filters are used for terminating the output stages of amplifiers and mixers. In this work, we discuss the design of low-pass reflectionless filters employing a diplexer architecture with the intent to separating the useful signal (low-pass) from the higher harmonics which will be terminated externally to the filter.**

***Index Terms*—Reflectionless filters, constant-resistance filters, switch-mode radiofrequency amplifiers, S-band**

I. Introduction

Most transmission or reflection filters used in the industry are designed as lossless tow-port networks that exhibit minimal amount of loss in passband, while in the stopband they are highly reflective. Constant resistance filters, on the other hand are absorbing filters, which exhibit real and constant input impedance for all frequencies when all filter ports are terminated with a matched load and hence can realize ideally zero input-port reflection for all frequencies. Such filters have been investigated for nearly a century [1], [2], [3], with a number of methods developed for the design of asymmetric configuration, in which the input port exhibits constant resistance when the output port is matched [4], [5], [6], [7], [8], [9] and symmetric configurations, in which both ports exhibit zero reflection when port terminations are matched [10], [11]. Constant-resistance filters are used to control the frequency response of transmission lines and amplifiers in communications systems [12], [5] and phase distortion and speaker impedance responses in audio systems.

This work discusses the design and assembly of asymmetric constant-resistance low-pass filters wherein both the low-pass (LP) and the high-pass (HP) sections are Butterworth-filter type. The motivation for this work is to build filters for harmonic clean-up of the output of switch-mode radiofrequency amplifiers. To this end we use a constant resistance filter with a diplexer architecture in which the useful low-pass signal is taken out of one port and the higher harmonics generated by the switching output stage are passed through the high-pass port. The filter of interest has the structure of a lossless two-way diplexer in which the output ports are terminated with a matched load. Figure 1 illustrates a radiofrequency switching modulator output stage having one transistor operating as a switch and one inductor connected between the drain of the transistor and the constant power supply v_{DD}. The voltage at the transistor drain $v(t)$ is filtered through an absorbing low pass (ALP) filter to let only the fundamental harmonic reach the load Z_0. The RF signal at the input of the output stage is assumed to be perfectly square so that it controls the transistor from open to closed state. The goal is to use the filter to independently measure the fundamental output power and compare it to the power in higher harmonics.

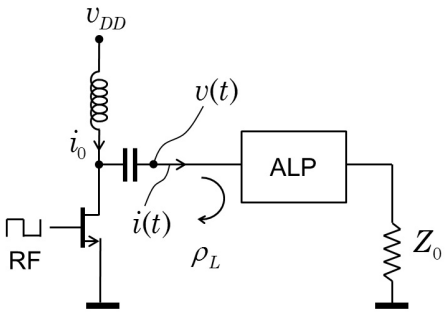

Fig. 1. A single-stage switch-mode modulator output terminated with an absorbing low-pass filter (ALP) that exhibits negligible reflection $\rho_L \approx 0$.

Constant resistance filters with diplexer architecture can be realized with two distinct architectures: in an *admittance complementary* diplexer filter, the LP and HP filter networks are connected in parallel at the input port of the filter, as shown in Figure 2(*a*) [3], [13], [14] while an *impedance complementary* diplexer filter the two filters are connected in series, as shown in Figure 2(*b*). We choose to investigate the admittance complementary configuration because coupling to the high-pass section where it remains single ended is significantly simpler.

The transfer function through the low-pass section (port 1 to port 2) when terminated with Z_0 has a low-pass characteristic and the transfer function through the high-pass section (port 1 to port 3) has a high-pass filter characteristic. In a diplexer architecture, the two filters may be ladder filters and can be connected in parallel at the port 1, or in series at port 1.

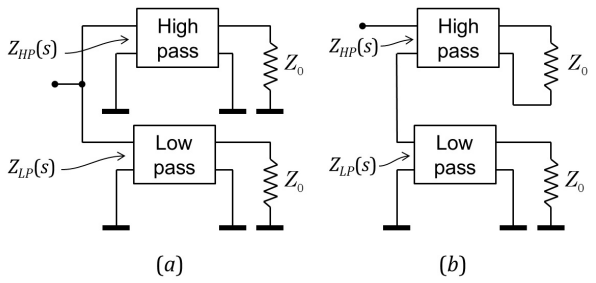

Fig. 2. Two possible architectures of a complementary two-way diplexer filter: (*a*) admittance complementary and (*b*) impedance complementary filters.

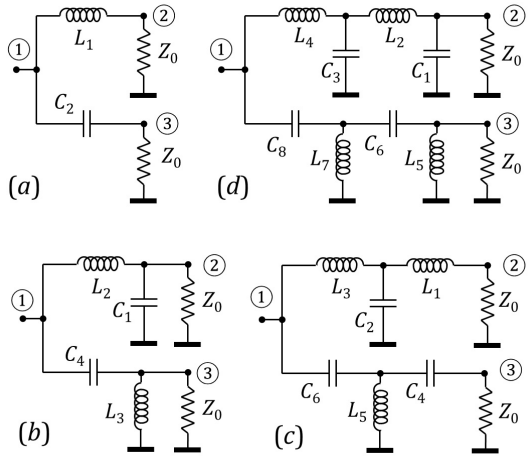

Fig. 3. Circuit diagrams for first four orders of complementary ladder filters examined in this work: the circuit diagrams (*a*) through (*d*) correspond to the first to fourth order filters. The port designations are shown in circled numbers.

II. Complementary filter design

The admittance complementary filter comprises two ladder-filter sections connected in parallel at the input of the filter as shown in Figure 2(*a*). In order to ensure that the input reflection coefficient of this filter equals zero, the input impedances of the low-pass and the high-pass section, $Z_{LP}(s)$ and $Z_{HP}(s)$, seen from port must satisfy the following relationship:

$$\frac{1}{Z_{LP}(s)} + \frac{1}{Z_{HP}(s)} = \frac{1}{Z_0} \tag{1}$$

where Z_0 is the characteristics impedance of the transmission lines in the system and Im(Z_0) = 0.

We investigate the design rules for complementary filters wherein both the low-pass and the high-pass sections are ladder filters (Cauer type filters) [15] of the first, second, third and fourth order. The order of the complementary filter refers to the order of the low-pass or the high-pass filter sections. The circuit diagrams for all four filter orders are shown in Figure 3 with components designations. Each filter is characterized with a crossover frequency ω_0 as the frequency at which the power transfer function of the low-pass section $|s_{21}(\omega_0)|^2$ and the high-pass section $|s_{31}(\omega_0)|^2$ each equal to $1/2$.

A. First order

The first order complementary filter, shown in Figure 3(*a*), will exhibit input impedance equal to Z_0 if $C_2 Z_0^2 = L_1$. The L_1 and C_2 are related through the crossover frequency ω_0. It is straightforward to show that the component values that satisfy equation (1) are:

$$L_1 = \frac{Z_0}{\omega_0} \qquad C_2 = \frac{1}{\omega_0 Z_0} \tag{2}$$

The transfer functions at the output on ports 2 and 3 are respectively:

$$s_{21}(s) = \frac{1}{s/\omega_0 + 1} \qquad s_{31}(s) = \frac{s/\omega_0}{1 + s/\omega_0} \tag{3}$$

B. Second order

The second order complementary filter, shown in figure 3(*b*), will exhibit input impedance equal to Z_0 if $C_1 = C_4 = C$, $L_1 = L_3 = C$, and $2L = CZ_0^2$. The C and L values are again related through the crossover frequency ω_0. We can show that the component values that satisfy equation (1) are:

$$L_3 = L_2 = \sqrt{2}\left(\frac{Z_0}{\omega_0}\right) \quad C_2 = C_4 = \frac{1}{\sqrt{2}} \cdot \frac{1}{\omega_0 Z_0} \tag{4}$$

The transfer functions are then given by,

$$s_{21}(s) = \frac{1}{\left(\frac{s}{\omega_0}\right)^2 + \sqrt{2}\left(\frac{s}{\omega_0}\right) + 1} \tag{5}$$

$$s_{31}(s) = \frac{\left(\frac{s}{\omega_0}\right)^2}{\left(\frac{s}{\omega_0}\right)^2 + \sqrt{2}\left(\frac{s}{\omega_0}\right) + 1} \tag{6}$$

C. Third order

The third order complementary filter, shown in figure 3(*c*), will have input impedance equal to Z_0 for inductance and capacitance values:

$$L_1 = \frac{1}{2}\left(\frac{Z_0}{\omega_0}\right) \qquad C_2 = \frac{4}{3} \cdot \frac{1}{Z_0 \omega_0} \tag{7}$$

$$L_3 = \frac{3}{2}\left(\frac{Z_0}{\omega_0}\right) \qquad C_4 = 2 \cdot \frac{1}{Z_0 \omega_0} \tag{8}$$

$$L_5 = \frac{3}{4}\left(\frac{Z_0}{\omega_0}\right) \qquad C_6 = \frac{2}{3} \cdot \frac{1}{Z_0 \omega_0} \tag{9}$$

The transfer functions are given by,

$$s_{21}(s) = \frac{1}{\left(\frac{s}{\omega_0}\right)^3 + 2\left(\frac{s}{\omega_0}\right)^2 + 2\left(\frac{s}{\omega_0}\right) + 1} \tag{10}$$

$$s_{31}(s) = \frac{\left(\frac{s}{\omega_0}\right)^3}{\left(\frac{s}{\omega_0}\right)^3 + 2\left(\frac{s}{\omega_0}\right)^2 + 2\left(\frac{s}{\omega_0}\right) + 1} \tag{11}$$

D. Fourth order

The fourth order complementary filter, shown in figure 3(d) will be resistive with Z_0 input resistance for the following values of the inductors and capacitors:

$$\alpha = 2\sqrt{\frac{2+\sqrt{2}}{2}} \qquad \beta = 2+\sqrt{2} \quad (12)$$

$$L_2 = \frac{\alpha}{\beta-1}\left(\frac{Z_0}{\omega_0}\right) \qquad C_1 = \frac{1}{\alpha}\cdot\frac{1}{Z_0\omega_0} \quad (13)$$

$$L_4 = \frac{\alpha(\beta-2)}{\beta-1}\left(\frac{Z_0}{\omega_0}\right) \qquad C_3 = \frac{1}{\alpha}\frac{(\beta-1)^2}{\beta-2}\cdot\frac{1}{Z_0\omega_0} \quad (14)$$

$$L_5 = \alpha\left(\frac{Z_0}{\omega_0}\right) \qquad C_6 = \frac{\beta-1}{\alpha}\cdot\frac{1}{Z_0\omega_0} \quad (15)$$

$$L_7 = \alpha\frac{\beta-2}{(\beta-1)^2}\left(\frac{Z_0}{\omega_0}\right) \qquad C_8 = \frac{\beta-1}{\alpha(\beta-2)}\cdot\frac{1}{Z_0\omega_0} \quad (16)$$

The transfer functions:

$$s_{21}(s) = \frac{1}{\left(\frac{s}{\omega_0}\right)^4 + \alpha\left(\frac{s}{\omega_0}\right)^3 + \beta\left(\frac{s}{\omega_0}\right)^2 + \alpha\left(\frac{s}{\omega_0}\right) + 1} \quad (17)$$

$$s_{31}(s) = \frac{\left(\frac{s}{\omega_0}\right)^4}{\left(\frac{s}{\omega_0}\right)^4 + \alpha\left(\frac{s}{\omega_0}\right)^3 + \beta\left(\frac{s}{\omega_0}\right)^2 + \alpha\left(\frac{s}{\omega_0}\right) + 1} \quad (18)$$

As the reader may notice, the transfer functions are actually all Butterworth types. In fact, if we require that the low-pass and the high-pass filters be ladder-filters with a single component in each ladder position, then the only solution for admittance-complementary filter is that both the low-pass and the high-pass sections be Butterworth filters.

In some applications, one may require a different low-pass filter characteristic. In this case, finding the complementary high-pass filter may become a network synthesis challenge. It is important to note that not every lossless low-pass ladder filter has a complementary lossless ladder-type high-pass filter. For complementary high-pass filters to be realizable, there are restrictions on low-pass section architecture. These restrictions manifest themselves by the appearance of negative circuit elements in the synthesis of the high-pass section, which imply non-Foster solutions.

Figure 4 illustrates the transfer functions of the low-pass $|s_{21}(\omega/\omega_0)|^2$ section and the high-pass $|s_{31}(\omega/\omega_0)|^2$ sections for first four Butterworth orders. Similarly, Figure 5 shows the corresponding Smith diagrams.

III. Filter Assembly and Measurements

All four filter designs were assembled with the purpose of investigating performance and implementation. A set of four filters were tuned to crossover frequency 2500 MHz and another four with crossover frequency 800 MHz to be used as a comparison. The printed circuit board design is

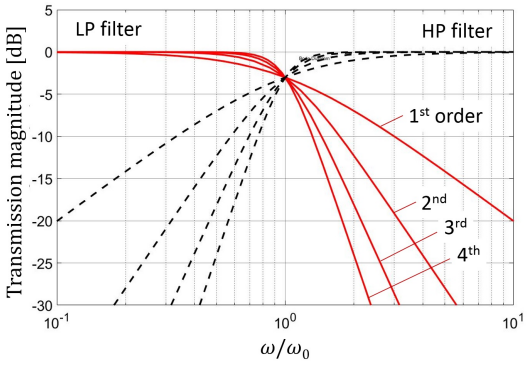

Fig. 4. Transfer functions for Butterworth filter sections

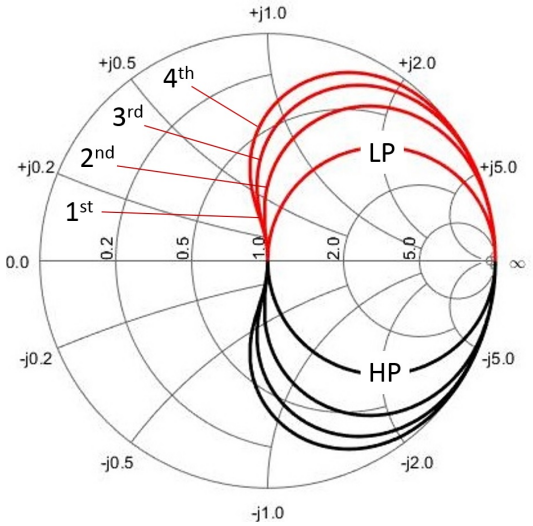

Fig. 5. Smith diagram of the diplexers input impedances

shown in Figure 6(a) and it features one input transmission line that branches in the middle of the board allowing one to implement any type of ladder filter by cutting the line for series elements and scratching of the solder mask to add parallel elements and allow for soldering the components. The printed circuit board substrate material was Rogers 4350B and the substrate thickness was 0.5 mm (20 mils). Surface-mountable 0603 thin-film capacitors and 0402 wirewound inductors were used, while ground-backed coplanar waveguide was used for transmission lines. The boards were connectorized using bolt-on end-launch SMA connectors. The actual values of capacitors and inductors used on the fourth-order complementary filter are shown in the following table:

Element	Value	Element	Value
C_1	0.5 pF	L_2	3.6 nH
C_3	2.0 pF	L_4	4.7 nH
C_6	1.2 pF	L_5	8.2 nH
C_8	0.8 pF	L_7	2.0 nH

The filters were characterized using s-parameter measurements performed on a 40-GHz vector network analyzer (VNA) and a 35-ps-rise time time-domain reflectom-

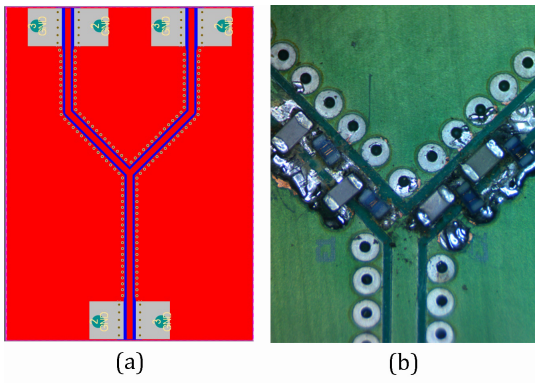

Fig. 6. (*a*) Printed circuit board design and (*b*) fourth-order 2.5 GHz filter assembled with 0402 inductors and 0603 capacitors.

etry (TDR). We were primarily interested in the magnitude of the reflection coefficient $|s_{11}|^2$, for which we used open-short-load single-port calibration on the VNA, and the transmission properties of both branches of the filter $|s_{21}|^2$ and $|s_{31}|^2$, for which we added two 10-dB attenuators at the VNA ports and calibrated by normalizing the transmission through the attenuated path. The attenuators are needed to eliminate the reflection from the VNA ports and they enable significantly simpler and quicker calibration procedure.

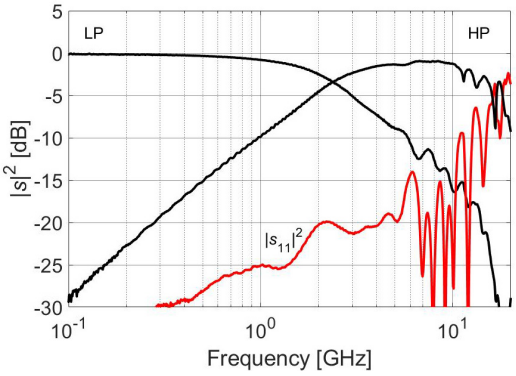

Fig. 7. First order complementary diplexer filter S-parameters

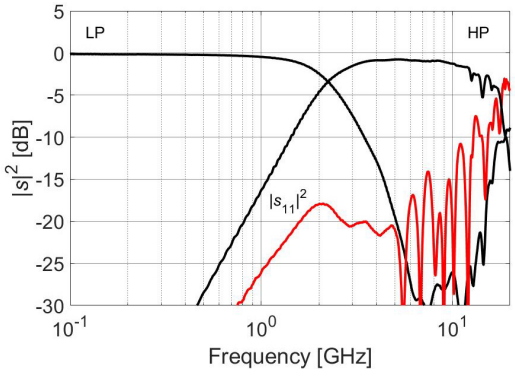

Fig. 8. Second order complementary diplexer filter S-parameters

The *s*-parameter measurements on the 2.5-GHz filter boards are shown in Figures 7, 8, 9 and 10. In these

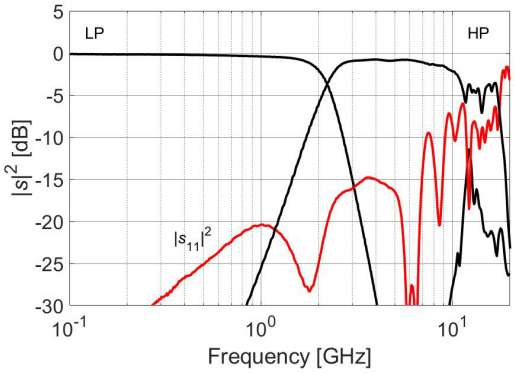

Fig. 9. Third order complementary diplexer filter S-parameters

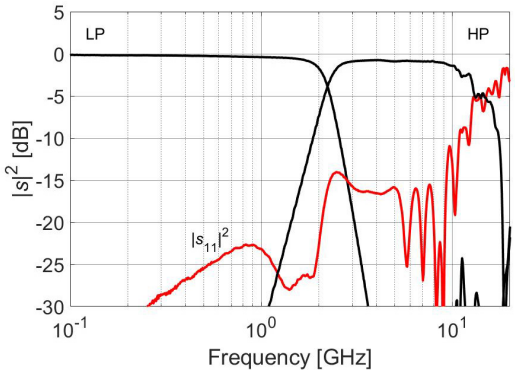

Fig. 10. Fourth order complementary diplexer filter S-parameters

figures, the low-pass filter transmission magnitude (labeled with "LP") shows no ripple in the passband and progressively steeper stopband blocking: from 20 dB/decade top 80 dB/decade as expected for a Butterworth filter of designed order. The ripple and increased transmission in the stopband is a result of second-order resonances in the components: the parallel resonances in the capacitors and series resonances in the inductors. Note that the first-order resonances in the components (series resonance in the capacitors and the parallel resonance in the inductors) benefit the attenuation in the stopband. For the fourth order filter, the spurious transmission is rather low and does not appear to be significant up to at least 20 GHz (see Figure 10). Inasmuch as the harmonic output from a switching output stage shown in Figure 1 reduces with the square of the harmonic number for a square wave, the output will be well filtered using this type of filter. A good high-pass filter is always a bit harder to build using lumped components as the second order resonances of those lumped components produce significant attenuation.

We built and characterized the 800-MHz filters as a reference against which we could compare the S-band filters and we found that the 2.5-GHz filters are not better than our 800-MHz filters and hence we do not show the results for latter.

IV. Discussion

The quality of the constant-resistance filter is measured by the ability of the combined filters to realize low reflection coefficient (labeled with $|s_{11}|^2$ in the figures). The reflection coefficient of the constant-resistance filter is significantly more sensitive to the components resonances than the transmission coefficients because the realization of the low reflection coefficient critically depends on the matching of the reflection phases of the two filters. The deviation from the designed characteristics of the low-pass and high-pass filters are a result of two independent phenomena: (*i*) the resonances in the individual components (first resonance included) and (*ii*) the electrical delay differences between the two branches built into the layout of the components on the printed circuit board. We used TDR to illustrate the importance of the latter

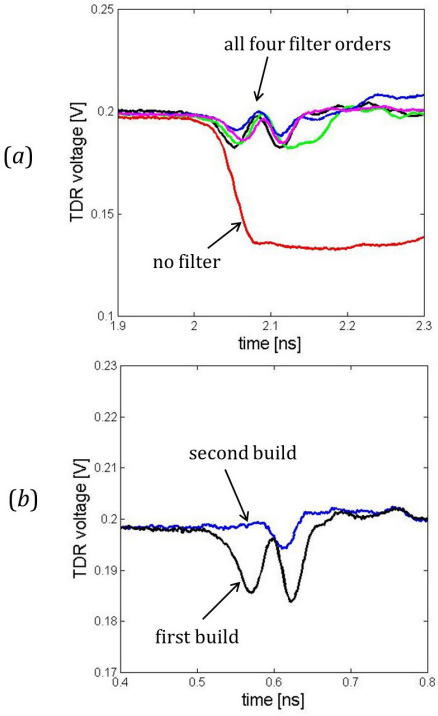

Fig. 11. Time-domain characterization: (a) step-responses from the board with no filters and the boards with filters of different order, and (b) magnified view of the step-response from two fourth order filters: the first build and the second build in which the first inductor and capacitors were placed immediately onto the branch point in the transmission line.

phenomenon. Figure 11(a) shows the step-response from the branch point on the printed circuit board measured by time-domain reflectometry. When there is no filter present the two 50-ohm transmission lines branching off present a 25-ohm load at the branch point which results in a reflection coefficient magnitude equal to 1/3. The step-response hence dips below the 0.2 V horizontal level by a third of the step voltage as expected (0.2-V step is standard for TDR equipment). The reflection response for all four filters, also shown in Figure 11(*a*), exhibits several short (≈30-ps) dips and peaks after the signal reaches the branching point. These reflections indicate that there is an impedance mismatch present immediately at the beginning of the filter.

To check whether the phase mismatch contributes to the increase in input reflection, we rebuilt the fourth order filter by moving the first inductor and capacitor of the two branches closer into the branching point. This resulted in an improvement in the response shown as the "second build" in Figure 11(*b*). The dip in this trace is smaller and there is only one dip rather than two deeper dips shown for the original "first build". This simple analysis illustrates that building complementary diplexer filters exhibits one more degree of complexity relative to the conventional lossless filters: the phase of the input reflection on each of the filters and their difference is crucial for achieving low input reflection.

Different delays in the two branches are the origin of excessive reflection from the complementary filter seen in the measured $|s_{11}(\omega/\omega_0)|^2$ graphs in Figures 7 through 10. This was confirmed by simulation: a series of small (≈ps) delays were embedded into the ladder network and the effect of the delay differences was explored to determine its effect on the $|s_{11}|^2$. An example of this simulation is shown in Figure 12 where the local increase in $|s_{11}|^2$ around 2 GHz is a result of the introduction of phase mismatch.

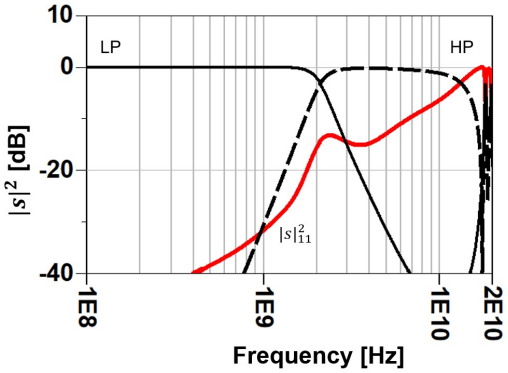

Fig. 12. Transmission and reflection responses of the fourth order filter in which delays between components were introduced to show that the magnitude of the reflection coefficient quickly grows with the presence of phase mismatch.

V. Conclusion

Building constant-resistant filter using lumped components for S-band applications presents tighter constraints on the layout and selection of components than lossless filters because for lossless filter matching the reflection coefficient in the stop band is not a part of the design requirement. Besides the VNA, a tool critical to analyze and debug such filters is the time-domain reflectometry as it presents a quick and intuitive understanding of the character of the input stage of the filter.

In this work, we discussed the design of constant-resistance filters that have ladder-type segments in the diplexer architecture and showed that with the ladder-type requirement, these filters always have the Butterworth configuration. We also assembled four different type

of filters at two different frequencies and showed that, although satisfactory transfer characteristics are readily obtainable, bringing the reflection coefficient below -20 dB is challenging.

The assembled filters, however, exhibit reflection that is sufficiently low to perform the planned experiments with switch-mode radiofrequency amplifiers.

VI. Acknowledgement

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Design and Characterization of Bias Tee Used for S-parameter Characterization of Power Inductors

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***Abstract*—This paper presents the design and characterization of the bias tee for *S*-parameter characterization of surface-mount power inductors used in switching power converters. The bias tee is used to vary DC current through the measured power inductor. The equivalent circuit models of the inductive and capacitive elements are imported into the circuit simulator. The insertion loss, reflection loss and isolation are obtained from the simulations in the frequency range from 300 kHz to 100 MHz. The bias tee is designed on a dual layer printed circuit board and characterized using the vector network analyzer. The impedance characteristics of a 4.7-µH power inductor are extracted from measurements up to 100 MHz using the designed bias tee.**

***Index Terms*—frequency-domain characterization, inductor power loss, insertion loss, switching power converters.**

I. INTRODUCTION

High-frequency switching DC-DC converters that operate at frequencies in a MHz range are being designed to increase power density and decrease dimensions of power supplies, and the efficiency of switching converters is more and more determined by the AC losses of the power inductor [1]. The precise frequency-domain characterization of power inductors, as described in [2] and [3], is important to predict the AC power losses in the inductor and to achieve the best performance of switching DC-DC converters under various switching frequencies and inductor current levels.

Ferrite-core power inductors are typically used in switching power converters to achieve high power density. Characteristics of ferrite-core inductors largely depend on the current value, especially when the ferrite core reaches the saturation area in which the inductance progressively decreases while the average inductor current increases [4]. Therefore, the S-parameter characterization of power inductors at different DC bias current levels has to be done to accurately extract the impedance characteristics of the inductor and to precisely estimate the inductor power losses.

The bias tee used for S-parameter characterization has to be designed to estimate the impedance characteristics of power inductors in a frequency range which includes the frequencies of the higher harmonics of the switching frequency of a DC-DC converter in which an inductor is used. Furthermore, the designed bias tee has to sustain DC bias currents of several amps to extract the impedance characteristics for the typical operating conditions of the power inductor.

A low-cost bias tee unit operating up to gigahertz range is proposed in [5], a bias tee design in microstrip line technology is presented in [6], an active bias tee design for low-frequency measurements is described in [7]. However, the presented investigations do not propose the bias tee design that could be used for bias currents large enough to extract the impedance characteristics of power inductors in typical operating conditions. Furthermore, commercially available bias tee elements either do not operate in the frequency range below tens of megahertz, or they allow DC bias currents up to 1 A, or they are too expensive.

A bias tee structure that is used for S-parameter characterization of power inductors up to 100 MHz is designed and presented in this paper. The designed bias tee can be used for setting the DC bias currents up to 7 A. The S-parameter characterization setup with the designed bias tee is based on a two-port shunt measurement method that has been proposed as an accurate characterization method for low-impedance components [3], [8].

The design and characterization of the proposed bias tee is described in Section II. The test case to evaluate the operation of the designed bias tee is shown in Section III, while Section IV concludes the paper.

II. DESIGN AND CHARACTERIZATION OF BIAS TEE

A. Electrical design

Basic bias tee design is a coupling capacitor and an inductor, where the capacitor represents DC block and the inductor represents the DC feed as shown in Fig. 1. This design can only be used if a narrow band of frequences is required.

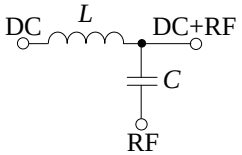


Fig. 1. Basic bias tee design.

The proposed design is shown in Fig. 2. The DC feed contains four sections each having one inductor with values of 1 µH, 10 µH, 18 µH and 47 µH. Every section also has a 1.5-kΩ resistor which value is optimized for

damping the impact of inductors self resonating frequencies and a bypass capacitor which is used to short RF signal that bypasses the inductor. The last piece in the DC feed is a capacitor C_5 which is implemented as a group of two 10-µF capacitors and one 1-µF capacitor to have a large capacitance and also a smaller equivalent series resistance, which greatly improves isolation throughout the bandwidth. Single 47-nF capacitor C_4 is used as the DC block with a voltage breakdown of 500 V. Fig. 3 shows the schematic of the inductor model with parasitic elements, while Table 1 contains parameters of the parasitic elements for each inductor used in simulations.

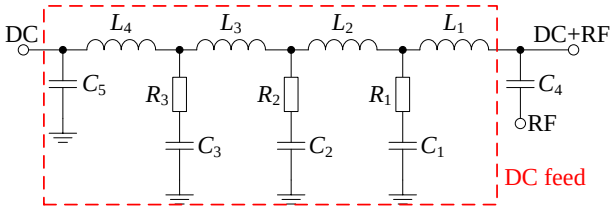


Fig. 2. Schematic of the designed bias tee.

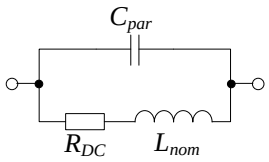


Fig. 3. Inductor model.

Table 1. Parameters of the inductor models.

	L_{nom}, µH	C_{par}, pF	R_{DC}, mΩ	I_{sat}, A	f_{res}, MHz
L_1	1	9.739	2.1	34.0	51
L_2	10	12.924	6.9	21.5	14
L_3	18	5.497	22.0	7.5	16
L_4	47	5.389	12.2	8.5	10

B. Bias tee characterization

The schematic of the setup used for characterization of the designed bias tee by simulations and measurements is shown in Fig. 4.

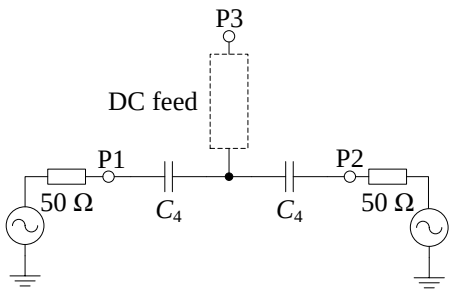
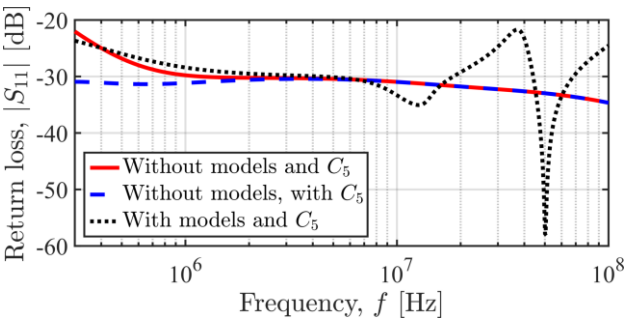
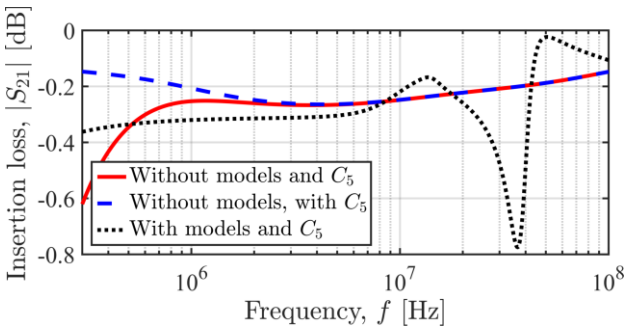


Fig. 4. Setup used for bias tee characterization.

Simulations of a bias tee in range from 300 kHz to 100 MHz are done in Keysight ADS and the results are shown in Fig 5. Three types of results are shown: Fig. 5(a) shows return loss, Fig. 5(b) shows insertion loss and Fig. 5(c) shows isolation measured at the port P1. The impact of the component models and capacitor C_5 can be observed. Inductors are modelled as shown in Fig. 3, capacitor models are imported as touchstone files obtained from the manufacturer websites, the resistors are used as ideal components and the transmission lines are modelled as coplanar waveguide segments. The impact of the resonating frequencies on the isolation and somewhat insertion loss and return loss can be seen in Fig. 5. Difference between isolation with and without C_5 capacitor is 65 dB. The results with models follow the results without models from the beginning to around 10 MHz when parasities of the components start to affect the bias tee. The structure is symmetrical so that implies that the simulation results are the same measured from the port P2.



(a)



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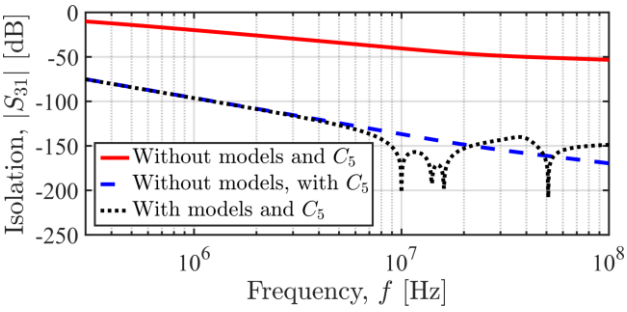
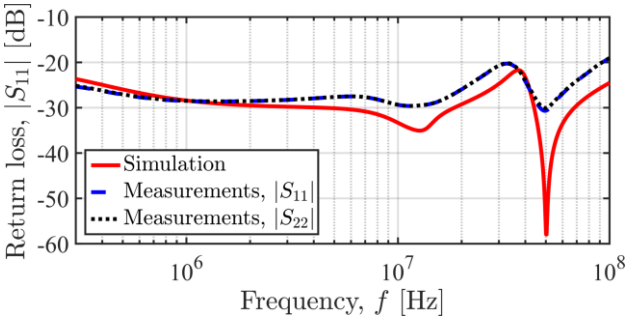


(c)

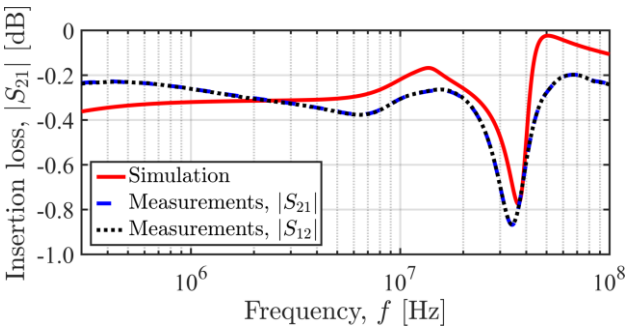
Fig. 5. Simulation results for bias tee: (a) return loss, (b) insertion loss, (c) isolation.

Measurements are conducted using a two-port vector network analyzer (VNA) which is connected to ports P1 and P2, while port P3 is terminated into 50 Ω. Settings used for measurement are: frequency range from 300 kHz to 100 MHz, output power of 0 dBm, resolution bandwidth of 1 kHz, 1201 points and an average factor of 10.

Measurement results for the bias tee characterization are shown in Fig. 6. Fig. 6(a) shows return loss, Fig. 6(b) shows insertion loss and Fig. 6(c) shows isolation. It is visible that resonating frequencies again impact the isolation but their impact is also significant in insertion loss and return loss. Return loss is worse in the middle of the bandwidth where the difference is up to 10 dB between the simulation and the measurement but the resonating frequency of 51 MHz does not impact the reflection as much as predicted, insertion loss is worse by 0.1 dB throughout the bandwidth and worse by 0.7 dB around the 30 MHz when the characteristic falls below -0.8 dB. The measured isolation is continuously worse than in simulations by 9 dB until it reaches -100 dB where the VNA starts measuring the noise. Measurements at different biases are not needed because the DC bias currents that are used to test the DUT are well below the saturation or heating current ratings of the inductors in the bias stage.



(a)



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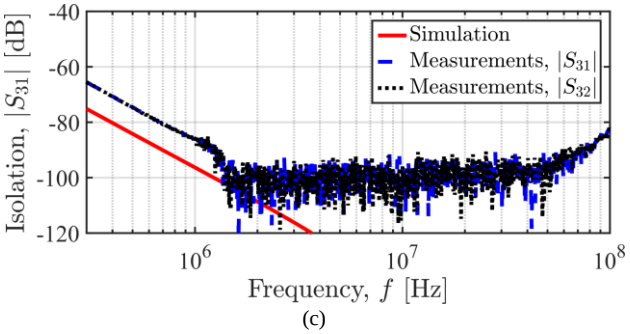

(c)

Fig. 6. Simulation and measurement comparison: (a) return loss, (b) insertion loss, (c) isolation.

III. TEST CASE

The device under test (DUT) is the 4.7-µH surface-mount power inductor SRP4020FA-4R7M from Bourns [9]. Two-port shunt measurement characterization set-up is designed to extract the impedance characteristics of the DUT [3]. Three calibration structures are processed to extract the parasitics of the test fixture, specifically, SMA connectors and transmission line segments. Both characterization set-ups and calibration structures are designed on dual-sided PCB using the 50-Ohm conductor-backed coplanar waveguide (CBCPW) transmission lines [10]. The parameters of the CBCPW lines are center strip width (2.5 mm), center strip thickness (0.035 mm), gap between the center strip and surrounding ground planes (1.5 mm) and dielectric thickness (1.5 mm). All measurements are performed in the frequency range from 300 kHz to 100 MHz by the VNA R&S ZVB8.

A. *Calibration structures*

The calibration structures are 30-mm, 55-mm and 100-mm long CBCPW lines that connect two SMA connectors denoted as P1 and P2 in Fig. 7. The model parameters of the SMA connector [11], interconnects and substrate are optimized to fit the measured S-parameters of the calibration structures which are obtained after the VNA is calibrated up to the tips of the VNA cable by the SMA calibration set. The parameters are fitted in ADS using the sequence of random and gradient optimization in order to get a robust model of the DUT [12]. The RF connectors and the part of the CPWG line between the connectors and C_4 are de-embedded as a result.

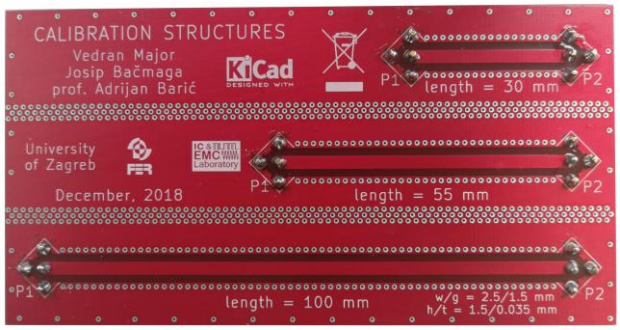

Fig. 7. Calibration structures for SMA connector modelling.

B. *S-parameter measurement setup*

The same PCB is used for bias tee characterization shown in Fig. 6 and for DUT measurements shown in Fig. 10, but different DUT is used for measuring the impact of the bias tee as shown in Fig. 11 and Fig. 12. The schematic of the two-port shunt measurement setup is shown in Fig. 8, and the top view of the designed setup is shown in Fig. 9. Two-port shunt method is used because it allows good results for low-impedance DUTs and allows the design of less complex bias tee compared to the two-port series method. Firstly, the S_{ij} parameters of power inductor are measured using the designed measurement setup. Secondly, the parasitics of the test fixture are de-embedded from the measured S_{ij} parameters to obtain the S_{ij} parameters of the DUT. The test fixture parasitics consist of the SMA connectors, CPWG line

segment between the connector and DC block, DC block C_4 and CPWG line segment between the C_4 and the DUT. Thirdly, the impedance of the DC feed is obtained by measurements when the DUT is unsoldered in the same way. Fourthly, the z_{ij} parameters of the DUT are calculated from the measured S_{ij} parameters of the DUT and measured S_{ij} parameters of the DC feed [14]. The two-port shunt measurement method can be represented by theT-model network [3], and the impedance of the extracted inductor model, Z_{DUT}, is calculated as $Z_{DUT} = (z_{12} + z_{21}) / 2$. Finally, the resistance and the apparent inductance are extracted. The apparent inductance is calculated as $L = \text{imag}(Z_{DUT}) / (2 \cdot \pi \cdot f)$.

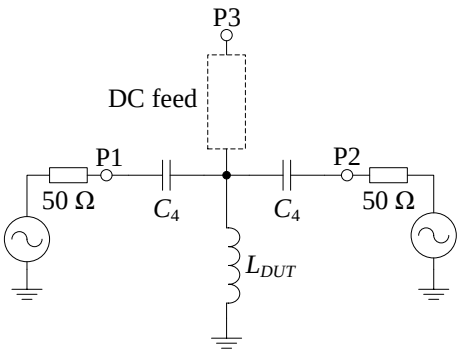

Fig. 8. Measurement setup scheme.

C. Measurement results

Measurement results for the L_{DUT} used in a setup shown in Fig. 8 are shown in Fig. 10. Fig. 10(a) shows resistance and Fig. 10(b) shows apparent inductance of the impedance Z_{DUT} for different values of DC current that is biased to the inductor through port P3. A small decrease in resistance of couple of ohms and a decrease from 4.4 µH to 4.2 µH in apparent inductance is present when the bias current is increased from 0 A to 1 A which is a 4.5% decrease, then for the 2 A to 3.9 µH which is 11% and lastly to 3.6 µH which is 18% for 3 A bias current. These results are comparable to the data provided in the datasheet [9], where DC bias current od 3.4 A is specified to cause the inductance drop of 20%. At frequencies higher than 30 MHz, the bias current has almmost negligible impact on the impedance of the DUT.

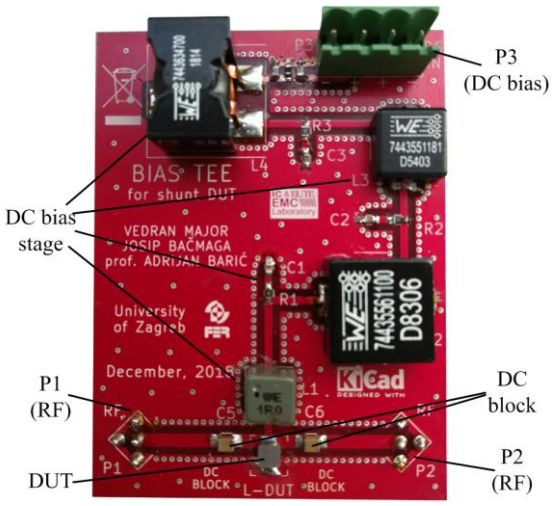

Fig. 9. Top view of the designed PCB.

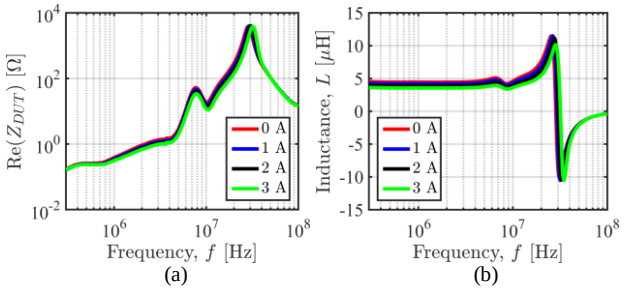

Fig. 10. Inductor characteristics for different bias currents: (a) resistance, (b) apparent inductance.

Results shown in Fig. 11 and Fig. 12 present the impact of the DC feed on the measurements. Fig. 11(a) and Fig. 11(b) show the impact of the DC feed when the L_{DUT} is the 4.7-µH inductor and Fig. 12(a) nad Fig. 12(b) show the impact for the 72-nH inductor L_{DUT}. The apparent inductance is the same with or without DC feed from 300 kHz to 6 MHz whereas the resistance differs throughout the bandwidth and has some oscillations in the middle of the bandwidth. Furthermore, the self resonant frequency (SRF) for the 4.7-µH inductor specified in datasheet is 25 MHz, while the value extracted from measurements is 28.5 MHz at 0 A, and 31.8 MHz at 3 A. An increase of the SRF can be attributed to the lower inductance due to the operation of the inductor in the saturation region.

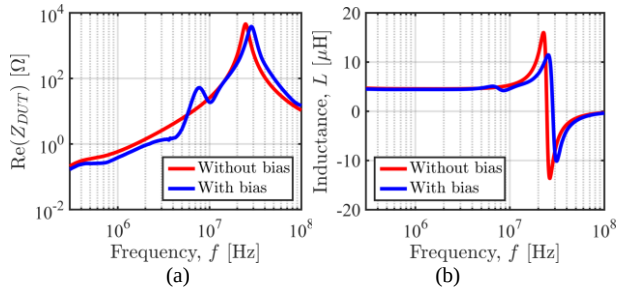

Fig. 11. Impact of the DC feed for the 4.7-µH inductor: (a) resistance, (b) apparent inductance [9].

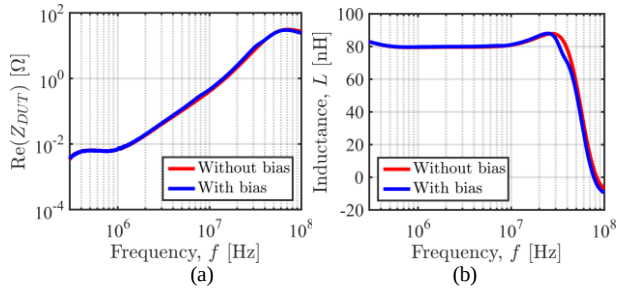

Fig. 12. Impact of the DC feed for the 72-nH inductor: (a) resistance, (b) apparent inductance [13].

IV. Conlcusion

The bias tee used for estimation of impedance characteristics of power inductors is designed and characterized by simulations and measurements. The impact of component parasitics on the return loss,

insertion loss and isolation is observed by simulations. The model of the designed bias tee is analyzed by measurements, and the difference of 20 dB between model and measurements is observed for the return loss. The impedance characteristics of a power inductor are extracted for bias currents up to 3 A, and the inductance drop of almost 20% is recorded, while a significant impact of the bias stage on the impedance characteristics is observed. The designed circuit is suitable for characterization of low-impedance components in shunt measurement topology.

ACKNOWLEDGEMENT

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High Speed DPWM for Digital Power Converter Controller

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Abstract - **This study proposes a new architecture of digital pulse width modulator (DPWM) for power converter with digital control loop. The described architecture is based on a new counter-based concept. The new approach requires two counter loops: a slow big one and a fast small one. The fast counter loop is driven by a clock generated with a digital implemented ring oscillator, which is located on the chip close to the DPWM block. The slow counter measures the switching period. The fast counter provides the high precision duty cycle. The proposed concept was examined on the buck converter with 10-32V input voltage range, 5.8V output voltage, 2MHz switching frequency, 4.7uH filter inductance and 22uF filter capacitance. A proportional–integral–derivative (PID) controller was taken as a control loop feedback mechanism. To maintain the optimal duty cycle resolution of the DPWM the 576MHz ring oscillator was required. The proposed architecture improves the static characteristics of the converter while there is no impact on the dynamic characteristics. The results are showing that the output voltage ripple can be improved by 15% with absolute improvements of 14.4mV and the output current ripple can be reduced by 220mA for 1.1A load current. The ring oscillator frequency deviation of -20% to +30% has a small impact on the functional efficiency of the DPWM.**

Keywords - switch-mode power conversion, digital control, digital pulse width modulation, high speed DPWM, SMPS

I. INTRODUCTION

Integrated DCDC converters are an important building block in power management, which should be highly efficient, fast to regulate the output voltage depending on the change of the external parameters and easily adjustable to accommodate the different external components [1]. Such requirements create a great interest in the digital-based approach of DCDC converter implementation.

Digital control for power dc-dc converters has significant advantages compared to analog architectures [2]. It introduces not only simple techniques for advance control [3], [4], but also it makes it possible to reuse the same hardware architecture for a different output power by simply changing the configuration value of the registers. From an integrated circuit design point of view digital flow enables the short development time, because it has automated tools and well-structured high-level verification methodology. Digital circuits also have significant benefits for technology transfer and can be tested on FPGA board without spending the effort on a dedicated test chip.

On the other hand, the digital control mode converters have also the disadvantages. One of the most common issues is connected with the digital pulse width modulator (DPWM), which forms duty cycle duration and has a direct impact on static characteristics of a dc-dc [5]. High resolution of PWM is required to decrease output voltage ripple and to avoid limit-cycle oscillation effect [6]. In order to solve this issue, different architectures were proposed. Most of the proposals are trying to achieve high resolution time quantization using a tapped string of delay cells, which is often called delay line [7]. Such circuits take advantage of the linear propagation, which is a function of a number of delay cells. The delay is controlled by the multiplexer driven by the n lowest bits of the duty cycle digital value [6]. This multiplexer and a big number of controlled delay cells is the drawback of this approach. The alternative solution is based on combination of the counter and delay line approach. In such systems most and least significant bits of duty cycle digital word are used to control counter- and delay-based parts respectively. The delay-line in this architecture type can be implemented from analog buffers [8] or from digital cells [9]. The main disadvantage of the analog buffers is to make the design stable over the process, voltage and temperature variations. One of the approaches to remove limit-cycle oscillation effect from the output voltage is to use DPWM based on second-order sigma-delta [9]. This concept requires separate computation units, which can introduce some additional total loop delay and as a result worsen the output dynamic characteristics of the dc-dc converter.

This paper presents the new digital high speed pulse width modulator approach developed for the buck converter based on two counters, one of which is slow and measures the switching period, the other which is fast and provides a high precision duty cycle. The proposed architecture improves the static characteristics of the converter while there is no impact on the dynamic characteristics.

The paper is organized as follows: the buck architecture is presented in section I, the high speed DPWM is described in Section II, the impact analyses on the static characteristic of the dc-dc is shown in Section III and Section IV summarizes the simulation results, and sets the tasks for future work.

II. DC-DC ARCHITECTURE

In Fig.1, a buck converter with digital control is shown. The buck converter consists of 4 blocks: analog filter, analog-to-digital converter, control unit, pulse width modulator.

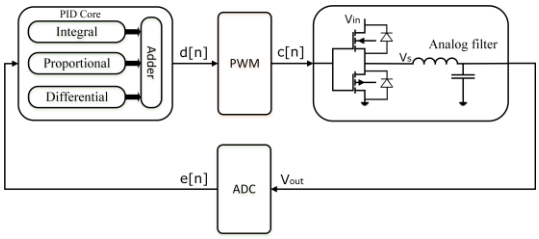

Figure 1. Block diagram of the basic buck converter with digital control unit based on PID approach

A PWM output signal c[n] controls two switches, PMOS and NMOS. When c[n] is equal to 1, PMOS conducts and the current charges the inductor, and the output capacitor. When c[n] is equal to 0, NMOS conducts and the inductor discharges the current to the output capacitor. This repeats periodically with period $T_s = 1/f_s$, where f_s is the converter switching frequency. The switching nature of the converter converts the DC input voltage to the desired output voltage which is defined as function of input voltage:

$$V_{out} = DV_{in}, \tag{1}$$

where D is a fraction of time when PMOS is conducting and is called duty cycle.

The buck converter should regulate the output voltage in the specified window irrespective of the line or load changes in the defined region. The reaction time should be small enough to guarantee proper regulation. Therefore, the duty cycle D cannot be constant over all conditions. Thus, DCDC converter requires a smart control concept to manage both load and line changes. One of the common approaches is the proportional-integral-derivative compensator to generate the duty cycle of the command d[t]. The simplified version of the compensator can be described using the following equations:

$$\begin{aligned} u_p[t] &= K_p e[t], \\ u_i[t] &= u_i[t-1] + K_i T_s e[t] \\ u_d[t] &= \frac{K_d}{T_s}(e[t] - e[t-1]), \\ u[t] &= u_p[t] + u_i[t] + u_d[t] \end{aligned} \tag{2}$$

where e[t] is the digital voltage error signal generated by ADC, which compares output voltage signal with predefined reference value. The gains K_p, K_i, and K_d are designed so as to meet the control loop specifications, such as a crossover frequency, a phase margin and a switching frequency. It is important to notice that the compensator produces the computational delay, t_{calc}, which is a part of total loop delay and has the impact on dynamic characteristics of dc-dc converter.

III. HIGH SPEED DIGITAL PULSE WIDTH MODULATOR

The buck converter with digital control uses a digital pulse width modulator as digital-to-analog converter. A discrete error of signal transformation depends directly on PWM resolution. If it is not high enough, output voltage ripple can be significant and limit-cycle oscillation effect appears. Limit-cycling oscillation occurs in the dc-dc system where the resolution of PWM is smaller than the resolution of the corresponding output voltage/feedback ADC. In general, a non-limit-cycling condition is described by the following equation:

$$q_{adc} > V_{dpwm}, \tag{3}$$

where q_{adc} and q_{dpwm} are the last significant bits of the ADC and DPWM respectively. As one can see, DPWM resolution has a direct impact on the output ripple voltage.

In Fig.2 a block diagram of the proposed high speed DPWM is presented. It contains the two counters which are working at different frequencies. Counter 1 is driven by the system frequency of 72MHz. It is responsible for setting an output trigger at the beginning of every switching period. Counter 2 is more accurate. It does not work during the entire switching period, but only during the time when the output value of counter 1 is equal to the six highest bits of the duty cycle. For this purpose, the special enable signal is generated. Counter 2 is driven by a higher clock frequency of 576MHz. When the output value of counter 2 is equal to the last three significant bits of the duty cycle d[2:0], it generates a reset strobe for the output trigger.

A generalized behavior of the DPWM ramp is illustrated in the Fig. 3. From this figure it is clear that the resolution of the DPWM is defined by the resolution of the fast counter 2. The clock frequency for the second

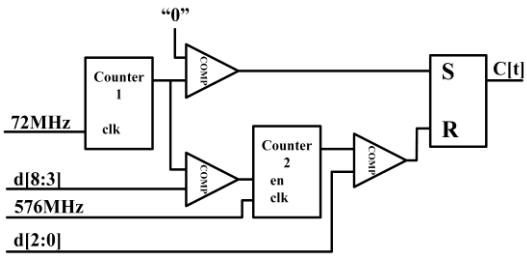

Figure 2. Simplified diagram of the 9-b high speed DPWM

counter is generated by the ring oscillator, which is small and can be implemented using only digital cells. Despite the fact that the ring oscillator is not so precise, it is possible to achieve an accuracy of ±30%. It is quite a big variation, but it depends only on the temperature, which changes slowly and the PID core (illustrated in the Fig.1 PID core) has enough time to compensate this inaccuracy. Some advanced calibration techniques can also be used to decrease the generated clock variation range to ±1%.

The power consumption of the described converter should increase slightly, because only limited numbers of sub-blocks are driven by the high frequency: counter 2 and the driver finite state-machine. These sub-modules

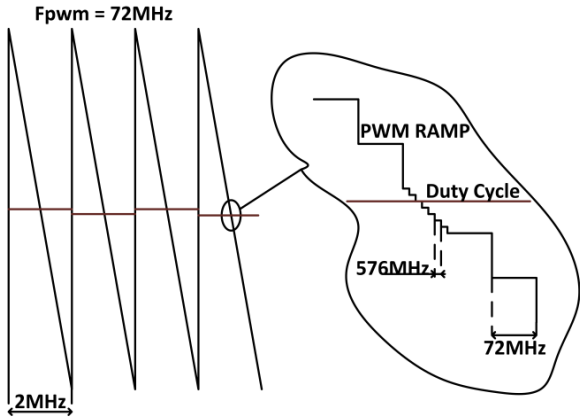

Figure 3. Ramp behavior for high speed DPWM

occupy a small part of the design compared to the PID core. Increased power consumption can also be compensated in case the increased DPWM resolution is high enough to eliminate the noise-shaping block from the design. One of the advantages of the proposed solution is that the control unit can be tested by FPGA.

TABLE I. BUCK PARAMETERS

Parameter	Value
Input Voltage	10-32V
Reference Voltage	5.8V
Switching frequency	2MHz
Filter Inductance	4.7uH
Filter Capacitance	22uF

IV. SIMULATION RESULTS

The task of the simulations is to compare the standard counter-based DPWM solution with the new high speed DPWM, described above. In order to make the comparison equal, the same configurations are used for both digital controls. The only difference is DPWM implementation. The models were built in Simulink. The parameters of the buck converters can be found in Table 1:

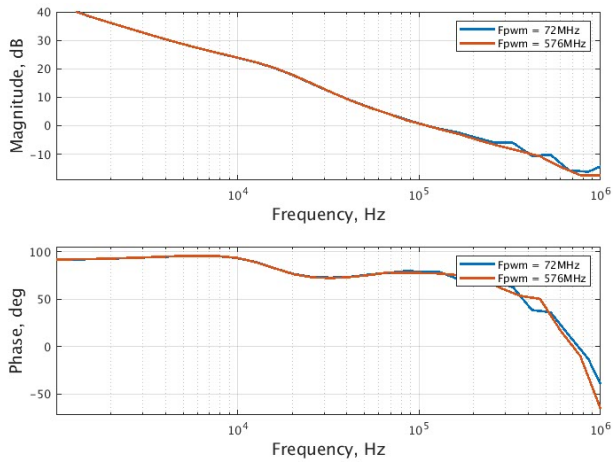

Figure 4. Control-to-output magnitude and phase responses for the system with counter-based DPWM and for the system with high speed DPWM

First of all, the frequency response was taken to prove that both systems are stable and can react similarly to the external disturbances. The Matlab function "Frestimate" was used for this purpose. The magnitudes and the phases of the frequency response can be observed in Fig.4. Blue and red lines are converters with counter-based and high speed DPWMs respectively. The calculated bandwidth is about of 100kHz and the phase margin is about 78°. As was expected from the frequency response analysis and was proven in simulations, the reaction on line and load disturbances for both types of controllers is the same and the difference is less than 1%.

The second test compares the output ripple of the converters for different input conditions. During the simulation load current and input voltage changes from 0.12A to 1.2A and from 10V to 32V respectively. Since the analog integrated clock circuit can have the variation of ±30% from the nominal values this was taken into the account in the test benches. In total 432 different input conditions were simulated for each type of DPWM. The output ripple was calculated as a difference between the highest and the lowest values of the output voltage or output current in the 2ms window in steady-state.

In Fig.5a the results for the output voltage ripple are presented. Blue and orange lines correspond to the counter based and high speed DPWM respectively. As can be seen the results are sorted by the counter-based ripple. From the plot it can be seen that the high speed DPWM gives lower ripple in all tested cases. The largest improvement achieved for the voltage ripple is about 14.4mV for an absolute value of voltage ripple about 50mV.

In Fig. 5b the results for the output current ripple are presented. Blue and orange lines correspond to the counter based and high speed DPWM respectively. The results are sorted by the output voltage ripple values. It can be seen that it is possible to decrease output current ripple by about 220mA. The tendency shows that the high speed DPWM always provides lower ripple than the counter-based approach.

In Fig.5c the data from Fig. 5a and Fig. 5b is combined on one plot, but results are normalized by the counter-based values. A blue line corresponds to counter-based DPWM and that is why it equals always 1. The orange and yellow lines are voltage and current ripple of the high speed DPWM respectively. This figure shows that the average ripple reduction is about 15%.

As was previously mentioned, the high speed DPWM requires a ring oscillator, which is temperature dependent. Thus, some tests were conducted to see what impact a ring oscillator has on the output ripple of the DPWM. In Table 2 the results of these tests are presented. The ring oscillator variation is about ±30% of the nominal frequency, which is 576MHz ± 173MHz. 16 different input conditions were checked for every deviation of the oscillator. In the second column the output ripple for the counter-based DPWM can be observed.

The test shows that the largest ripple reduction happens if the oscillator frequency has a zero or positive deviation: 576MHz, 633MHz, 691MHz and 748MHz. The

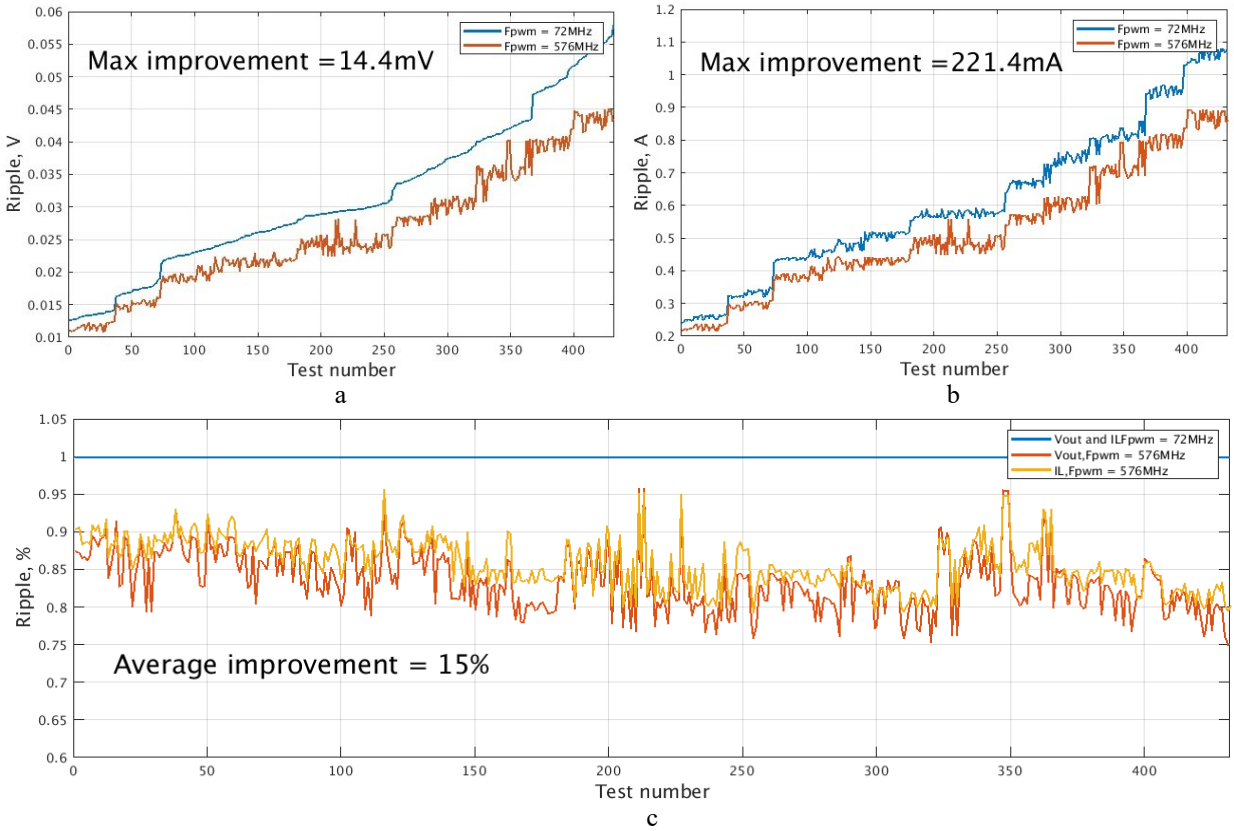

Figure 5. Simulation results for control-to-output magnitude and phase responses for the system with counter-based DPWM and for the system outcome of this research is that the optimal DPWM resolution is 8 bits, which requires 576 MHz ring oscillator with high speed DPWM.

TABLE II. SIMULATION RESULTS FOR VOLTAGE OUTPUT RIPPLE AS FUNCTION OF RING OSCILLATOR VARIATIONS

DPWM frequency, MHz	72	403	460	518	576	633	691	748
Test configurations	Counter-Based DPWM, mV	High speed DPWM, mV						
Vin = 10V, Iload = 0,12A	17.6	15.6	15.0	15.1	14.7	14.8	14.7	15.1
Vin = 10V, Iload = 0,5A	17.4	15.1	14.3	14.8	14.4	14.1	14.4	14.6
Vin = 10V, Iload = 0,9A	16.8	14.7	14.1	14.1	13.5	13.8	14.1	14.0
Vin = 10V, Iload = 1,2A	16.9	14.3	14.3	14.1	13.2	13.6	13.6	13.8
Vin = 18V, Iload = 0,12A	29.3	23.6	23.7	23.2	22.5	22.9	22.9	23.1
Vin = 18V, Iload = 0,5A	29.2	23.7	27.0	23.5	22.7	23.1	23.2	23.2
Vin = 18V, Iload = 0,9A	29.4	24.3	23.9	23.6	23.4	23.2	23.5	23.4
Vin = 18V, Iload = 1,2A	29.1	25.0	24.3	24.4	23.9	23.8	24.2	24.3
Vin = 25V, Iload = 0,12A	33.6	33.8	25.9	26.0	25.3	25.2	25.6	25.9
Vin = 25V, Iload = 0,5A	34.6	32.3	30.4	26.8	26.2	26.6	26.4	26.9
Vin = 25V, Iload = 0,9A	34.5	34.5	33.3	28.3	26.7	27.5	27.4	27.2
Vin = 25V, Iload = 1,2A	33.6	30.6	32.6	27.3	26.4	26.4	27.2	27.3
Vin = 32V, Iload = 0,12A	38.1	30.1	28.3	28.5	27.5	27.4	28.1	28.3
Vin = 32V, Iload = 0,5A	38.2	42.9	35.8	31.7	28.5	29.5	28.4	29.1
Vin = 32V, Iload = 0,9A	38.4	35.8	32.6	30.9	29.3	30.3	29.4	29.7
Vin = 32V, Iload = 1,2A	36.0	30.7	30.0	30.0	29.1	29.1	29.6	30.1

output ripple improvements for the negative deviation are not large, but still significant. The only cases that do not provide any benefits are located in the left low corner of the table. This can be explained by the fact that if DPWM frequency is getting lower, a larger error is introduced by every additional bit. This is illustrated in Fig. 6, which shows the influence of DPWM resolution on the output voltage ripple. It can be seen that the larger the DPWM resolution is, the lower the impact each additional bit has.

V. CONLUSION

This paper proposes a new architecture for a digital pulse width modulator. The new high speed DPWM consists of two basic blocks: slow and fast counters. The slow counter is responsible for keeping the switching period constant, and the fast counter makes the duty cycle more precise. This concept also requires a high frequency ring oscillator to drive the fast counter. The power consumption is slightly increased because only a small part of the design is driven by this high frequency.

In order to evaluate the impact of this approach the high speed DPWM was tested as a part of a buck converter and its results were compared with the counter-based DPWM converter. Based on the results it is possible to confirm that the high speed DPWM can decrease both output voltage and current ripples by about 15%, with maximum absolute improvements of about 15mV for the voltage ripple and about 220mA for the current ripple. It is also important to notice that the high speed DPWM has the same frequency response as a standard counter-based approach. This means it does not increase reaction time for different kind of line and load jumps. Furthermore, it was shown that the proposed solution is quite stable to frequency variation. It shows stable improvements if the DPWM frequency changes in the range -20% to +30%. Another observation shows that the higher DPWM frequency becomes, lower the impact of each additional bit. The simulation results show that the optimal DPWM resolution for this particular buck converter is 8bits. There is no sense in making it higher because it does not provide any benefits to the output ripple.

The study of this problem is relevant and important for the development of power dc-dc converters, especially if the tolerances for the output ripple are tight and the old implementation approach cannot guarantee the performance. The future step of the project is to make FPGA prototype in order to prove the concept and to evaluate the power consumption increase of the proposed DPWM architecture.

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Impact of Choke Selection on Performance of Current-Mode Class-D Amplifier in WPT System

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***Abstract* – This paper observes impact of the various chokes on resonant frequency for the two different topologies of current-mode class-D (CMCD) amplifier used in the transmitter side of wireless power transmission (WPT) system. Both topologies are evaluated through measurements and simulations and the chokes with different inductance values were selected and applied to determine their impact on transmitter performance. In resonant WPT system, in particular transmitter subsystem, we suggest CMCD amplifier with center tapped transmitter coil. The most relevant features that are achieved, using CMCD amplifier with center tapped transmitter coil, in comparison to common CMCD amplifier are decreased choke voltage and significantly lower impact on resonant frequency.**

Key words – wireless power transmission; current-mode class-D amplifier; resonant frequency shift

I. INTRODUCTION

Various inductive WPT systems operate in wide range of frequencies, going from kHz up to MHz range [1]-[6]. Among other amplifiers, the transmitter design uses the common CMCD amplifier [7]-[10], Fig. 1.

Powered from DC power supply, it generates high frequency AC voltage and current in resonant L1C1 circuit. The coil L1 in the resonant L1C1 circuit then generates alternating magnetic field through which the power is transmitted. Common CMCD amplifier consists of resonant L1C1 circuit, two switches (MOSFETs M1 and M2), and two chokes (L). Additional clock generator circuit is needed to drive MOSFET gates with counter-phase square wave signals (clkA and clkB). This way, only one switch (MOSFETs M1 or M2) is closed at any time. The frequency clock signal should match the resonant frequency of resonant circuit. Chokes are used as constant current sources, and as such their inductance and quality factor (Q factor) must be as large as possible. That results with constant current from DC power supply, which has its minimal value when CMCD amplifier operates at resonant frequency of L1C1 circuit (for parallel resonant circuit).

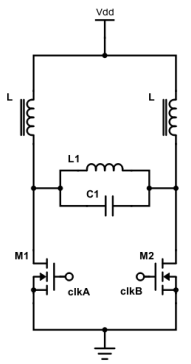

Figure 1. Common CMCD amplifier with resonant circuit L1C1

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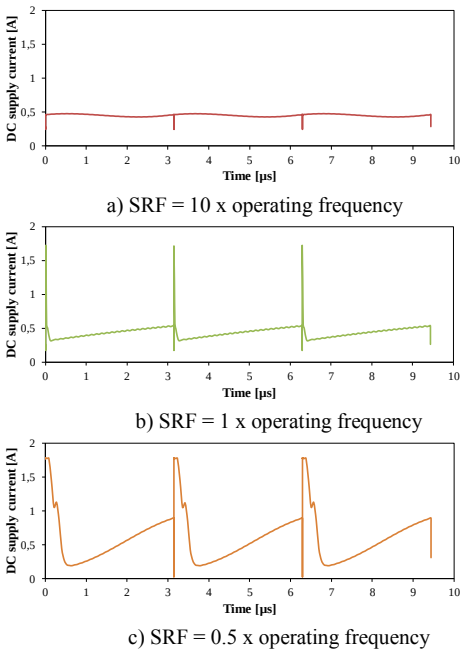
In practice, there are some limitations: due to parasitic capacitance, chokes with large inductance tend to have lower self-resonant frequency (SRF). With choke self-resonant frequency close to the operating frequency of the CMCD amplifier, the chokes do not longer behave as constant current sources. At their self-resonant frequency, the chokes behave as parallel resonant circuits, what results with current spikes. Simulation confirmed, the lower the SRF is with respect to operating frequency of the CMCD amplifier, the more pronounced the current



a) SRF = 10 x operating frequency

b) SRF = 1 x operating frequency

c) SRF = 0.5 x operating frequency

Figure 2. Simulated DC power supply current for different SRF values

spikes are, Fig. 2.

For best performance, the SRF of chokes should be at least ten times higher than the operating frequency, which means using chokes with lower inductance.

For a WPT transmitter with large size transmitter coil L1, it is common to have the choke inductance of the same order-of-magnitude as a transmitter coil inductance. This leads to resonant frequency change of CMCD amplifier. The two following sections evaluate the impact of choke selection on the resonant frequency and voltage drop across choke. According to measurement and simulation results CMCD amplifier with center tapped transmitter coil [9]-[12] turned out to be more adequate than common CMCD amplifier with respect to the resonant frequency shift and choke voltage. At the end of the paper, the conclusion and references are given.

II. MEASUREMENTS

Measurements were carried out on the same prototype circuit from the Fig. 3 for the both topologies of CMCD amplifier, Fig. 4 a) and b), including no-load condition at receiving side.

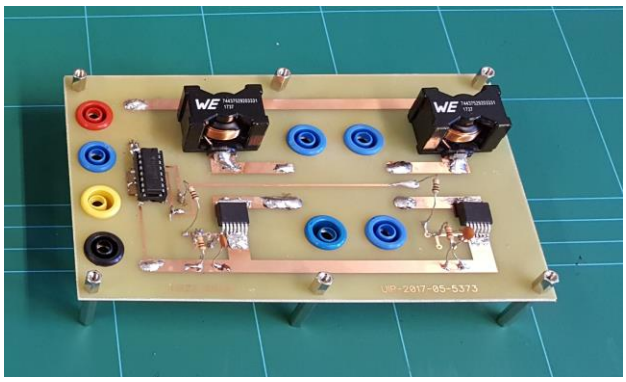
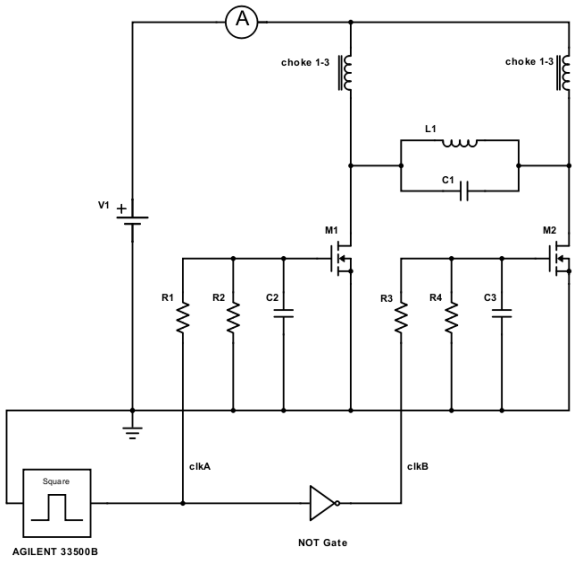
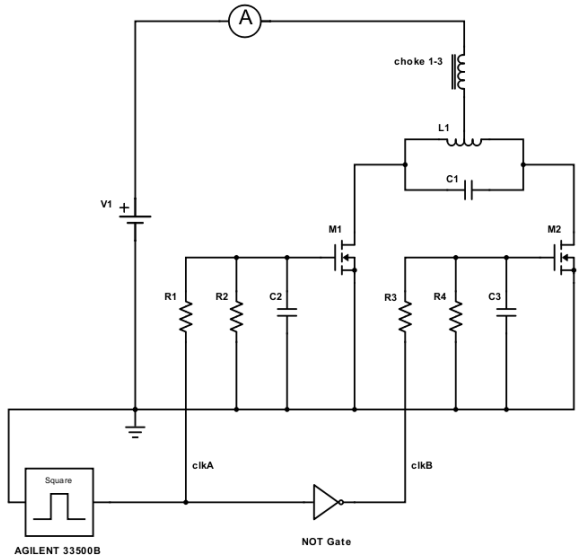


Figure 3. Prototype circuit of CMCD amplifier



a) Transmitter subsystem schematic with common CMCD amplifier



b) Transmitter subsystem schematic with CMCD amplifier with center tapped transmitter coil

Figure 4. Transmitter subsystem schematics for both CMCD amplifier topologies

Independent of the CMCD amplifier topology, the DC source, denoted as V1 in the Fig. 4, was connected directly across the terminals of the CMCD amplifer and applied supply voltage was 20 V. The gates of Wolfspeed C2M1000170J MOSFETs M1 and M2 were driven by the counter-phase square wave voltage to ensure operation of only one MOSFET at a time. The NOT Gate CD4049UBE was used to invert the original voltage signal from the waveform generator AGILENT 33500B. According to Fig. 4, the gate of M1 was directly applied to the waveform generator, i.e. clkA, and the gate of M2 was driven by inverted signal clkB with respect to the original signal clkA. Amplitude of clkA and clkB voltage was 10 V. During measurements voltage source provided supply voltage of 10 V for NOT Gate which is necessary for an operation of a NOT Gate. To avoid serious damage or failure of MOSFETs due to voltage spikes that are present in square wave voltage applied to the gates of MOSFETs, passive low pass RC filters at the gates of MOSFETs M1 (R1 and C2) and M2 (R3 and C3) were used. In Fig. 4, resistance of each R1 and R3 is 100 Ω, R2 and R4 are 10 kΩ resistors for discharging capacitors C2 and C3 which are 0.56 nF capacitors. Resonant circuit L1C1 was tuned to 137 kHz. Thus, the inductance of inductor L1 is 218 μH and the capacitance of capacitor C1 is 6.2 nF for the both CMCD amplifier topologies. In Fig. 4 there are chokes labeled as choke 1-3. That designation indicates three different chokes used to determine choke impact on CMCD amplifer performance. It is relevant to mention that the pairs of identical chokes were used in the common CMCD amplifier topology during measurements at the same time, e.g. choke 1 together with choke 1, not the combination of different chokes at the same time. Table 1 on the next page shows measured parameters values of each choke used in experimentation.

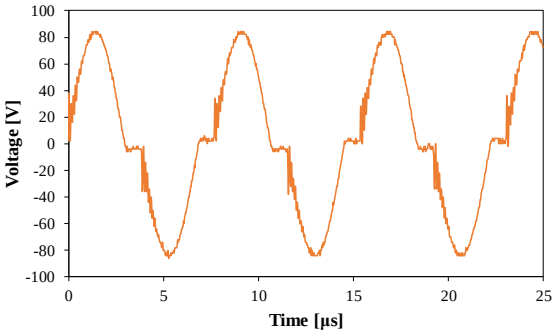
TABLE I. DESIGNATIONS AND PARAMETERS OF CHOKES

Parameters of choke	Designations of chokes		
	choke 1	*choke 2*	*choke 3*
Inductance [μH]	441.10	320.80	100.08
Parasitic capacitance [nF]	52.89	42.07	19.53
Self-resonant frequency [MHz]	1.042	1.37	3.6
Photography of choke			

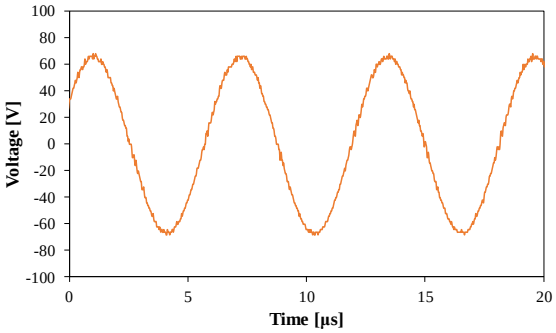
There are two conditions that indicate whether the transmitter subsystem is at resonance. Firstly, a minimal current is drawn from a source due to the maximal impedance of a parallel L1C1 circuit at resonance. Secondly, an off-resonant state is characterized by voltage waveform distortion while a pure sinusoidal voltage waveform is a characterisitic of a parallel L1C1 circuit at resonance. Keeping that in mind, we observe current drawn from the source V1 and the parallel L1C1 circuit voltage waveform while changing frequency of the transmitter subsystem by virtue of the waveform generator AGILENT 33500B which drive the gates of MOSFETs. Current drawn from the voltage source V1 was measured by the ammeter shown in Fig. 4. Voltage across the choke and voltage of the parallel L1C1 circuit were measured by differential probes connected to Agilent Technologies DSO-X 3024A oscilloscope.

Fig. 5 shows voltage of the L1C1 circuit for common CMCD amplifier topology from the Fig. 4 a). Also, Fig. 5 refers to the application of the pair of choke 2 from the Tab. 1. It was established by the measurements that the subsystem from the Fig. 4 a) with the pair of choke 2 was tuned at 161 kHz. That was confirmed by Fig. 5 b) which shows sinusoidal voltage waveform of L1C1 circuit from Fig. 4 a) at 161 kHz. In addition, current measured by ammeter, according to Fig. 4 a), was 35.7 mA at 130 kHz, 9.9 mA at 161 kHz and 27.8 mA at 190 kHz. Measured current at 161 kHz was the lowest level of current with respect to any frequency up to 30 MHz applied to the subsystem in the Fig. 4 a) with the pair of choke 2. Fig. 5 a) and c) represent voltage waveform of L1C1 cirucit from Fig. 4 a) at frequency lower and higher than resonant frequency of subsystem, respecitvely. Distortions in voltage waveforms and amount of current measured by the ammeter indicate that the subsystem from the Fig. 4 a) at 130 kHz and 190 kHz is in the off-resonant state. Although the resonant L1C1 circuit from Fig. 4 a) is adjusted to be tuned at 137 kHz there is the 24 kHz resonant frequency shift with pair of choke 2.

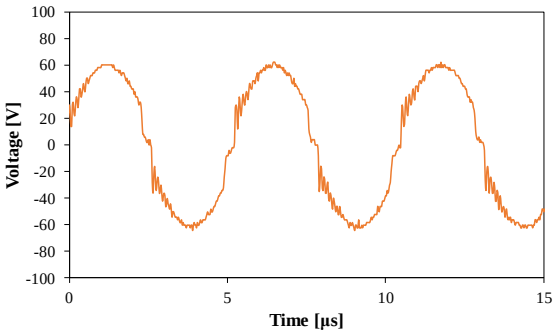
Resonant frequency of transmitter and receiver in WPT system should match. Any resonant frequency shift at transmitting side is regarded as problem because of



a) Voltage at 130 kHz



b) Voltage at 161 kHz (resonant frequency)



c) Voltage at 190 kHz

Figure 5. Voltage waveforms of L1C1 circuit from Fig. 3 a) for different frequencies

fixed resonant frequency at receiving side. Therefore, the intention is to keep resonant frequency as constant as possible. Fig. 6 shows difference between common CMCD amplifier and CMCD amplifier with center tapped transmitter coil used in transmitter subsystem with

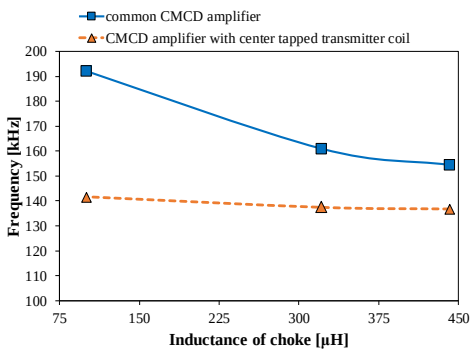
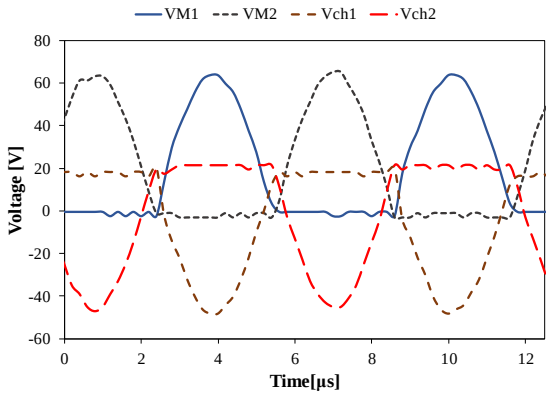


Figure 6. Transmitter subsystem resonant frequency depending on CMCD amplifier topology and choke selection

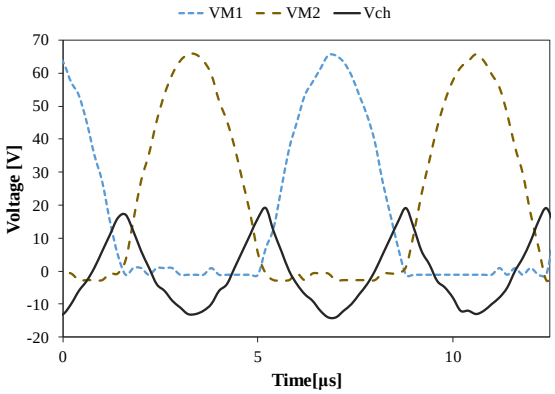
respect to the resonant frequency shift.

In the Fig. 6 the squares and triangles represent measured values of resonant frequencies of transmitter subsystems for the three different chokes presented in the Tab. 1. The solid blue curve displays interpolated change of resonant frequency with regard to inductance of choke in the common CMCD amplifier used in the transmitter subsystem presented in the Fig. 4 a). On the other hand, the dashed orange curve displays interpolated change of resonant frequency with regard to inductance of choke in the CMCD amplifier with center tapped transmitter coil used in the transmitter subsystem presented in Fig. 4 b). According to Fig. 6, undesired and significant resonant frequency shift of the transmitter subsystem with common CMCD amplifier is present permanently in spite of various inductance of chokes. However, resonant frequency shift of the transmitter subsystem with the CMCD amplifier with center tapped transmitter coil is negligible. Also, the transmitter subsystem with the CMCD amplifier with center tapped transmitter coil was quite independent from inductance of choke. Therefore, the transmitter subsystem with CMCD amplifier with center tapped transmitter coil topology is more robust, from the aspect of resonant frequency shift, in comparsion to the transmitter subsystem with the common CMCD amplifier topology.

The next figure shows voltages across chokes and drain-source voltages of the MOSFETs used in transmitter subsystems from Fig. 4 a) and b) at resonance. Inductance of each choke used in these experiments was 320.80 μH, i.e. used chokes were that denoted as choke 2 in Tab. 1. Fig. 7 a) refers to the common CMCD amplifier used in the transmitter subsystem from the Fig. 4 a). Voltages across the left and right choke introduced in the Fig. 1 are marked as Vch1 and Vch2 in Fig. 7 a), respectively. Also, drain-source voltage of MOSFET M1 and MOSFET M2 that are introduced in Fig. 1 are marked as VM1 and VM2, respectively. The MOSFETs M1 and M2 operate in switching mode regime and that is clearly presented in Fig. 7. When the VM1 is zero, the VM2 is present and vice versa. Zero voltage drop across each of the MOSFETs is the characteristic of conducting regime. Peak to peak value of Vch1, Vch2, VM1 and VM2 exceeds 60 V. Fig. 7 b) refers to the the CMCD amplifier with center tapped transmitter coil used in transmitter subsystem from the Fig. 4 b). Voltage drop across MOSFETs are also marked as VM1 and VM2. Amplitude of the VM1 and VM2 in Fig. 7 b) is equivalent to the amplitude of VM1 and VM2 in Fig. 7 a). The voltage drop across the single choke used in the CMCD amplifier with center tapped transmitter coil or Vch is significantly lower in comparison to the Vch1 and Vch2. Peak to peak value of Vch is lower than 35 V. As a result, choke used in CMCD amplifier with center tapped transmitter coil do not require high class insulation as chokes used in common CMCD amplifier for high voltage application.



a) Measured voltages of common CMCD amplifier in transmitter subsystem



b) Measured voltages of CMCD amplifier with center tapped transmitter coil in transmitter subsystem

Figure 7. Measured voltages of chokes and MOSFETs

III. SIMULATIONS

Main purpose of simulation model is to find resonant frequencies for different choke inductances and different topologies of CMCD amplifier used in transmitter subsystem. Simulations are computed in MATLAB Simulink environment. Mathematical models for components in transmitter subsystem are provided in Simscape library. For all capacitors mathematical model is serial linear time invariant RC equivalent circuit and for all inductors (air, and iron cored) serial linear time invariant RL equivalent circuit is used. Equivalent parameters are obtained by measurements on real components. DC power supply is considered ideal. Semiconductor components (MOSFETs) are modeled using on/off drain-source resistance as well as on/off resistance and integral MOSFET body diode forward voltage drop, while body diode dynamics is neglected. For simulation purposes MOSFET switching frequencies are between 100 – 250 kHz, as measured resonant frequencies can be found between those frequencies. All simulation parameters can be found in Tab. 2.

Frequency sweep, Fig. 8, is used for resonant frequency calculation, so MOSFET switching frequency step is 1 kHz (inside 100-250 kHz range). For every switching frequency step instantaneous voltages and currents (with zero capacitor voltages and zero inductor currents as initial conditions) are obtained. Accordingly,

TABLE II. SIMULATION PARAMETERS

CMCD amplifier topology	Common	With center tapped transmitter coil
choke 1	$L_{choke\ 1}$ = 441.10 [µH]; R = 11.25 [Ohm] @ 100 kHz	
choke 2	$L_{choke\ 2}$ = 320.80 [µH]; R = 6.62 [Ohm] @ 100 kHz	
choke 3	$L_{choke\ 3}$ = 100.08 [µH]; R = 3.23 [Ohm] @ 100 kHz	
DC power supply	U_{DC} = 20 [V]	
LC tank capacitor	C1 = 6.2 [nF]; R_{C1} = 1 [Ohm]	
LC tank inductor	L1 = 218 [µH]; R_{L1} = 0.5 [Ohm]	
MOSFET	R_{DS} (on) = 0.01 [Ohm]; R_{DS} (off) = 10^6 [Ohm]	
MOSFET body diode	U_F = 0.8 [V]; R (on) = 0.01 [Ohm]; R (off) = 10^5 [Ohm]	

transient and steady-state waveforms are obtained. Simulation duration should be set high enough in order to reach steady-state, in this case 10 ms is used, also simulation step time should be small enough in order to capture waveforms precise enough, in this case 100 ns is used. From simulation duration and simulation time step overall number of waveform samples can be calculated (10^5), but only last 20000 is used for frequency sweep calculation, i.e. for resonant frequency calculations only steady state responses are used. So, for every step of switching frequency DC component of power supply current is calculated. Resonant frequencies are detected at minimal DC component of power supply current in frequency sweep diagram. Detected resonant frequency, based on simulation, for specified chokes and topologies are shown in Fig. 9 and in Tab. 3 as well.

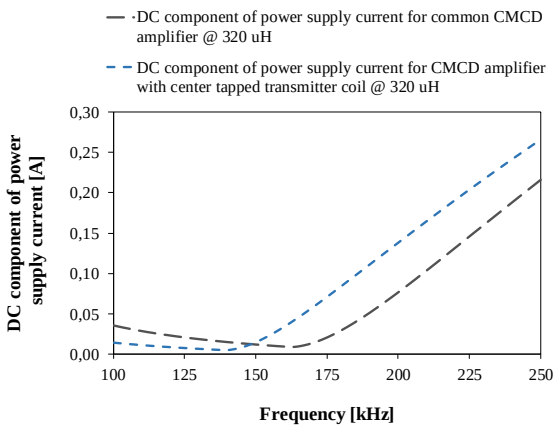


Figure 8. Simulated frequency sweeps of power supply current

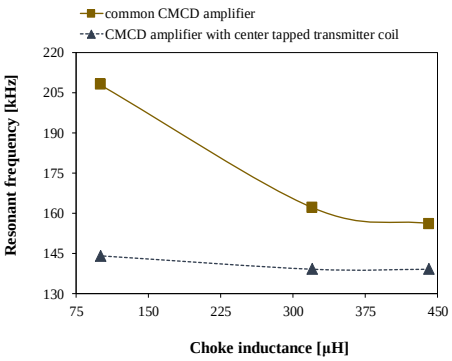
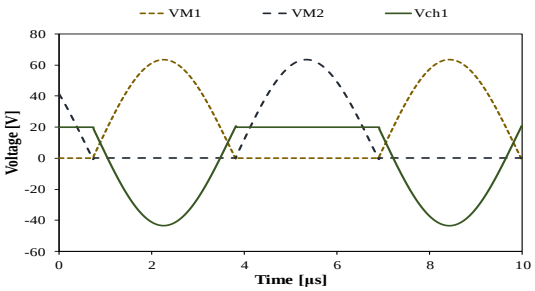


Figure 9. Simulated resonant frequencies in dependence of choke inductance and CMCD amplifier topology

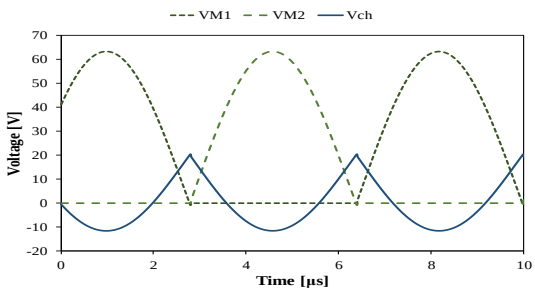
TABLE III. RESONANT FREQUENCIES BASED ON SIMULATION

CMCD amplifier topology	Common			With center tapped transmitter coil		
Used choke(s)	***chokes 1***	***chokes 2***	***chokes 3***	***choke 1***	***choke 2***	***choke 3***
Resonant frequency [kHz]	156	162	208	139	139	144
DC component of power supply current at resonance [A]	0.0090	0.0093	0.0181	0.0051	0.0051	0.0057

For validation purposes of simulated data typical waveforms in steady-state are shown in Fig. 10 and 11. Also, Fig. 10 and 11 refer to the application of the pair of chokes 2 from the Tab. 1.

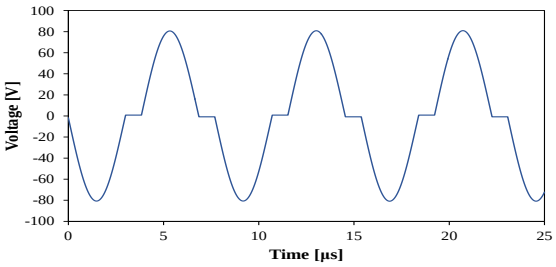


a) Simulated voltages of common CMCD amplifier in transmitter subsystem

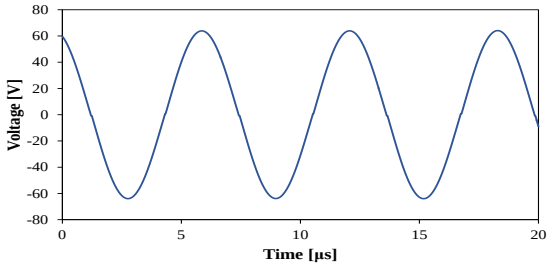


b) Simulated voltages of CMCD amplifier with center tapped transmitter coil in transmitter subsystem

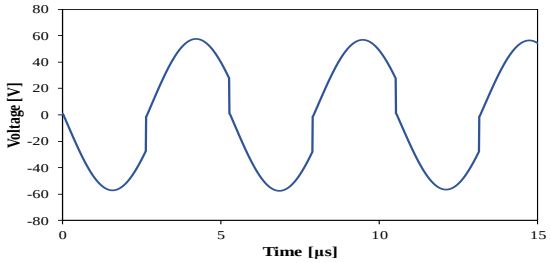
Figure 10. Simulated voltages of choke and MOSFET



a) Simulated voltage at 130 kHz



b) Simulated voltage at 161 kHz (resonant frequency)



c) Simulated voltage at 190 kHz

Figure 11. Simulated voltage waveforms of L1C1 circuit from Fig. 4 a) for different frequencies

IV. CONCLUSION

A comparison of common CMCD amplifier and CMCD amplifier with center tapped transmitter coil topology used in transmitter subsystem of WPT system has been demonstrated in this paper. Furthermore, three different chokes were used in both CMCD amplifier topologies to determine their impact on resonant frequency shift. It is desirable to have a minimal or none resonant frequency shift of transmitter resonant circuit. Both measurements and simulations with three different chokes gave results that are matched to a high degree. It is established by the measurements that the minimal shifts of resonant frequency in common CMCD amplifier and CMCD amplifier with center tapped transmitter coil are 12.78% and 0.095%, respectively. According to simulations, minimal resonant frequency shift for common CMCD amplifier used in transmitter subsystem is 13.87 %. On the other hand, minimal resonant frequency shift for CMCD amplifier with center tapped transmission coil used in transmitter subsystem is 1.46%. CMCD amplifier with center tapped transmission coil turned out to be more convenient from the aspect of frequency shift in comparison to common CMCD amplifier. Minimal resonant frequency shift in both topologies of CMCD amplifier was achieved by using choke 1 from Tab. 1. Also, analyses showed presence of lower choke voltage by using CMCD amplifier with center tapped transmission coil. Peak to peak voltage (V_{pp}) across choke in CMCD amplifier with center tapped transmission coil is 47.10% of V_{pp} across choke in common CMCD amplifier.

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Soft-Start Circuit in Wireless Power Transmission System

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***Abstract* - Transmitter circuit in wireless power transmission system runs on DC power supply. In high power WPT system, a rectifier circuit requires soft-start circuit to avoid inrush currents. In this paper we propose a soft-start circuit based on a MOSFET switch. Main features of the proposed circuit are that it does not require additional power supply and its power dissipation can be regulated. Design is evaluated through simulations and measurements. The proposed circuit is compared to a standard resistor-based soft-start circuit with respect to turn-on cycle behavior and power dissipation.**

Keywords – MOSFET circuits; Soft-start circuit; Wireless Power Transmission;

I. INTRODUCTION

In resonant wireless power transmission system, a common type of power transmitter is a class-D amplifier which drives parallel LC tank [1]-[4]. Class-D amplifier operates from a DC power supply. If mains power supply is used, then an additional rectifier circuit is needed. Using rectified mains power supply with class-D amplifier results in RMS voltage across LC tank up to 800 V. Such high voltage allows using large transmitting coils and still achieving output power levels in the kW range. For a high power WPT system, large value capacitors are used in rectifier circuit. To avoid large inrush currents, a soft-start circuit must be used. The simplest soft-start circuit solution is usage of NTC resistor, Fig 1.a. When "cold", it has high resistance, thus limiting initial inrush current. Once it warms up, its resistance drop, and with correct selection of the NTC resistor, it can provide nominal current. In resonant WPT system, one transmitter can provide power to one or more receivers. Therefore, the nominal current cannot be defined, since the number of receiver circuits (and their power demand) dictates the current drawn from the rectifier. Considering significant changes in operating current, the usage of NTC resistor would be cumbersome. NTC resistor would went back to "cold" state during "lower" current demand and would require a certain start-up time upon higher current demand.

Another simple solution consists of a resistor with relay in parallel, Fig 1.b. Initial capacitor charging is done through resistor which limits the inrush current. When the capacitor is charged, the relay turns on and provides low resistance path for higher current values. There are two main cons for using this design in WPT system. First, the WPT system aims at high efficiency and the relay has continuous power consumption. Second, it requires additional control circuit and DC supply (up to 24 V) to operate the relay. There are more complex soft-start solutions available [5]-[7] which also require additional power supply and logic, but provide power factor corrections.

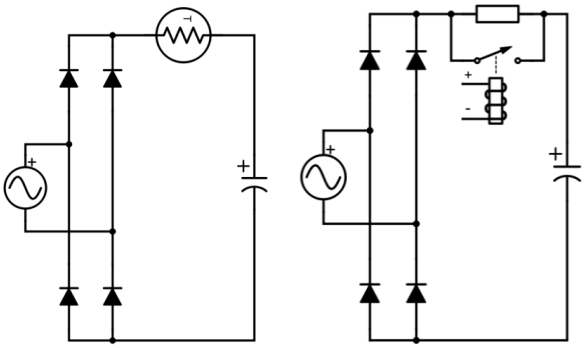


Figure 1. Soft-start circuit using a) NTC resistor and b) resistor-relay combination

For WPT system, a soft-start circuit should accommodate various rectifier output currents. It should have very low steady state power consumption, and preferably no additional power supply unit.

In this paper, we propose soft-start circuit based on MOSFET switch, with adjustable maximal current and MOSFET power dissipation. The proposed design is described in Section 2. Section 3 gives the measurement results, followed by Conclusion and References.

II. SOFT-START CIRCUIT FOR WPT SYSTEM

Proposed soft-start circuit is based on a MOSFET switch with current limiting. Fig. 2a shows the basic concept of the proposed design.

Zener diode (6.1 V) is used to set maximal U_{GS} voltage, thus setting the maximal MOSFET current I_D. Resistor R_1 should be selected in concordance with two contradictory requirements. First, it should have high enough resistance to limit the Zener diode current. Second, it should have low enough resistance since it

This work has been supported in part by Croatian Science Foundation under the project "Efficient Wireless Power Supply" (UIP-2017-05-5373).

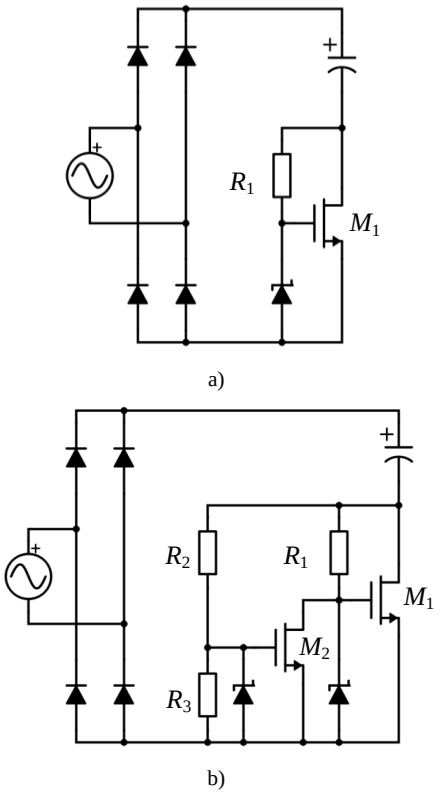


Figure 2. Proposed soft-start circuit a) without and b) with MOSFET power dissipation limitation

forms a low-pass filter together with C_{GS} which limits the response time of the MOSFET.

Also, with mains power supply of 230 Vac, the power rating of the resistor should be taken into account. With 100 kΩ resistor used the maximal RMS power dissipation equals to 0.5 W and it occurs only at the beginning of the soft start.When the soft-start cycle is done, the power dissipation on R_1 drops below 1 mW.

Fig. 3 shows the simulation results for a turn-on cycle of soft-start circuit shown in Fig 2a. Simulations are done in MultiSim SPICE simulator using models for actual devices.

While such design (Fig. 2a) gives simple and reliable soft-start solution with fast start-up time, it also gives additional strain on the MOSFET switch. This can be seen in Fig. 3 when comparing MOSFET current and voltage. The capacitor charges with current limited by the MOSFET and it requires a certain number of ac voltage periods to fully charge. During this time period and depending on the ac voltage source amplitude, the voltage

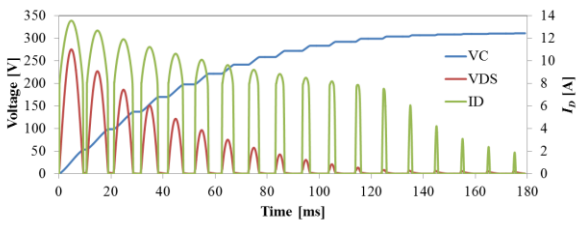


Figure 3. Simulation results for a turn-on cycle of soft-start circuit shown in Fig. 2a

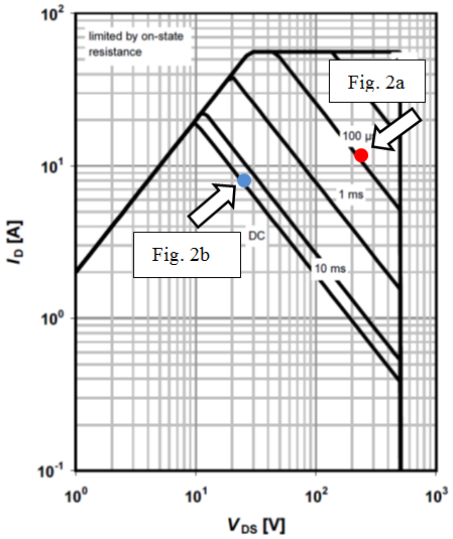
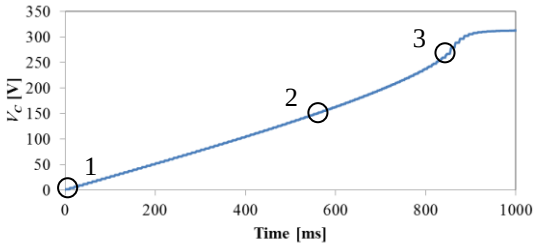
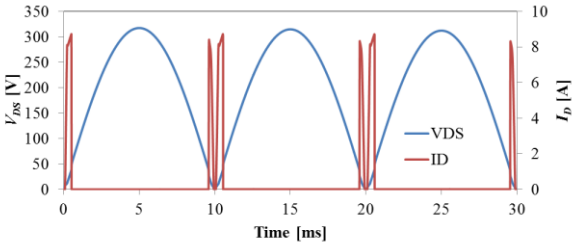


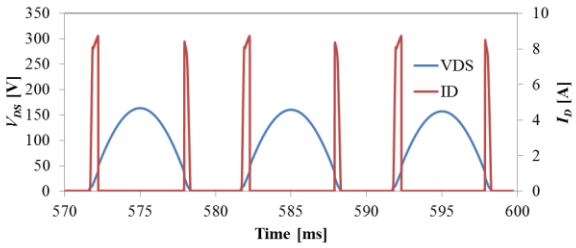
Figure 4. Safe operating area (SOA) for IPP50R140CP MOSFET [8]



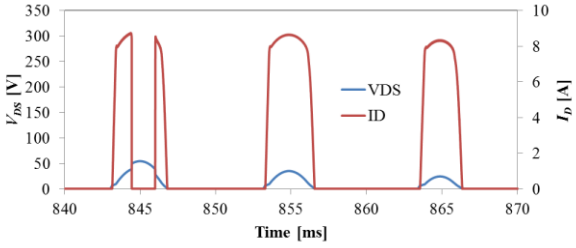
a) Capacitor voltage



b) MOSFET M1 current and voltage in point 1



c) MOSFET M1 current and voltage in point 2



d) MOSFET M1 current and voltage in point 3

Figure 5. Simulation results for a turn-on cycle of soft-start circuit shown in Fig. 2b

across MOSFET can exceed the values of SOA (Safe Operating Area). Fig. 4 gives the SOA chart for IPP50R140CP MOSFET. The red dot marks the operating point of MOSFET during initial operating cycles. The duration of time interval in which the MOSFET is placed in this operating point is well above 5 ms, which leads to MOSFET damage.

Proposed solution (Fig. 2b) limits the maximal power dissipation of MOSFET keeping it within safe operating area. Additional MOSFET M_2 (BS170) is biased by resistive divider (R_2 = 100 kΩ, R_3 = 10 kΩ) and it defines at which V_{DS1} voltage value MOSFET M_2 starts conducting. At that point, the gate of M_1 is pulled to the ground and M_1 turns off, until the V_{DS1} voltage drops below the value defined by resistive divider (R_2, R_3) and M_2 threshold voltage.

Fig. 5 shows the simulation results for a turn-on cycle of proposed soft-start circuit, Fig 2b. With shorter current pulses (points 1 and 2), the duration of soft-start cycle is longer. A the end of the cycle (point 3), when the maximal voltage across M_1 drops below defined value, the current and voltage waveforms equal to those of a soft-start circuit from Fig. 2a. This way, the operating point of MOSFET M_1 is placed within the SOA, marked with blue dot on Fig. 4.

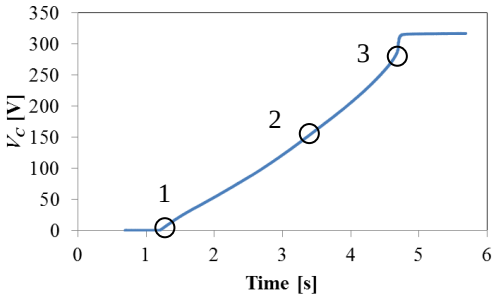
III. MEASUREMENTS

Measurements of a proposed soft-start circuit are done on a prototype circuit, Fig. 6. Full bridge rectifier with implemented soft-start circuit was connected to the mains power grid (230 Vac, 50 Hz) and the turn-on cycle is measured. Voltage across rectifier output capacitor and V_{DS} voltage of MOSFET M_1 are measured directly. The MOSFET M_1 current is measured by resistive shunt of 0.1 Ω. All three waveforms are measured by differential probes on Keysight MSO-X 4024A oscilloscope. Acquired waveforms are given on Fig. 7.

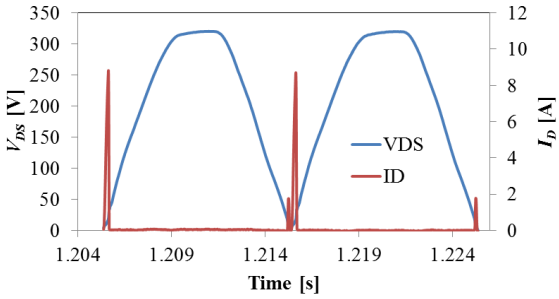
Measurement results show good matching with simulation results. There are two main discrepancies between simulation and measurement results. First, the turn-on cycle takes 1 s in simulations and 4 s in measurements. This is due to MOSFET M_1 mismatch between simulations and measurements. For simulations IRF840 is used, which was replaced on the prototype with IPP50R140CP whose SPICE model was not available. The second difference can be seen on I_D current waveform. In simulations, each half period of rectified voltage has two pulses of I_D current. These two pulses have similar amplitude, but the first one has a bit longer duration. This is more pronounced in measured waveforms, where the second pulse has significantly lower amplitude and duration. The reason for such behavior is the time constant formed by R_1 and M_1 input capacitance C_{GS1}. When M_2 turns off, it takes time (R_1C_{GS1}) for M_1 to turn on. This can be improved by using R_1 with lower resistance, but with higher power rating. The maximal power dissipation on R_1 occurs only during first half of the turn-on cycle (e.g. up to point 2 on Fig 7). After the turn-on cycle is complete, the voltage across soft-start circuit should not exceed maximal V_{DS1} voltage defined by resistive divider (R_2, R_3) and M_2 threshold voltage.



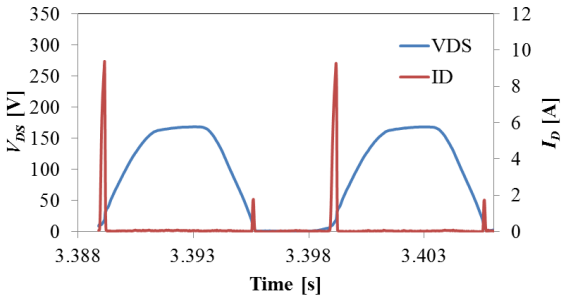
Figure 6. Full bridge recitifer with proposed soft-start circuit



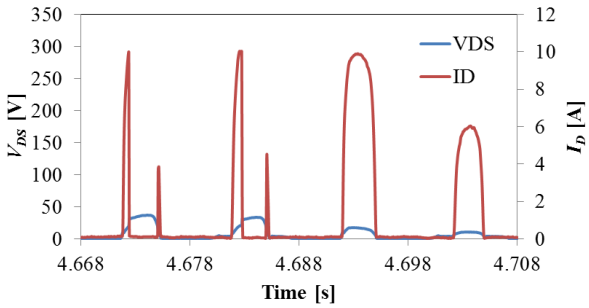
a) Capacitor voltage



b) MOSFET M1 current and voltage in point 1



c) MOSFET M1 current and voltage in point 2



d) MOSFET M1 current and voltage in point 3

Figure 7. Measurement results for a turn-on cycle of a proposed soft-start circuit

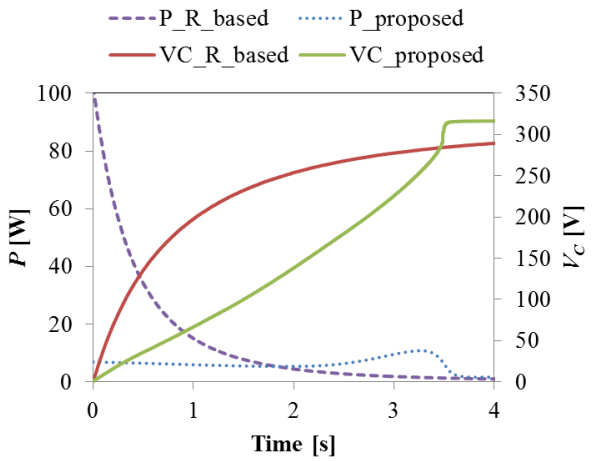


Figure 8. Soft-start circuit comparison

Additional measurement was done to compare proposed soft-start circuit with simpler resistor based solution, Fig. 1b. Fig. 8 gives the comparison results for measured capacitor voltage of both proposed soft-start circuit and soft-start circuit with 500 Ω resistor.

Compared to exponential charging of simpler resistor based solution, the proposed soft-start circuit has more linear charging behavior. While resistor based solution charges slower as it approaches maximal value, the proposed solution increases charging speed when close to maximal value. Fig. 8 also shows the power dissipated during capacitor charging. For resistor based solution this equals to the power dissipated on a 500 Ω resistor, and for the proposed soft-start circuit it equals to power dissipated on MOSFET M_1. The power is averaged for each period of mains power supply (20 ms). Resistor based soft-start circuit creates significantly higher strain on the current limiting resistor at the beginning of the turn-on cycle, but with relatively short duration of under 5 s, the power rating of the resistor can be 5 to 10 times lower than the maximal power [9]. For the measured scenario, a resistor with power rating of 10 W to 20 W would suffice. With proposed soft-start circuit, the power dissipated on MOSFET M_1 is almost constant with slight increase at the end of the turn-on cycle.

IV. CONLUSION

A simple and versatile soft-start circuit designed for use in wireless power transmission system is presented. It does not require any additional power supply and is suitable to work with mains power supply voltage levels. The maximal current and maximal power dissipation can be adjusted by choosing appropriate component values. Measurement results have shown good matching with simulation results. Measurements on laboratory prototype have shown that the proposed design has linear charging with constant power dissipation throughout the turn-on cycle.

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Survey on the Generation of Equivalent Circuit Cable Models for Transient Simulation

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***Abstract*—Especially in automotive and aerospace applications very long and complex cable harnesses are part of virtually all electronic systems. To precisely predict their electromagnetic behavior by simulation, accurate models of cables and harnesses are essential. In this work a semi-automatic workflow to derive a lumped circuit transmission line (LCTL) model from the 2D cross section of an arbitrary cable harness is presented. In contrast to conventional measurement based behavioral models (e.g. S-parameters) this approach provides flexibility to depict different harness compositions without the need for repeating measurements. The model generation process and involved limitations are discussed in detail. For validation, the simulation results obtained with the LCTL model are compared to measurements, 3D finite element method (FEM) and 3D hybrid multi transmission line (MTL) simulation in frequency and time domain. The considered frequency range is up to 1 GHz.**

Keywords—cable harness; equivalent circuit; 3D EM simulation; finite element method (FEM); lumped circuit transmission line (LCTL); multi transmission line (MTL); per-unit-length parameters (p.u.l.)

I. Introduction

Cable harnesses are an intrinsic part of modern electronic systems. Especially in vehicles and aerospace applications (e.g. more electric aircraft (MEA)) long and complex harnesses are prevailing, but also for wired data transmissions the electrical performance of transmission lines is essential. For the prediction of suchlike system's performance by simulation, the modeling of cable harnesses is an inevitable task - even if the device being designed is e.g. an integrated circuit (IC) and the attached harness connects a load. The generation of accurate and broadband electrical harness models is the first necessary step for system level simulation. Nonetheless, its complexity is often underestimated.

Generally speaking, due to the flexible nature of cables, measurements of their transmission properties are hardly repeatable. Stochastic approaches describing cross talk in terms of mean value and standard deviation are common, e.g. [1]–[6], where it is shown that measurement results may easily deviate by $10\,\mathrm{dB}$ depending on the (unknown) position of a wire within a harness. In simulation one needs to define a specific harness cross section and wire routing. This can never cover all possible variations of a real setup, hence the goal of cable harness simulation is not to precisely depict a single measurement result, but rather to predict a typical mean value. Behavioral data to describe the influence of transmission lines (TL) on electric signals is usually obtained by measurement in frequency domain (FD) using vector network analyzers (VNA). The resulting scattering parameter matrices (S-parameter) yield non-transparent black-box models when used for circuit simulations, which are known to frequently cause issues during time domain (TD) transient simulation [7]. Furthermore, S-parameter models cannot be transformed to depict a different harness composition than that of the original measurement. To increase stability of transient simulations, acquire more flexible harness models and to overcome the need for repetitive measurements, the use of lumped circuit transmission line (LCTL) models is proposed in this work.

Commercial EM solver tools to automatically generate LCTL models from multi-conductor transmission lines (MTL) exist. In this paper it is investigated if the same can be accomplished sole from the harness' 2D cross section. The used cables are twisted wire pairs (TWP). Thus, the 3D information on the wire's twist will be lost. The circuit topology and necessary parameter extraction from the cross section are already analytically described in [8], [9]. Often analytical examples tend to drastic simplifications on 2D cross section and material to ease calculations. With todays computational resources such are not necessary anymore. Per-unit-length (p.u.l.) parameters, i.e. RLCG/m, can be determined precisely from the detailed 2D cross section. Actually, a number of commercial simulation tools offer the functionality to generate (behavioral) TL models from 2D cross sections. This paper may be understood as a study on the usability and limitations for day-to-day cable modeling. Generating broadband models manually is complicated, error-prone and time consuming work. Hence, we present a workflow to semi-automatically generate a SPICE netlist from the 2D cross section of an arbitrary harness. The approach is motivated as follows:

First, p.u.l. parameter extraction in 2D is computationally faster than accomplishing the same from full 3D setups. However, the question remains if 3D parameters like cable routing, twisting and discontinuities at the cable ends need to be considered.

Second, the less RLCG components the LCTL netlist is made from, the faster is the circuit simulation. A minimalistic consideration of frequency dependent phenomena like skin or proximity effect will result in a simple netlist and reduce circuit

simulation times (however, also adversely affect the models effective bandwidth).

The paper is structured as follows:
Section II gives an overview of state-of-the-art approaches to generate models of cable harnesses for transient simulation and clarifies the motivation for the proposed approach.
In Section III a methodology to semi-automatically generate a minimalistic LCTL circuit from only the 2D cross section of a cable harness is presented. Limitations in terms of accuracy and frequency bandwidth are discussed.
In Section IV the method is validated against time and frequency domain measurements in comparison to results obtained with commercial 3D electromagnetic (EM) simulation tools applying the finite element method (FEM) or hybrid multi transmission line (MTL) solvers. As example serves a harness consisting of three parallel twisted wire pairs (TWP).
Section V concludes the work and summarizes known issues.

II. Common approaches for the generation of transmission line models

The authors distinguish between the following approaches to include models of cable harnesses into circuit simulation:

S-parameters (FD): Non-physical behavioral descriptions by S-parameters can be obtained from measurement or simulation. Because these network parameters are defined in FD, transient TD simulation require to generate an equivalent circuit description fitted to the FD data in a pre-processing step [7]. This is usually computed by the circuit simulation software in a background process, without notice of the user. However, the performance of the fitted circuit depends on the capability of the used engine (especially to extrapolate a correct DC operating point), thus it might vary between circuit simulators (or even between versions of the same simulator). That means, the same set of S-parameters can lead to very different transient simulation results. As a consequence, many circuit designers prefer models that have real physical meaning.

Non-physical equivalent circuit model (TD+FD): Instead of using the S-parameter raw data for simulation, above described equivalent models can be directly used as input to circuit simulation, i.e. as netlist, to overcome the issue of fitting-dependent simulation results. Most common is the use of so-called broadband SPICE (bbspice) models. Such are composed of a set of ideal voltage and current sources which reflect the poles and zeros of the complex-valued frequency data. One example for the specific netlist generation process is for instance given in [10]. Actually, this is again a behavioral model, hence circuit simulation computes very fast. Furthermore, the model is well suited for transient simulation. However, suchlike equivalent circuit models might behave non-physically and could also cause convergence issues, depending on the quality of data that was used to generate the model.

Expression-based p.u.l. or RLCG/m models (FD): Instead of using S-parameters themselves for the description of transmission lines, they can be expressed as frequency dependent per-unit-length (p.u.l.) parameters (or more generally transmission line (TL) parameters), i.e. RLCG/m(f). The works [11], [12] show how to convert S-parameters to RLCG/m(f). These can be used as input to e.g. the W-element of HSPICE or the similar mtline object of Cadence Spectre (to name only two examples). Respective circuit blocks use again rational fitting algorithms to generate a behavioral model from the RLCG/m(f) input data. As above, the simulation result depends on the quality of the source data and on the specific internal implementation. Alternatively, p.u.l. parameters can also be obtained by analytical expressions, e.g. [13], [14] for specific cable types. These expressions may be implemented as functions of frequency in the circuit simulator. However, due to the used modeling language, e.g. Verilog-A, the model will not be universally usable with any circuit simulation software.

Physical equivalent circuit model (TD+FD): The last approach mentioned here is to generate a physically meaningful equivalent circuit which consists of 'real' circuit components only, i.e. resistors, inductors, capacitors and conductors - in short RLCG. It is fairly obvious that a single set of RLCG cannot reflect broadband frequency dependency, hence the length of the harness is divided into lumped RLCG blocks derived from the p.u.l. values (as sketched in the center right schematic of Fig. 1). The component values correspond to the respective length of the transmission line. The result is a so-called lumped circuit transmission line (LCTL) model. Commercial software tools are able to automatically generate LCTL models from the 2D cross section of a cable harness while also taking 3D properties into account [15], [16]. The clear advantage of suchlike physically meaningful circuits is, that they are usable with any circuit simulator, sure to cause no convergence problems, behave well at DC point and the corresponding netlist is human interpretable. It is even possible to describe frequency dependency of p.u.l. parameters RLCG/m(f) with discrete RLC components, like e.g. the skin effect as exemplified in [17]. This, however, increases the complexity of the model substantially which slows down the simulation.

III. Methodology

The used methodology is depicted by Fig. 1. It was applied before in [18]. Per-unit-length RLCG/m parameters of the transmission line cross section (sketched in the top left of the figure) are extracted from quasi-static 2D simulation (ANSYS 2D Extractor [19]) and exported to MATLAB. From the given coupling matrices a script automatically generates a lumped elements SPICE netlist of N cascaded RLCG blocks, whereas each of the blocks has to be electrically short. According [20] (Chapter 5.1.2) the maximal length of transmission line that could be represented by a single lumped equivalent circuit is limited to $\Delta l \leq \lambda/10$, where Δl is the length of one transmission line segment and λ the wavelength related to the maximum frequency of interest and the isolation material. The wavelength in a transmission line with dielectric material between the conductors is described in [21] (Chapter 4.1) as

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \quad \text{and} \quad \lambda_0 = \frac{c_0}{f} \tag{1}$$

where ε_r is the relative permeability of the isolation material, c_0 the speed of light and f the frequency. A long transmission line is represented by cascading RLCG blocks of length Δl until the desired overall length l is obtained. To calculate the necessary number N of segments, the aforementioned equations are put together to

$$N \geq \frac{10 \cdot f_{\max} \cdot l \cdot \sqrt{\varepsilon_r}}{c_0} \tag{2}$$

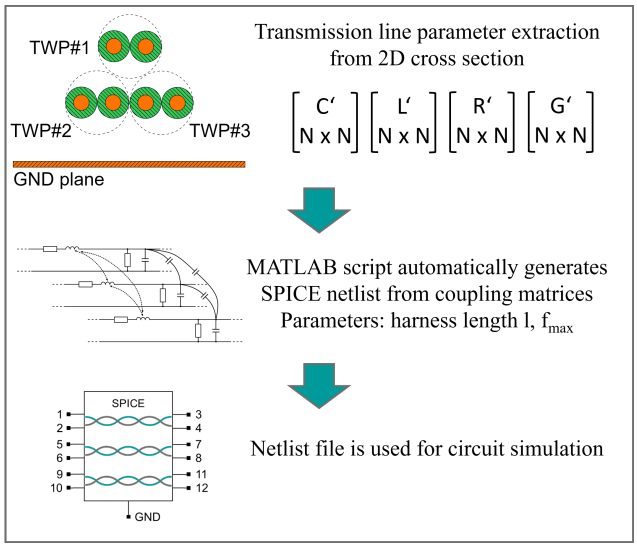


Fig. 1. Schematic overview of the proposed workflow for semi-automatic netlist generation from a 2D cross section of a harness [18].

Since the used dielectric materials have $\varepsilon_r \leq 4$, (2) can be further simplified to:

$$N \geq \frac{20 \cdot f_{\max} \cdot l}{c_0} \tag{3}$$

A. Work-Flow to Obtain Cable Parameters

Besides the real cable routing inside the harness, other typically unknown variables during simulation are the actual dielectric properties of the cable's insulation, i.e. the (effective) relative permittivity ε_r and the dielectric loss tangent $\tan(\delta)$. Furthermore, the 2D cross section can only be approximated by sample measurement or data sheet information. The workflow that is described below is based on measurements and can be used to obtain the correct insulation material parameters for the simulations shown in this work:

1) S-parameter measurements on a short piece of (twisted) wire. By rule of thumb, the used wire needs to be shorter than $\lambda/4$ of the maximum considered frequency to ensure that no reflections due to unmatched line termination invalidate the measurement.
2) Extraction of the dielectric material parameters from the measured S-parameters similar to [11], [12].
3) Obtained material parameters are applied to a nominal 2D cross section. The exact 2D geometry is fitted by utilizing an optimization task with the goal to decrease the deviation between simulation and reference result. For this work, the software ANSYS 2D Extractor [19] was used.
4) Verification of the material properties by measurement and 3D simulation (this work used EMCoS Hybrid MTL solver [22]) with the actual wire length and twisting.

For the automotive FLRY-A $0.5\,\mathrm{mm}^2$ TWP mostly used in this work, the described procedure resulted in $\varepsilon_r = 3.354$ and $\delta_{\text{loss}} = 0.0178$, in contrast to the expected values for PVC of $\varepsilon_r = 2.7$ and $\delta_{\text{loss}} = 0.007$.

B. Discussion of Limitations

The methodology described by Fig. 1 involves two drastic simplifications: First, the cross section is assumed to be constant over the whole length of the harness. Second, the RLCG/m parameters are extracted at a single frequency point, although it is well known that they are frequency dependent. This is mainly due to the dielectric properties of the cable insulation material, namely the dielectric loss tangent $\tan(\delta)$ and skin effect. The issue is visualized by Fig. 2 for two materials with different values of $\tan(\delta)$. The coupling capacitance C_{12} and conductance G_{12} between wires are influenced by $\tan(\delta)$, but the deviation of C_{12} over frequency is negligible. Due to the vast frequency dependency of the conductance a LCTL model based on the extraction at a certain frequency cannot be broadband. For above described method of extracting RLCG/m from the harness cross section a solution frequency needs to be chosen. The problem is the p.u.l. parameters need to be exact at the DC point if the resulting LCTL model should be usable for transient simulations. Unfortunately, a low extraction frequency will yield incorrect simulation results at high frequencies.
Besides the change of inter-wire conductance G_{12}, Fig. 2 also shows the increase of series resistance R_s within $500\,\mathrm{MHz}$ which can be explained by the skin effect. Note that it is no function of the insulation material. The impact of the deviation of R_s from $0\,\Omega$ to $2.5\,\Omega$ is negligible compared to the impact of increasing G_{12} from $0\,\mathrm{mS}$ to $2\,\mathrm{mS}$, i.e. the isolation resistance from infinite to only $500\,\Omega$.
For the materials values used in Fig. 2, Fig. 3 shows simulations of the forward transmission S-parameter S_{21} when respective dielectric properties are applied to a harness made from three similar TWPs. The dielectric loss leads to deviations increasing with frequency. The results shown in Fig. 3 were obtained with EMCoS Hybrid MTL solver [22] which is able to generate LCTL models reflecting frequency dependencies. With the proposed workflow this is not yet possible. Measurements on two types of TWP cables were conducted to investigate the consequence by experiment. Fig. 4 gives S_{21} of an $1\,\mathrm{m}$ Ethernet cable in comparison to an automotive FLRY-A $0.5\,\mathrm{mm}^2$ type. It is visible, that the attenuation of the latter increases rapidly with frequency, while that of the Ethernet cable stays constant. The figure also shows the simulation results obtained with the proposed minimalistic LCTL model which neglects the frequency dependency of the insulation material. The conclusion is, that the presented modeling approach can work very well, as long as the considered cable type is frequency stable.

IV. Verification

The proposed methodology is verified with an experimental setup of three FLRY-A $0.5\,\mathrm{mm}^2$ TWPs above a large ground plane and in between metallic fixtures as illustrated by Fig. 5.

A. Frequency domain (FD): S-parameters

Results from S-parameter simulation and measurement are compared in Fig. 6. Two measurement results of forward transmission factors S_{21} and S_{65} are exemplified to display the deviation of measurements. One could be tempted to simplify the setup as perfectly symmetric with six equal forward

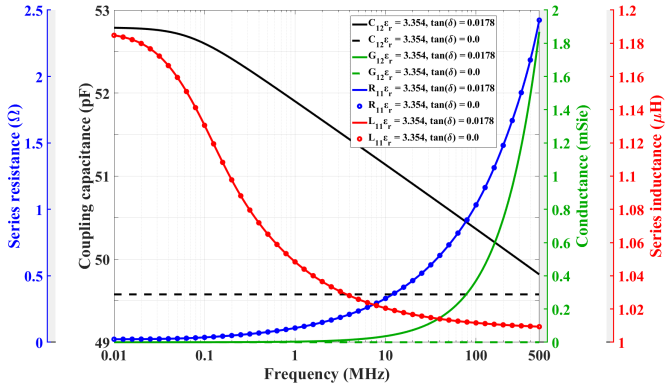


Fig. 2. S_{21} of single TWP above ground plane: Frequency dependency of p.u.l. series inductance L_{11}, coupling capacitance C_{12} and conductance G_{12} between wires and series resistance R_s as function of dielectric loss tangent $\tan(\delta)$ of the insulation material. Data extracted from frequency sweep based on a single 2D cross section, using ANSYS 2D Extractor [19].

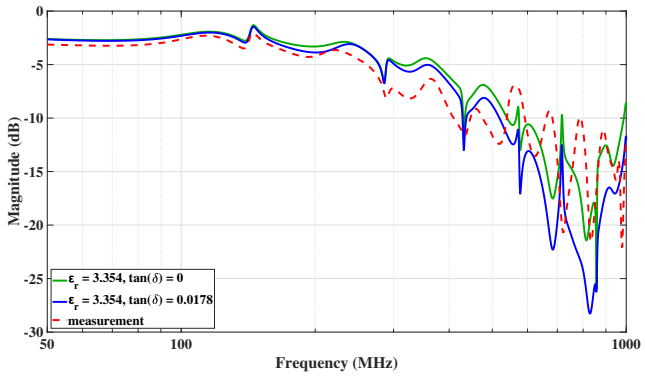


Fig. 3. S_{21} of 1 m bundle of three TWP in between metallic fixtures and above a large ground plane (setup of Fig. 5): Impact on insulation material properties ε_r and $\tan(\delta)$ on simulation result. Simulations conducted with EMCoS Hybrid MTL solver [22].

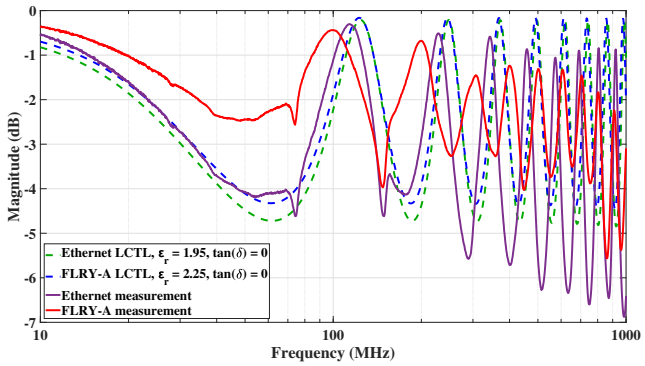
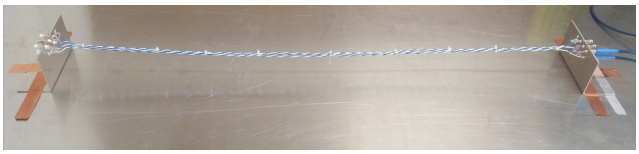
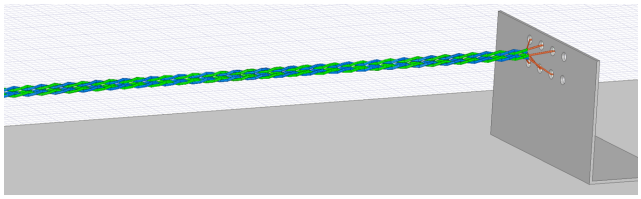


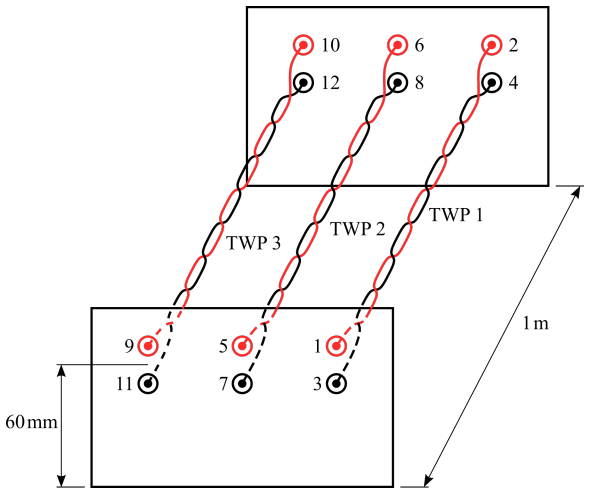
Fig. 4. Comparison of two types of TWP: Ethernet cable versus automotive FLRY-A. Shown is the forward transmission S_{21} of 1 m TWP, where one of the wires is the GND reference. The Ethernet cable is more frequency stable. The idealized LCTL model neglects frequency dependent dielectric loss, hence it does not reflect the differences between the cables.



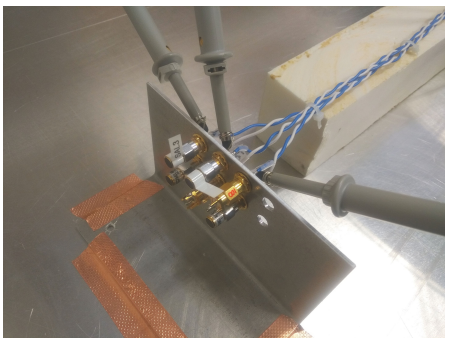
(a) Measurement setup



(b) 3D simulation setup (ANSYS HFSS)



(c) Definition of ports and dimensions



(d) Termination of ports for time domain measurement with voltage probes.

Fig. 5. Measurement and simulation setup for bundle of 3 TWP above ground plane [18]. During FD simulation, the fixture is respected by either including it to the 3D model or with an equivalent circuit. In TD simulation it has no noteworthy impact due to the limited bandwidth.

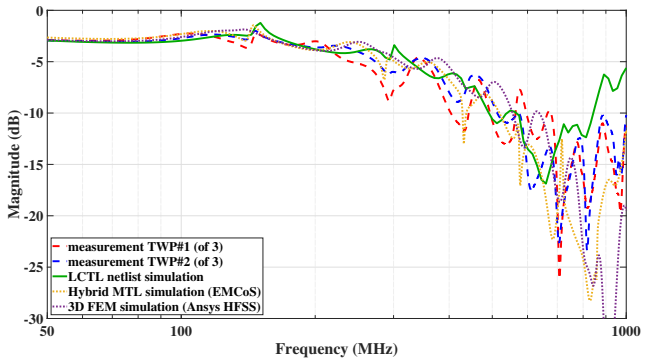


Fig. 6. S-parameter Measurements for forward transmission (S_{21}, S_{65}). Comparison of measurement results with simulation using the proposed workflow, 3D FEM (ANSYS HFSS) or Hybrid MTL (EMCoS).

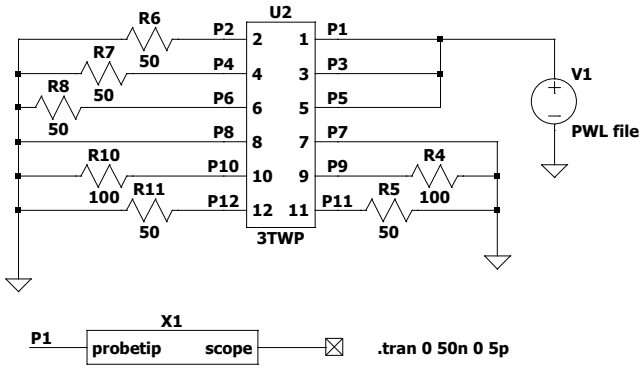


Fig. 7. Simulation schematic used for transient simulations. Stimuli is a piecewise linear (PWL) file of the signal captured at respective ports in the real measurement. Component U2 is the LCTL netlist of the cable bundle consisting of 3 TWP. The subcircuit X1, detailed by Fig. 8, models the impact of an oscilloscope probe. For clarity, only one of four instances is depicted in this schematic.

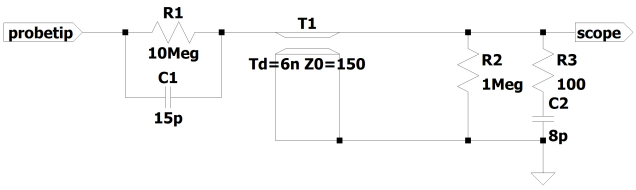


Fig. 8. Subcircuit for oscilloscope probe inspired by [24].

transmission factors but in reality, none of it equals another. The green trace 'LCTL netlist simulation' gives the result obtained with the presented approach. Additional simulations were conducted with the commercial 3D EM software tools ANSYS HFSS (FEM) and EMCoS (Hybrid MTL). It can be observed, that all of the simulation results are within $\pm 5\,\mathrm{dB}$ of the measurement result for frequencies up to $700\,\mathrm{MHz}$. An extension of the frequency range is possible with higher model generation effort but was outside the scope of this work. Note that using FEM, simulation time is in the range of hours and significantly affected by the model's level of detail, hence the solution's accuracy.

B. Time Domain (TD): Transient Pulses

To validate the usability and correctness of the generated netlist for transient simulation in time domain, an experiment with different terminations at the 12 ports of the three TWP harness as sketched in Fig. 7 was set up. Fig. 5(c) depicts the physical setup where ports 1-4 belong to TWP1, ports 5-8 to TWP2 and ports 9-12 to TWP3. Fig. 5(d) shows the measurement of port voltages with standard $500\,\mathrm{MHz}$ oscilloscope probes. In simulation their influence on the measured signal is modeled by the equivalent circuit of Fig. 8. At ports 1,3 and 5 a broadband ($> 1\,\mathrm{GHz}$ bandwidth) pulse of $2\,\mathrm{ns}$ and $2.5\,\mathrm{V}$ with $5\,\mathrm{MHz}$ repetition rate was injected. The resulting pulse form is shown in the bottom subplot of Fig. 9. The fast rise time of the pulse guarantees well observable distortions at all other ports of the harness.

- Injection to TWP1 at ports P1 and P3 mimics common-mode (CM) disturbance into symmetric termination (2x $50\,\Omega$ at P2 and P4). This represents e.g. the idle-stated outputs of a symmetric line driver.
- One wire of TWP2 is grounded, while the other is terminated by $50\,\Omega$. This condition represents e.g. a single-ended driver topology.
- TWP3 is on both sides terminated with different ohmic loads. Here common-mode to differential-mode conversion by coupling between cables is investigated. The voltages induced to P10 and P12 are higher than these at P9 and P11 due to the lower resistance values. (For brevity, only the voltages at P10 and P12 are plotted in Fig. 9.)

Simulations were conducted with the free SPICE simulation software LTspice [23] using either the SPICE netlist generated by the methodology described in Section III or the equivalent circuit output of the Hybrid MTL task processed with EMCoS. The comparison in Fig. 9 shows generally good agreement between measurement and both modeling approaches in both voltage amplitudes and time delay. Note that the measurement's bandwidth was limited by the use of standard $500\,\mathrm{MHz}$ probes. Hence, the big deviations at higher frequencies observable from Fig. 6 have no impact on the TD results. A repetition of this experiment with higher bandwidth probes is planned for future investigations.

V. Conclusion

In this work, different approaches to obtain (equivalent circuit) models of cable harnesses were discussed with respect to their usability for transient circuit simulations. The advantage of physically meaningful LCTL models is, that they are reliably stable and usable with any circuit solver. As a matter of fact, the parameters of real harnesses are typically poorly defined or extremely variable, especially concerning the dielectric properties of the cable's insulation and the cross section of the harness composition over its full length. It was shown that the main parameter leading to frequency dependent p.u.l. parameters RLCG/m(f) is the dielectric permittivity $\varepsilon_r(f)$ of the insulation material. In the considered frequency range, slight variations in cross section or skin effect had a minor impact. Due to the frequency dependency it is generally not possible to generate a simple but nonetheless accurate and broadband TL model based on 2D extraction of the RLCG/m coupling matrix at only one single frequency point. However, even though frequency dependency of the isolation material

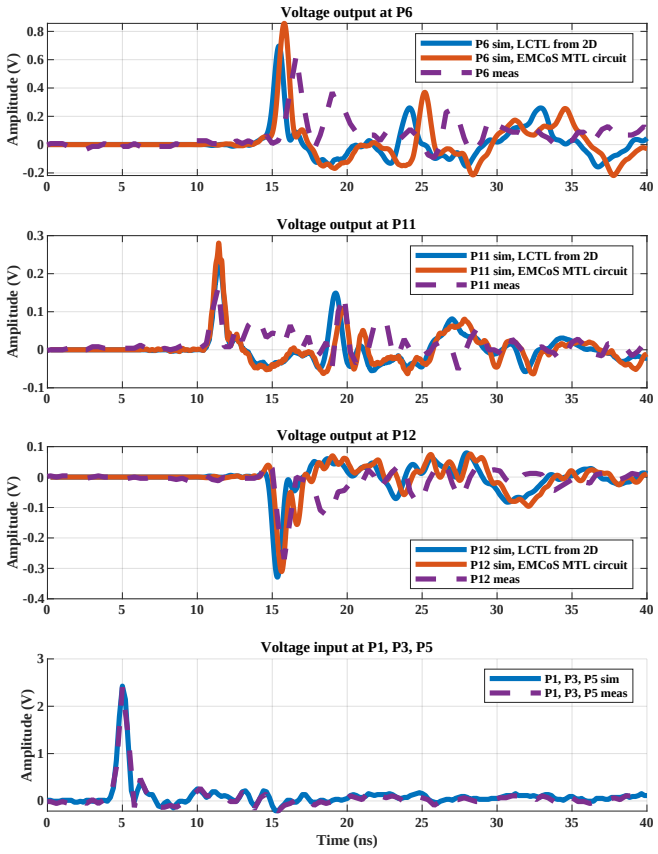


Fig. 9. Comparison of selected simulated and measured time-domain voltage signals for the setup of Fig. 7.

was not taken into account for the proposed simplified LCTL modeling approach, simulation results of similar accuracy as those obtained from 3D MTL or FEM simulation could be achieved in case of a harness of multiple TWP. That is because the spread of measurement results from a realistic harness is even bigger than the variation introduced by neglecting material properties in simulation.

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Time-Domain Response Simulation of Incident Field Coupling to Transmission Lines

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***Abstract*—This paper presents an analysis of time-domain electromagnetic (EM) field coupling to transmission lines. The time-domain 3D EM simulation of the field-to-line coupling system is performed using the uniform plane wave excitation defined by the broadband Gaussian pulse. An analytic background is given to justify usage of the simulated time-domain response as an impulse response of the field-to-line coupling system. The simulated impulse response relates the induced voltages at the transmission line terminals to the EM plane wave excitation. By knowing the impulse response it is possible to predict induced terminal voltages for arbitrarily defined time-domain EM fields. This approach is validated by measurements of the EM field coupling in a transverse electromagnetic mode (TEM) cell and on a printed circuit board (PCB) transmission lines. Very good agreement is obtained between the measured results and results obtained by the convolution for various orientations of the transmission lines and various load impedances.**

***Index Terms*—EM field coupling, TEM cell, transmission lines, incident electromagnetic field, transient analysis, measurements, convolution.**

I. Introduction

Important parts of a complete electromagnetic compatibility analysis (EMC) are emission and immunity pre-compliance tests related to the electromagnetic (EM) radiation. The EMC radiation test set-up for integrated circuits usually comprises the printed circuit board (PCB) populated with electronic devices inserted into the wall of a transverse electromagnetic mode (TEM) cell. These tests are usually performed according to standardized procedures, i.e., IEC 61967-2 [1] and IEC 62132-2 [2]. The TEM cell test set-up offers a low-cost alternative to measurements over an open-area test site (OATS) as called for by various standards [3]. In the shielded environment of the TEM cell, the PCB can be exposed to the transverse EM field (immunity) or it can couple to the transverse EM propagating mode (emission). The transverse EM field mimics a uniform plane wave incident field due to some distant radiating source such as radio and television transmitters, radars, lightning, or generators of nuclear electromagnetic pulse (NEMP) and high-power microwave (HPM). The accurate analysis of the coupling between the PCB traces and an EM field is of great importance. This enables prediction of the induced voltages and currents on the trace which can severely degrade signal integrity and system performance, and potentially even permanently damage sensitive components.

There are number of algorithms developed for estimating the amplitude of the voltage and currents induced on transmission line terminals due to plane EM field illumination [4]–[6]. These algorithms are usually developed for simple transmission lines having a uniform cross-section. Modeling in the frequency domain using a transfer function for the field-to-line coupling system is presented in [7], [8]. The transfer function and the incident field frequency spectrum are used to calculate the spectrum of the induced voltages. A thin-wire model of a microstrip (MS) trace is used to accelerate frequency-domain EM simulations in [9]. The limitation of this method is that the same effective dielectric constant is used for all traces on the PCB. In [10] the prediction of the time-domain response at the transmission line terminals using the impulse response of the field-to-line system is successfully demonstrated. However, there is no analytic explanation as to how to use the simulated time-domain response as the impulse response of the field-to-line coupling system.

In this paper a very efficient finite difference time-domain (FDTD) 3D EM simulator is employed to simulate the impulse response of the field-to-line coupling system for arbitrarily shaped transmission lines. In Section II the analytic background is given for the interpretation of the results obtained from the 3D EM simulator as the impulse response of the field-to-line coupling system. Section III explains the measurement set-up used to validate the proposed approach. Several PCB transmission lines inserted in TEM cell are arbitrarily oriented and terminated in various load impedances for verification.

II. Impulse Response of Field-to-Line Coupling System

For a given impulse response $h(t)$ of a linear time-invariant system, the output signal $y(t)$ can be obtained for an arbitrary defined input $x(t)$ by the convolution as

$$y(t) = \int_0^\infty h(\tau)x(t-\tau)\mathrm{d}\tau. \tag{1}$$

The plane wave excitation in 3D EM solvers is usually defined by a Gaussian pulse. The time-domain width of the Gaussian pulse is defined by the maximum simulation frequency f_{max}. Fig. 1 presents three different Gaussian pulses defined for maximum frequencies of 25, 50 and 100 GHz. In this example the maximum simulation frequency f_{max} corresponds to the -20 dB point in the Gaussian pulse frequency-domain spectra $H_{EM}(f)$. For a given maximum

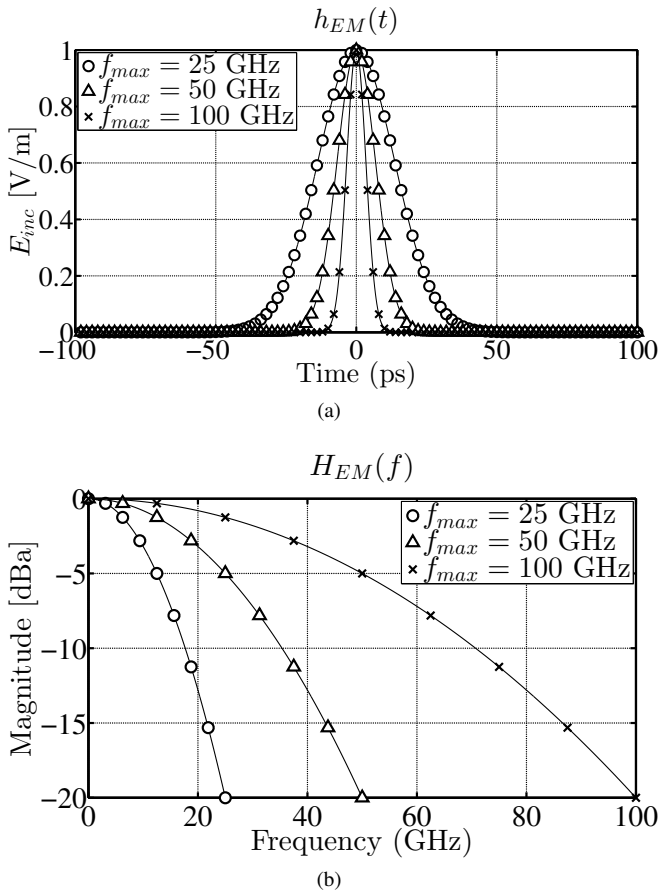


Fig. 1. The Gaussian pulse for three different maximum simulation frequencies $f_{max} = 25, 50$ and 100 GHz: a) $h_{EM}(t)$ in the time domain and b) $H_{EM}(f)$ in the frequency domain.

simulation frequency f_{max} the time-domain Gaussian pulse is calculated in [V/ms] as

$$h_{EM}(t) = |E_{inc}| \frac{\sqrt{\pi}}{a} \exp(-\frac{\pi t}{a})^2, \tag{2}$$

where $|E_{inc}|$ is the magnitude of the incident field and a is a constant given by

$$a = \sqrt{\frac{-\ln(H_{EM}(f_{max}))}{f_{max}^2}}. \tag{3}$$

The higher the maximum simulation frequency f_{max} the smaller the width of the Gaussian pulse. For high values of f_{max} the plane wave excitation of the field-to-line coupling system can be thought of as Dirac pulse excitation. To consider the voltage monitored at the transmission line terminal as an impulse response of the field-to-line coupling system, the area under the excitation pulse should be equal to one. Nevertheless, the area under the Gaussian pulse is not equal to one since the magnitude of the plane wave excitation is defined by the $|E_{inc}|$ value. The area A under the Gaussian pulse for $|E_{inc}| = 1$ V/m for three different maximum simulation frequencies f_{max} is presented in Table I.

The voltage obtained at the monitored end of the transmission line h_{end} represents the impulse response of the system for that particular line end. The impulse response h_{end} obtained from the EM simulator should be normalized by the area

TABLE I
THE AREA UNDER THE GAUSSIAN PULSE USED FOR EXCITATION IN EM SIMULATOR.

f_{max}	25 GHz	50 GHz	100 GHz
A [V/m] = $\int_{-\infty}^{\infty} h_{EM}(t)\mathrm{d}t$	3.42447e-11	1.71223e-11	8.56117e-12

A calculated for chosen Gaussian pulse as $\hat{h}_{end} = h_{end}/A$, resulting in a measurement unit [(V/ms)/(V/m)=1/s].

By knowing the normalized impulse response of the system $\hat{h}_{end}$, the induced voltage at the monitored line end u_{end} can be calculated for any type of the disturbance $x(t)$ by using the discrete version of the convolution integral

$$u_{end}[k] = \sum_{i=1} \hat{h}_{end}[i\Delta T]\Delta T \cdot x[i\Delta T - k], \tag{4}$$

where ΔT is the sampling time used for sampling the impulse response and the input signal, and i is the sample number.

III. VALIDATION

A. Measurement Set-Up

The measurement set-up is presented in Fig. 2. The step signal voltage source (S) is connected to the TEM cell input port. The step signal is generated using the Tektronix SD-24 time-domain transmissiometry/reflectometry head capable of launching the signal with a voltage swing of 250 mV and rise time of 30 ps. The far-end port of the TEM cell is terminated in 50 Ω.

The TEM cell used in this work is FCC-TEM-JM2 [11]. This TEM cell operates up to 1.65 GHz. The cell has a square opening on the top wall, allowing for the placement of the equipment under test (EUT), which is usually a PCB. For the TEM cell used in this work, the PCB size is 10 cm by 10 cm (opening is 9.1 cm by 9.1 cm). The TEM cell width is 148 mm and the height is $2d = 90$ mm. The septum thickness is 1 mm and the width is 102 mm.

The oscilloscope used in this set-up is the Agilent DSA80000B having a bandwidth of 6 GHz and a sampling rate of a 40 GS/s. The oscilloscope has 50 Ω inputs. The

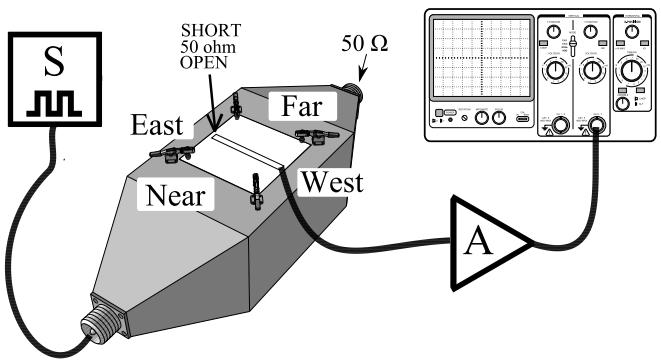


Fig. 2. Measurement set-up. The oscilloscope is connected to one end of the line, while the other end of the transmission line is shorted, left open or terminated in 50 Ω. The TEM cell is connected to the step signal generator and terminated in 50 Ω.

amplifier (A) used is the Aronia UBBV2 with 40 dB gain in the frequency range from 1 MHz to 10 GHz.

B. 3D EM Simulation of Impulse Response

The modeling here is performed in a 3D EM simulator [12] using the FDTD algorithm. The absorbing boundary conditions are realized in each direction by 7 perfectly matched layers (PML). The simulations are performed by using CUDA GPU Acceleration (2×GeForce GTS 450) and the time effort for all simulated lines is ≈5 min. for $f_{max} = 25$ GHz.

Fig. 3 presents the simulation set-up for a conductor-backed coplanar waveguide (CPW-CB). The simulations are performed for two different excitations: endfire and broadside. The endfire excitation is equivalent to the TEM cell measurement set-up when the PCB line position is longitudinal (Fig. 3), while the broadside excitation is equivalent to the case when the PCB line position is transversal (Fig. 2). In both cases the electric E-field-to-line coupling is constant (E-field vector remains perpendicular to the line), while the magnetic H-field-to-line coupling is maximized for the endfire excitation and minimized for the broadside excitation.

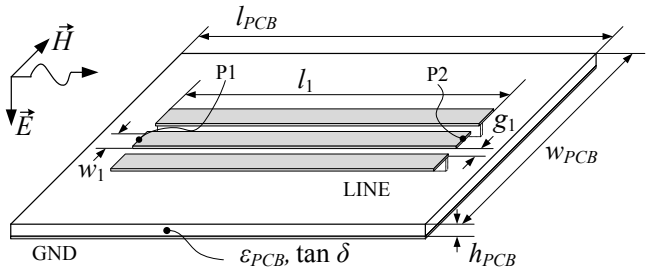


Fig. 3. 3D EM simulation set-up for endfire excitation to the CPW-CB line. Ports P1 and P2 are terminated in 50 Ω.

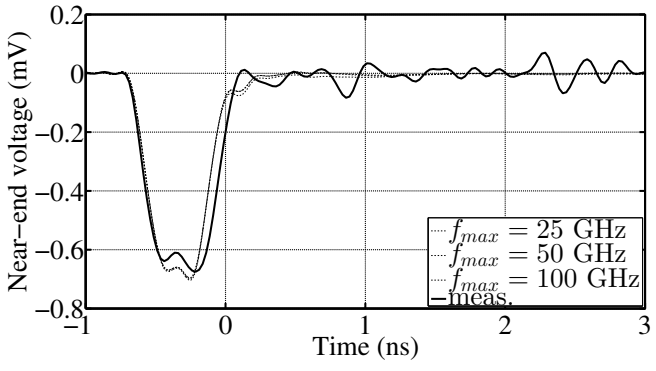
The impulse responses, i.e. the voltage responses at the transmission line terminals, are calculated using lumped ports, denoted as P1 or P2 in Fig. 3. The ports are defined between the line end and the ground plane (GND). In this paper the impulse response is monitored at one 50 Ω port, while the other port is also 50 Ω, shorted or disconnected (open).

The excitation is performed by a uniform plane wave defined in the time-domain by a Gaussian pulse (2). Several maximum simulation frequencies are chosen to test the validity of the presented approach. The amplitude of the $|E_{inc}|$ field vector component perpendicular to the line is equal to 1 V/m while the amplitude of the other components is equal to zero.

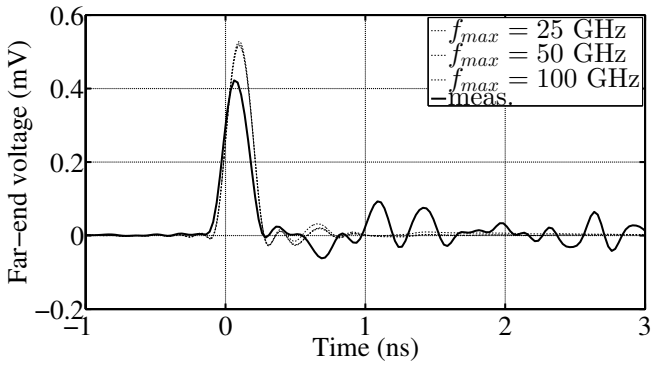
The electric field $|E_{inc}|$ in the TEM cell increases proportionally to the TEM cell input voltage u_{in} as $|E_{inc}| = u_{in}/d$, where d is the distance between the septum and the PCB. The simulated impulse response $\hat{h}_{end}$ is obtained for a 1 V/m magnitude of the incident electric field $|E_{inc}|$. In order for these simulation results to hold in the TEM cell excited by 1 V at its input, the normalized impulse response should be divided by the distance d between the septum and the PCB as $\hat{h}'_{end} = \hat{h}_{end}/d$.

C. Test Case: Simple CPW-CB Line

The first test case is a CPW-CB designed on FR-4 substrate having right-angle surface-mount SMA connectors at the terminals. Design parameters of the transmission line are defined according to Fig. 3: $w_1 = 1.4$ mm, $g_1 = 0.3$ mm, $l_1 = 50$ mm, $h_{PCB} = 1.55$ mm and $\varepsilon_{PCB} = 4.5$. The 3D EM simulation is performed using a lossless substrate $tan\delta = 0$ and using perfect electric conductor as the line and ground plane material. The PCB dimensions are $w_{PCB} = l_{PCB} = 100$ mm. The near-end and the far-end ports of the MS line (P1 and P2 according to Fig. 3) are terminated in 50 Ω.



(a)



(b)

Fig. 4. Comparison of the measurement results and results obtained by convolution for endfire excitation of a simple CPW-CB line at: a) near-end and b) far-end. Line is terminated in 50 Ω. The signal measured at the TEM cell input port is convolved with impulse response obtained for three different simulation frequencies f_{max}.

Fig. 4 presents the comparison of the measurement results and the results obtained by the convolution using three different impulse responses obtained for various max. simulation frequencies f_{max}. The measured step signal at the input port of the TEM cell is convolved with impulse response. Since the cut-off frequency of the TEM cell is equal to 1.65 GHz, the convolution results are filtered in time-domain by a RC low-pass filter having the same cut-off frequency. The reasoning behind the filtering is that in the TEM cell only the TEM mode is efficiently coupled to the transmission line. The presented results show very good agreement regardless the value of the frequency f_{max}. The agreement between the simulation results and the measurement results is very good, in spite of not including the losses in the impulse response simulation set-up.

D. Test Case: Meander MS Line

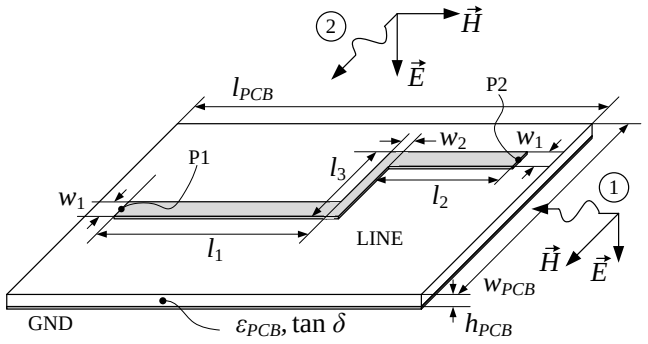
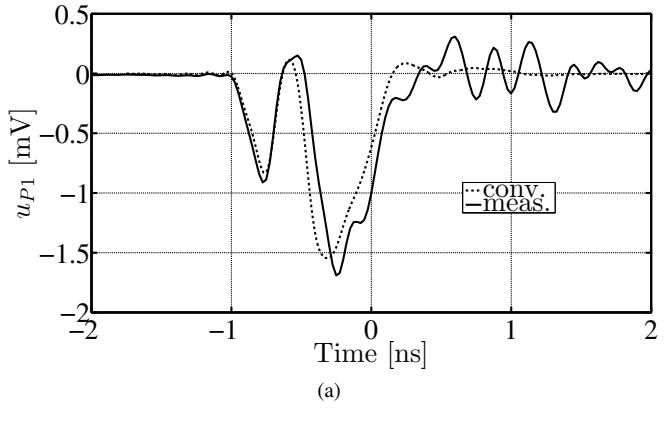
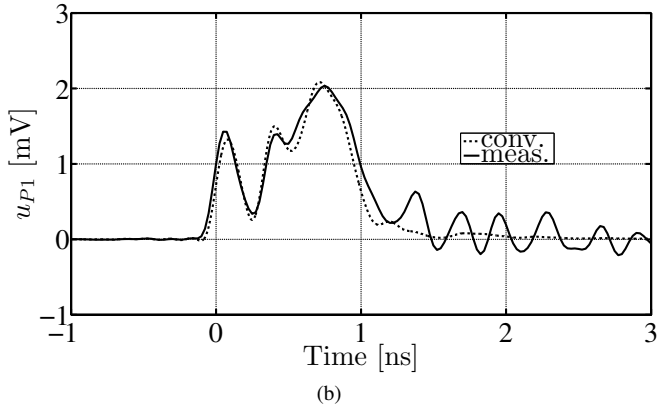


Fig. 5. 3D EM simulation set-up for a meander MS line. Two types of excitation are taken into account: (1) endfire and (2) broadside.

The second test case is a meander MS line on FR-4 substrate having right-angle through-hole SMA connectors at the terminals. Design parameters of the transmission line are defined according to Fig. 5: $w_1 = 2.6$ mm, $w_2 = 1.5$ mm, $l_1 = 40$ mm, $l_2 = 10$ mm, $l_3 = 22.6$ mm $h_{PCB} = 1.55$ mm and $\varepsilon_{PCB} = 4.5$. The 3D EM simulation (f_{max} =25 GHz) is performed using a lossy substrate $tan\delta = 0.02$ and using 35 μm thick copper (σ=5.8e7 S/m) as the line and ground plane material. The PCB dimensions are $w_{PCB} = l_{PCB} =$ 100 mm.



(a)



(b)

Fig. 6. Comparison of the measurement results and results obtained by convolution for: a) broadside excitation and P2 left open and b) endfire excitation and P2 shorted.

Fig. 6 presents the comparison of the measurement results and the results obtained by the convolution for the meander MS line. For two different line orientations as well as for different loading conditions the agreement between presented results is very good. The disagreement between the measurement and simulation results is attributed to the SMA connector-to-transmission line transition. This transition introduces additional delay for the measured results compared to the simulation results. In addition, this transition also represents a discontinuity in terms of characteristic impedance and introduces ringing in the measured response.

IV. Conclusion

The impulse response of the field-to-line coupling system can be obtained in a 3D EM simulator. The acceleration algorithms available for FDTD solver enable efficient calculation of the impulse response for complex shaped lossy transmission lines. This approach is verified by measurements performed in a TEM cell. The agreement between the measurements and the simulation results is very good. This approach enables efficient calculation of the time-domain response for an arbitrary shaped transmission line as well as for a user-defined disturbance. Future work will try to assess limitation of this approach in extended frequency range where non-linear effects of a transmission line play important role.

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A simple and fast tool for the modelling of inter-symbol interference and equalization in high-speed chip-to-chip interfaces

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***Abstract* – We describe a simulator that based on the architecture of a specified transmission channel (microstrip plus cables) and the main features of transmitter and receiver (impedance, voltage swing, etc.) computes the eye diagram and the bit-error rate of high-speed serial interfaces. Different equalization strategies are included in the model such as feed-forward equalization at the transmitter, continuous-time linear equalization and decision-feedback equalization at the receiver. A user-friendly graphical interface has been implemented to facilitate the use of the program in the lab for the courses of electronics.**

Keywords – Chip-to-chip communications, modelling, equalization

I. INTRODUCTION

Due to the continuing miniaturization of CMOS devices, the number of functionalities integrated on an integrated circuit and its speed have significantly increased over the last decade. The major bottleneck is becoming the communication between different integrated circuits that requires interfaces working up to 56 Gbps with energies per bit as low as 1 pJ [1]. At those rates, inter-symbol interference (ISI) due to the dispersive nature of the channel is the main factor affecting the performance of the interface and demands for complex equalization strategies [2]. These include feed-forward equalization (FFE) at the transmitter (a FIR filter that pre-distorts the transmitted pulses in order to compensate for the distortion introduced by the channel), decision-feedback equalization (DFE) at the receiver (the sequence of received bits is used to correct the analog voltage at the input of the sampler to cancel ISI) and continuous-time linear equalization (CTLE) at the receiver (a peaking amplifier that compensates for the high frequency attenuation of the channel). The interfaces also include algorithms for clock recovery and calibration/adaptation of their parameters, resulting in very complex electronic systems. Designing such systems directly at transistor level is almost impossible so that system level models have been developed to support the design [3]-[5].

In this paper, we describe a model based on the pulse response of the channel that includes an accurate description of the microstrip and of the equalization schemes described above. An efficient algorithm is used to derive the eye diagram and the bit-error probability. Such a tool is useful for an initial system level design of high-speed chip-to-chip interfaces in order to help selecting, e.g. the number of equalization taps, the structure of the CTLE filter and assessing the amount of jitter that can be tolerated. A graphical interface has been developed in order to be employed in the lab of a course on high-frequency electronic systems in the master degree of electronics. In fact, the topic of high-speed interfaces is becoming more and more relevant and should be covered at least at the master level. It is also a topic of interesting didactical implications since it merges know-how in signal theory, control theory, circuit design and signal propagation.

The paper proceeds as follows. The algorithms are described in section II, while the graphical interface is shown in section III. Results for a PCIe interface at 8 Gbps are reported in section IV. Conclusions are drawn in section V.

II. MODEL DESCRIPTION

The algorithm used to derive the eye diagram and the bathtub plot is briefly summarized in the following.

Its starts with a procedure to obtain the pulse response of the system, as sketched in Figure 1.

The microstrip impedance $Z_0(f)$ and the effective dielectric constant are modeled following [6][10]. These parameters are then used to derive the RLCG per-unit-length parameters $r(f)$, $l(f)$, $c(f)$ and $g(f)$, including skin effect and dielectric losses. Telegrapher's equations are used to derive the transfer function

$$H_{line}(f)=\frac{e^{-\gamma L}\left(1+\Gamma_{RX}\right)\left(1-\Gamma_{TX}\right)}{1-\Gamma_{TX}\Gamma_{RX}e^{-2\gamma L}} \qquad (1)$$

where $\gamma=\sqrt{(r+j\omega l)(g+j\omega c)}$, L is the line length and the TX and RX reflection coefficients are computed relative to the frequency-dependent line impedance $\Gamma_{RX/TX}=\left(Z_{RX/TX}-Z_0\right)/\left(Z_{RX/TX}+Z_0\right)$.

CTLE is implemented by multiplying $H_{line}(f)$ with a rational function $H_{CTLE}(f)$ that contains the poles and zeros of the corresponding CTLE filter.

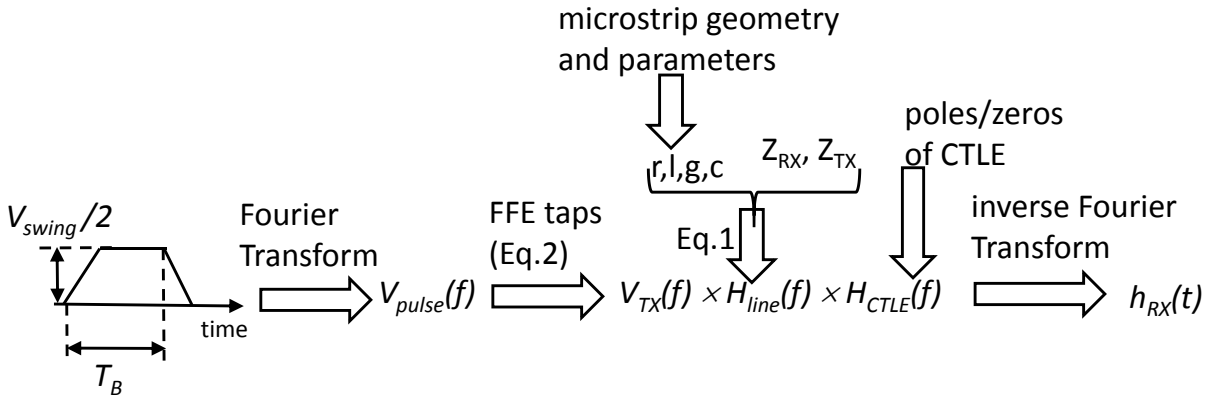

Figure 1 Sketch of the procedure to obtain the received pulse response.

The transmitted pulse is described as a trapezoidal pulse with Fourier transform $V_{pulse}(f)$. FFE is implemented in the frequency domain by considering that a single bit results in many pulses shifted by a bit time T_B and scaled by the tap weight w_n. The Fourier transform of the TX pulse is thus

$$V_{TX}(f) = V_{pulse}(f)\sum_n w_n e^{-j\omega n T_B} \quad . \qquad (2)$$

The inverse Fourier transform of $V_{TX}(f) \cdot H_{line}(f) \cdot H_{CTLE}(f)$ using the method in [11] gives the pulse response $h_{RX}(t)$. The time $t=0$ is set at the maximum of $h_{RX}(t)$.

DFE is modelled by subtracting to $h_{RX}(t)$ rectangular pulses with amplitude equal to the tap weight k_n and duration T_B, centered at $t=nT_B$ (see Figure 2).

The resulting response $h(t)$ to the trapezoidal pulse is used to derive the eye diagram. For a given sampling time t_S, the levels that can be received are all the possible combinations (with positive and negative signs) of the samples $h_n=h(t_S+nT_B)$, where n=0 is the main cursor and the index ranges from negative (pre-cursors) to positive (post-cursors) values [1]. To efficiently compute these levels we consider a permutation matrix similar to a truth table (where the '0' are replaced by -1 due to the differential signaling employed in chip-to-chip communications). For example, for a case with one pre- and one post-cursor:

$$P = \begin{pmatrix} -1 & 1 & -1 \\ -1 & 1 & 1 \\ 1 & 1 & -1 \\ 1 & 1 & 1 \end{pmatrix} . \qquad (3)$$

The product between P and h_n gives all the possible levels corresponding to the sampling time t_S. By defining voltage bins, we can create a histogram that represents the eye corresponding to the '1' bit sampled at t_S. This is denoted as $eye_1(V,t_S)$. The calculation is performed for t_S ranging from $-T_B$ to $+T_B$.

The eye for the '0' bit is just the flipped version of the one for the '1': $eye_0(V,t_S) = eye_1(-V,t_S)$.

To account for jitter, we use the simplified approach in [12] and convolve the eyes with a Gaussian distribution in time.

Finally, the overall eye diagram is given by

$$eye(V,t_S) = \frac{eye_1(V,t_S) + eye_1(-V,t_S)}{2} \quad . (4)$$

while the bathtub (bit-error rate with threshold equal to 0) is given as

$$BER(t_S) = \int_{-\infty}^{0} eye_1(V,t_S)dV \quad . \qquad (5)$$

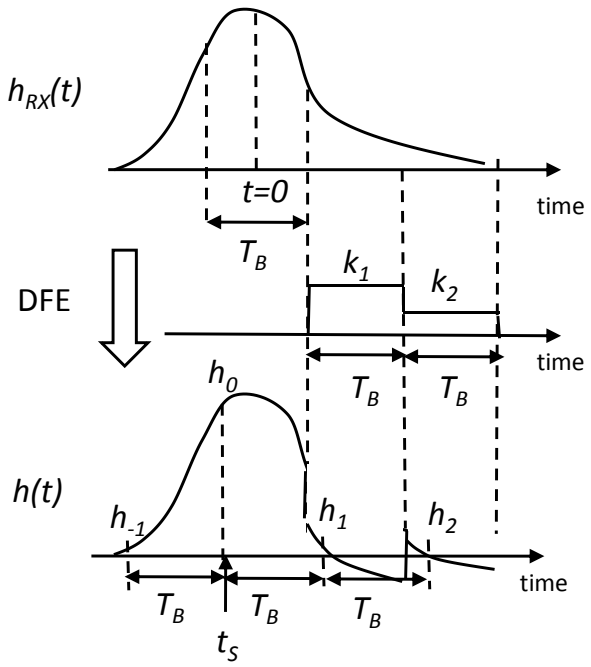

Figure 2 Procedure to derive the overall response to the transmitted pulse by applying DFE to the received pulse.

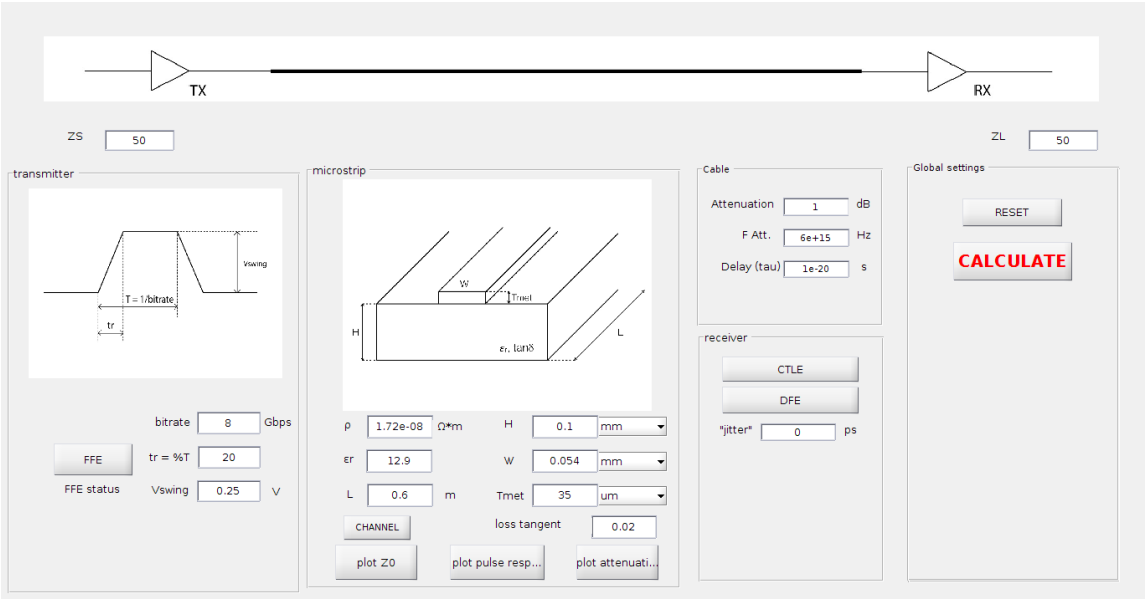

Figure 3 Screenshot of the main window of the graphical interface.

III. GRAPHICAL INTERFACE

The main window of the graphical interface is reported in Figure 3. It allows to enter the parameters of the model described in the previous sections. On top we see the boxes where to type the TX and RX impedance, on the left side the ones for the parameters of the transmitted pulse (bitrate, swing, rise/fall time), in the middle the microstrip parameters. Buttons allow plotting the microstrip's impedance and attenuation vs. frequency, and the overall response to the transmitted pulse. It is also possible to add to the microstrip a cable dominated by skin effect, so that one only needs to specify the attenuation at a given frequency (the other frequencies will be found by extrapolation). The button "CALCULATE" displays the eye diagram and the bathtub plot.

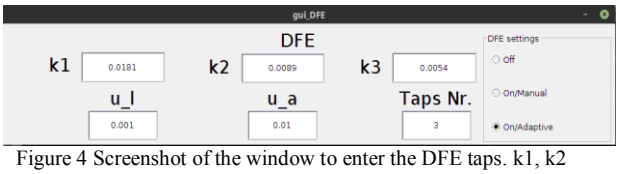

Figure 4 Screenshot of the window to enter the DFE taps. k1, k2 and k3 are the taps (see Figure 2), while u_l and u_a are the parameters of the LMS loop [13].

The equalization parameters are entered in separate windows. For example, the one for DFE is shown in Figure 4. Equalization taps can be entered manually or by emulating a fully-adaptive LMS loop with the procedure described in [13].

IV. RESULTS

To exemplify the possible analyses that can be performed with the model, we consider a template differential channel consisting of two microstrips separated enough to neglect their mutual coupling. They have both approximately 50 Ω impedance and both TX and RX are matched on this value. The material parameters are typical of PCB technology and the length is adjusted so to have the attenuation specified in the PCIe standard for links working at 8 Gbps [14]: 20 dB at the Nyquist frequency of 4 GHz. The voltage swing is set to 0.5 V.

The frequency response of the channel is plotted in Figure 5a and shows the linear dependence with frequency typical of PCB lines dominated by substrate loss. The corresponding response to the transmitted pulse is reported in Figure 5b: the high channel dispersion results in a large number of pre- and post-cursors, demanding equalization. In fact, the eye diagram reported in Figure 6 (top) is essentially closed and the resulting BER (bottom plot) is very high.

We first apply FFE using only two taps (pre- and main-cursor), that is the simplest architecture to implement FFE. We see in Figure 7a that this is not enough to open the eye. When instead 4 taps are used, a significant improvement is observed (Figure 7b), although this requires more complex transmitter architectures [15]. If instead we add DFE to the 2 tap FFE, we obtain the eye in Figure 8a that is largely improved thanks to the reduction of most of the cursors in the transmitted pulse response (Figure 8b). Notice that the pulse response has an amplitude of approximately 40mV and the DFE taps are just a few mV. This means that in a practical implementation, an amplifier should be present before the DFE summer, also to help the slicer.

The effect of timing jitter is analyzed with the bathtub plots in Figure 9: jitter with rms values as low as few ps strongly enhances the BER at the center of the eye. In this model the jitter is just an input parameter. A model to compute the rms value based on the noise of the oscillators and the CDR algorithm is under development.

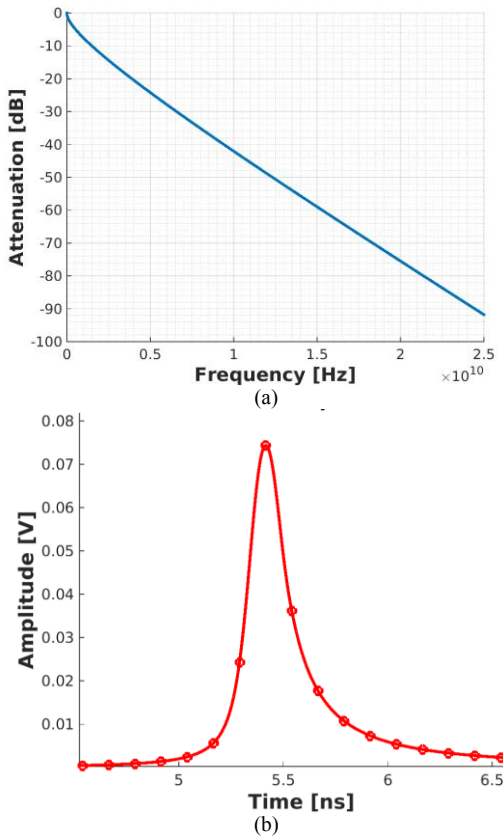

Figure 5 (a) frequency response and (b) response to the transmitted pulse of the template channel employed in the following.

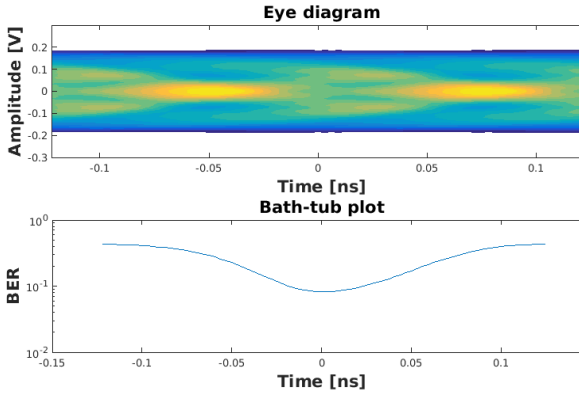

Figure 6 Eye diagram (top) and bathtub plot (bottom) for the channel of Figure 5.

V. CONCLUSION

We have presented a model to evaluate the performance of high-speed chip-to-chip communication interfaces. An efficient probabilistic algorithm is used to compute the eye diagram. As other similar models presented in the literature, such an approach is a powerful alternative to time-domain simulations, that for systems working with BER as low as 10^{-15} require simulating a huge number of bit periods. The effect of the major equalization strategies is included in the model, so that the simulation tool can be used for system level planning of interfaces working with various standard. We reported as an example a PCIe interface working at 8 Gbps, showing

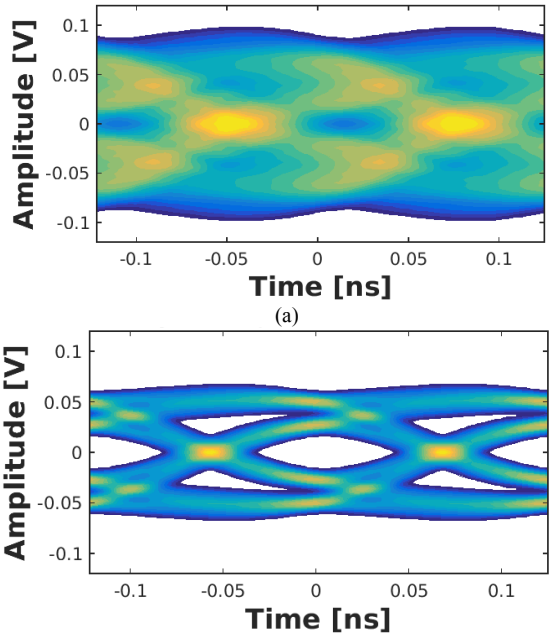

Figure 7 Eye diagrams obtained applying FFE to the channel in Figure 5. Plot (a): w_{-1}=-0.3, w_0=0.7. Plot (b): w_{-1}=-0.2, w_0=0.65, w_1=-0.1, w_2=-0.05.

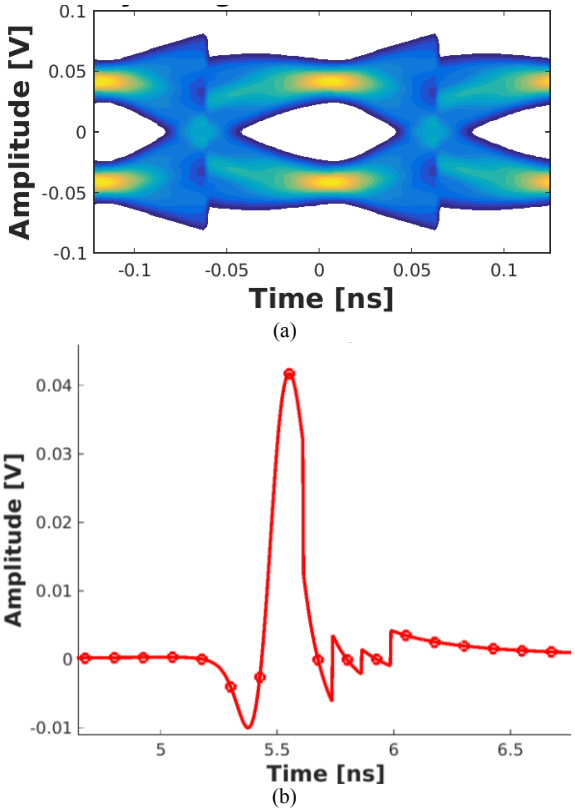

Figure 8 (a) Eye diagram and (b) response to the transmitted pulse for the channel in Figure 5 using FFE (w_{-1}=-0.3, w_0=0.7) and DFE (k_1=19mV, k_2=9mV k_3=5mV).

that the combination of different equalization strategies is needed to obtain a compliant bit-error-rate. A graphical interface has been developed in order to employ such a tool in the lab of the master degree in electronic engineering.

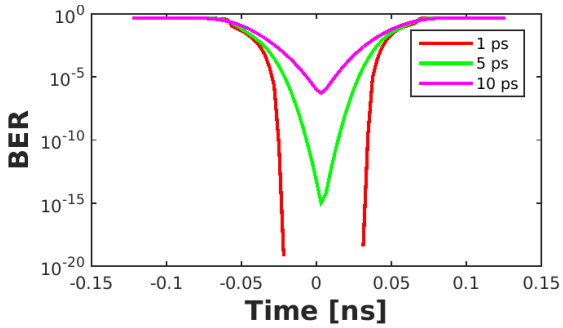

Figure 9 Bathtub plot for the channel in Figure 5 using the same equalization parameters as in Figure 8. Different jitter rms values are specified.

ACKNOWLEDGMENT

We would like to thank prof. Luca Selmi (University of Modena and Reggio Emilia) for support.

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Design of Linear Arrays Forming Pencil Beams Based on Derivatives of Chebyshev Polynomials

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***Abstract*—Polynomial approximation of pencil beam allows the analytical design of linear arrays with a direct control of the sidelobe level. The most popular polynomial approximation is Dolph-Chebyshev. It brings the beam with equiripple sidelobes and, consequently, high power in the sidelobe region. The sidelobe power can be reduced by using the arrays with decaying sidelobes. Such an array is obtained by employing a polynomial with nonequiripple behavior. In this paper, we propose a straightforward method for the design of uniform linear arrays forming narrow beams with decaying sidelobes. The method is based on the polynomial approximation in which an arbitrary order derivative of the Chebyshev polynomial is used. For the given sidelobe level, increasing the order causes a reduction in sidelobe power. A significant reduction is achieved for the derivatives up to the fifth order. However, such behavior deteriorates beamwidth, directivity, and dynamic range ratio.**

I. Introduction

In antenna array design, uniform linear arrays forming pencil beams are usually considered. For their design, various optimization [1]–[7] and analytical [8]–[20] methods have been developed. Despite higher efficiency of the optimization algorithms, the analytical methods are preferable since they ensure fast and robust design.

A well-established analytical approach is polynomial approximation. It allows the design of arrays with a direct control of the sidelobe level. The most popular polynomial approximation is Dolph-Chebyshev. For a given sidelobe level, it brings the beampattern with equiripple sidelobes and practically the narrowest main lobe. However, the Dolph-Chebyshev arrays radiate high power in the sidelobe region and, consequently, produce a beam with low efficiency. The efficiency of Dolph-Chebyshev beam can be improved by using the arrays with decaying sidelobes [10]. Such arrays are usually obtained by employing a bell-shaped function in the spatial domain or by using a polynomial with nonequiripple behavior in the azimuth angle domain. Popular bell-shaped functions are the Kaiser window and Gaussian, which are used in the design of Taylor-Kaiser [11], [12] and Gauss [13] arrays. A simple method for the design of Gauss arrays has recently been proposed in [14]. On the other hand, there are several nonequiripple polynomials suitable for the design of low-sidelobe arrays. These are Legendre [15], Gegenbauer [16], [17], second-kind Chebyshev [18], and Hermite [19]. Recently, Pascal polynomials [20] have also been used to improve the Dolph-Chebyshev beam efficiency.

In this paper, we propose an analytical method for the design of uniform linear arrays forming narrow beams with decaying sidelobes. The method is based on the polynomial approximation in which an arbitrary order derivative of the Chebyshev polynomial is used. For the given sidelobe level, increasing the order causes a reduction in sidelobe power. However, such behavior deteriorates beamwidth, directivity, and dynamic range ratio. Therefore, the derivative order can be used as a discrete design parameter which controls the beam performances. A special case is the first order derivative which results in the second-kind Chebyshev arrays [18].

II. Derivatives of Chebyshev Polynomials

A pth order derivative of the nth-order Chebyshev polynomial of the first kind is given by [21]

$$\frac{d^p T_n(x)}{dx^p} = 2^p n \sum_{k=0}^{\lfloor (n-p)/2 \rfloor} (n-1-k)^{\underline{p-1}} \binom{p+k-1}{p-1} T_{n-p-2k}(x) - [\![n-p \text{ even}]\!]\, 2^{p-1} n \left[(n+p)/2-1\right]^{\underline{p-1}} \binom{(n+p)/2-1}{p-1} \tag{1}$$

where $\lfloor u \rfloor$ denotes the greatest integer equal to or smaller than u, $x^{\underline{n}} := x(x-1)\ldots(x-n+1)$, and $[[P]]$ is Iverson's symbol which is 1 if P is true and 0 otherwise. It is clear that the derivative in (1) is the polynomial of order $n-p$. To obtain the derivative corresponding to an nth order polynomial, the Chebyshev polynomial of order $n+p$ needs to be differentiated. Such a derivative thus has the form

$$D_{n,p}(x) = \frac{d^p T_{n+p}(x)}{dx^p} = 2^p (n+p) \sum_{k=0}^{\lfloor n/2 \rfloor} (n+p-1-k)^{\underline{p-1}} \binom{p+k-1}{p-1} T_{n-2k}(x) - [\![n \text{ even}]\!]\, 2^{p-1} (n+p)\, (n/2+p-1)^{\underline{p-1}} \binom{n/2+p-1}{p-1} \tag{2}$$

It is clear that an even-order polynomial $D_{n,p}(x)$ is expressed by using only even-order Chebyshev polynomials, whereas an odd-order polynomial contains

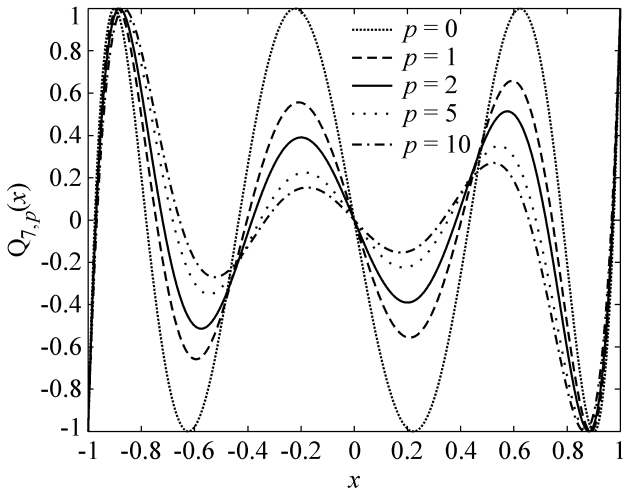

Figure 1. Modified *p*th order derivatives of Chebyshev polynomials, which result in polynomials of seventh order, together with seventh-order Chebyshev polynomial which is denoted as $p = 0$.

only odd-order Chebyshev polynomials. Furthermore, the choice for p is independent of the choice for n. Therefore, p represents a discrete parameter of polynomial $D_{n,p}(x)$.

The polynomial in (2) possesses the maximum deviation $D_{\max} = D_{n,p}(x_{\max})$ in the ripple region $|x| \le x_p$, where $x_{\max} < x_p$. $D_{\max}$ can be found using the first derivative of $D_{n,p}(x)$. Since $D_{n,p}(x)$ has $n-1$ local extrema, its derivative has $n-1$ real roots. The largest root corresponds to $x_{\max}$. On the other hand, the edge x_p is found by solving the polynomial equation

$$D_{n,p}(x) + D_{\max} = 0 \tag{3}$$

The equation has n roots of which the largest real root is x_p.

For the design of arrays, we need the polynomial having unity maximum deviation within the ripple region $|x| \le 1$. Therefore, the polynomial in (2) is modified. The modified polynomial has the form

$$Q_{n,p}(x) = -\frac{D_{n,p}(x_p x)}{D_{\max}} \tag{4}$$

Polynomial $Q_{n,p}(x)$ satisfies $Q_{n,p}(1) = 1$. In addition, for $n \le 3$ and arbitrary p, it is equal to the Chebyshev polynomial of the first kind. On the other hand, for $p = 1$, it corresponds to the nth-order Chebyshev polynomial of the second kind.

To illustrate the behavior of polynomials in (4), let us consider the derivatives with $p = 1$, 2, 5, and 10, which result in the seventh order polynomials. The maximum deviations and edges of ripple region of the derivatives are obtained as $D_{\max} = -14.666$, $-2.1431\text{e+}2$, $-1.0870\text{e+}6$, and $-8.8856\text{e+}12$, and $x_p = 0.9503$, 0.9034, 0.7903, and 0.6668, respectively. Figure 1 shows the obtained polynomials, assuming case $p = 0$ corresponds to the Chebyshev polynomial of the seventh order. It is clear that the polynomials have nonequiripple behavior within the interval $[-1, 1]$. Moreover, increasing p causes a decrease in the ripples placed in vicinity of zero. The decrease is significant for $p \le 5$. Such behavior is a consequence of the reduction of the rate of change of the original ripples from the interval's boundaries to the origin.

III. Design of pth-Derivative Chebyshev Array

A. Array Factor

Let us consider a symmetrical linear array with N isotropic elements equally spaced by a distance d, whose excitation coefficients have the form

$$\mathbf{h} = \begin{cases} \left[\frac{a_{(N-1)/2}}{2}, \ldots, \frac{a_1}{2}, a_0, \frac{a_1}{2}, \ldots, \frac{a_{(N-1)/2}}{2} \right], & N \text{ odd} \\ \left[\frac{a_{N/2}}{2}, \ldots, \frac{a_1}{2}, \frac{a_1}{2}, \ldots, \frac{a_{N/2}}{2} \right], & N \text{ even} \end{cases} \tag{5}$$

Assuming a single temporal frequency, ω, the array factor is given by

$$H(\omega) = \begin{cases} a_0 + \sum_{k=1}^{(N-1)/2} a_k \cos(k\omega), & N \text{ odd} \\ \sum_{k=1}^{N/2} a_k \cos\left[\left(k - \frac{1}{2}\right)\omega\right], & N \text{ even} \end{cases} \tag{6}$$

Each cosine term in (6) can be expressed as

$$\cos(2ru) = T_{2r}(\cos u) \tag{7}$$

where r is a positive integer and $u = \omega / 2$. By substituting (7) into (6), the array factor takes the form

$$H(u) = \begin{cases} a_0 + \sum_{k=1}^{(N-1)/2} a_k T_{2k}(\cos u), & N \text{ odd} \\ \sum_{k=1}^{N/2} a_k T_{2k-1}(\cos u), & N \text{ even} \end{cases} \tag{8}$$

If the elements are placed along the abscissa, the relationship between the temporal frequency and the azimuth angle θ is given by

$$\omega = \frac{2\pi}{\lambda} d \cos\theta \tag{9}$$

where λ denotes wavelength.

B. Design Procedure

For the given polynomial, the array factor is designed to achieve a desired sidelobe level or first-null beamwidth. Here, we use the former approach. Therefore, the design procedure follows the Dolph-Chebyshev algorithm.

For the given number of elements, N, derivative order, p, and minimum relative sidelobe attenuation, R, expressed in decibels, first we find the point x_0 that meets

$$Q_{N-1,p}(x_0) - r = 0 \tag{10}$$

where

$$r = 10^{R/20} \tag{11}$$

The polynomial equation in (10) has $N-1$ roots of which the largest real root is x_0.

By using the array factor in (8) and x_0, the excitation coefficients are found by solving the problem

$$H(u) = Q_{N-1,p}(x_0 \cos u) \tag{12}$$

Equating coefficients of like powers of $\cos u$ gives the system of linear equations. Let $c_{n,k}$ and $q_{n,k}$ denote the coefficients of $T_n(x)$ and $Q_{n,p}(x)$, which correspond to the power x^k. The solution of the system is given by

TABLE I
COMPARISON OF VARIOUS ARRAY FACTORS HAVING MINIMUM RELATIVE SIDELOBE ATTENUATION OF 20 dB, OBTAINED BY NINE ELEMENTS WITH SPACING OF $\lambda / 2$

Parameter	**Dolph-Chebyshev**	**Gauss**	***p* = 1**	**Taylor-Kaiser**	***p* = 2**	**Pascal and *p* = 16**
3dB-beamwidth	**12.5°**	**13.0°**	**13.1°**	**13.1°**	13.5°	14.4°
First null beamwidth	**30.5°**	31.8°	32.1°	32.2°	33.1°	35.7°
Directivity	**9.36 dB**	**9.26 dB**	**9.24 dB**	**9.23 dB**	9.14 dB	8.86 dB
Relative sidelobe power	3.20 %	1.71 %	1.53 %	1.51 %	**1.19 %**	**0.96 %**
Dynamic range ratio	**1.66**	**2.15**	**2.27**	**2.29**	**2.70**	4.35

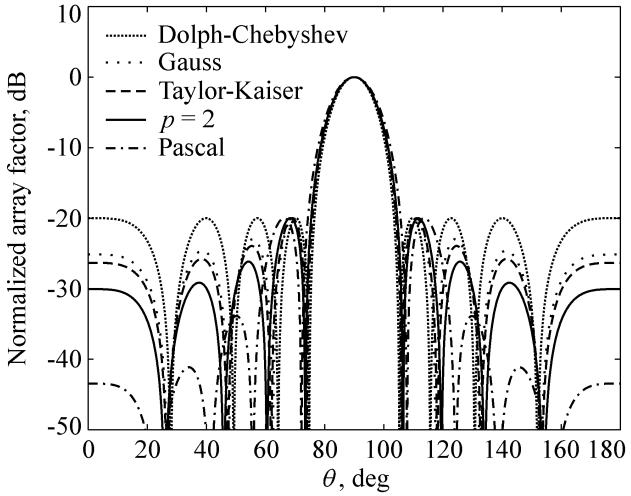

Figure 2. Normalized factors of Dolph-Chebyshev, Taylor-Kaiser, Gauss [14], Pascal [20], and second-derivative Chebyshev arrays having nine elements with spacing of $\lambda / 2$, assuming minimum sidelobe attenuation is 20 dB.

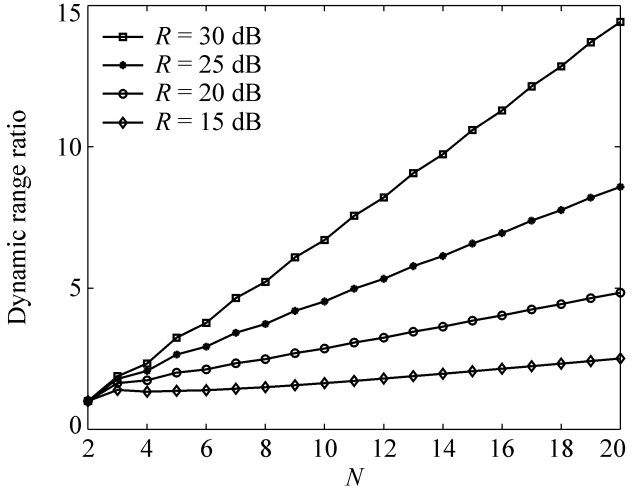

Figure 3. Dynamic range ratios obtained by second-derivative Chebyshev arrays with N elements, providing minimum relative sidelobe attenuation R.

$$a_{(N-1)/2} = x_0^{N-1} \frac{q_{N-1,N-1}}{c_{N-1,N-1}} \tag{13}$$

$$a_m = \frac{x_0^{2m} q_{N-1,2m} - \sum_{k=m+1}^{(N-1)/2} a_k \, c_{2k,2m}}{c_{2m,2m}} \; ; \; m = 0, 1, \ldots, \frac{N-1}{2} - 1 \tag{14}$$

for an odd N, and

$$a_{N/2} = x_0^{N-1} \frac{q_{N-1,N-1}}{c_{N-1,N-1}} \tag{15}$$

$$a_m = \frac{x_0^{2m-1} q_{N-1,2m-1} - \sum_{k=m+1}^{N/2} a_k \, c_{2k-1,2m-1}}{c_{2m-1,2m-1}} \; ; \; m = 1, 2, \ldots, \frac{N}{2} - 1 \tag{16}$$

for an even N.

An example of MATLAB code for the design of pth-derivative Chebyshev arrays is given in the Appendix.

IV. DESIGN EXAMPLES

Let us design the second-derivative Chebyshev array with nine elements equally spaced by $d = \lambda / 2$, providing the sidelobe level of 20 dB. The coefficients obtained are $a_0 = 1.502$, $a_1 = 2.889$, $a_2 = 2.542$, $a_3 = 1.954$, and $a_4 = 1.114$. Figure 2 shows the corresponding array factor together with the factors of the Dolph-Chebyshev, Taylor-Kaiser, Gauss [14], and Pascal [20] arrays meeting the same requirements. All factors are normalized to ensure unity gain at $\theta = 90°$. The Taylor-Kaiser and Gauss factors exhibit better sidelobe behavior than Dolph-Chebyshev, but they have a larger beamwidth. On the other hand, the Pascal factor has very low far-out sidelobes. However, it is paid by a wide beam. The proposed factor gives a good balance between sidelobe behavior and beamwidth, and it sits between the Taylor-Kaiser and Pascal factors. The 3dB-beamwidth, directivity, power in the sidelobe region relative to the total power, and dynamic range ratio of the described factors are given in Table I. The performances of the arrays with $p = 1$ and $p = 16$ are also tabulated. It is clear that the performances obtained for $p = 1$ are similar to Taylor-Kaiser, whereas for $p = 16$ they are close to Pascal.

Figure 3 shows the dynamic range ratios of the second-derivative Chebyshev arrays having $2 \le N \le 20$, obtained for $R = 15$ dB, 20 dB, 25 dB, and 30 dB. For $N \le 4$, the ratios are equal to the Dolph-Chebyshev ratios. For $N > 4$, the ratios obtained increase with an increase in N. However, for $N \le 20$, the ratios less than 10 are obtained by the arrays with $R \le 25$ dB.

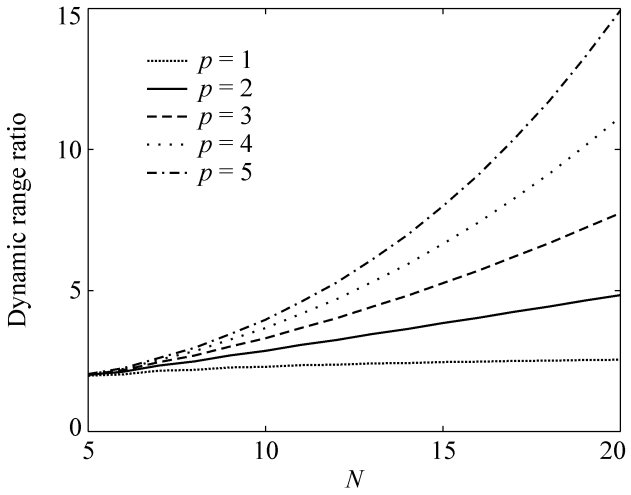

Figure 4. Dynamic range ratios obtained by *p*th-derivative Chebyshev arrays having N elements, assuming minimum relative sidelobe attenuation is 20 dB.

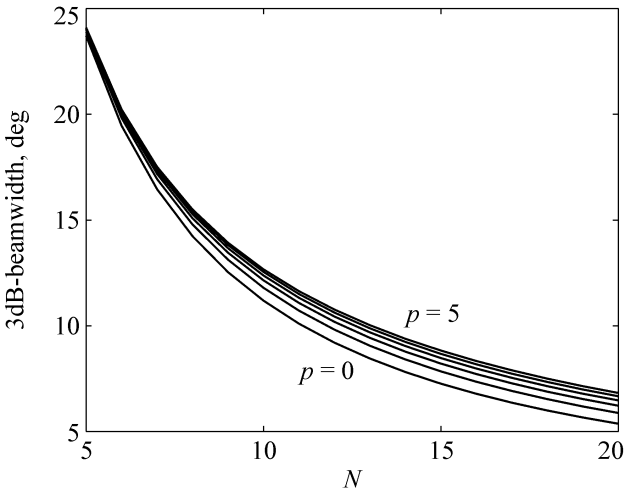

Figure 6. 3dB-beamwidths obtained by *p*th-derivative Chebyshev arrays having N elements with spacing of $\lambda/2$, assuming minimum relative sidelobe attenuation is 20 dB. Case $p = 0$ corresponds to Dolph-Chebyshev arrays.

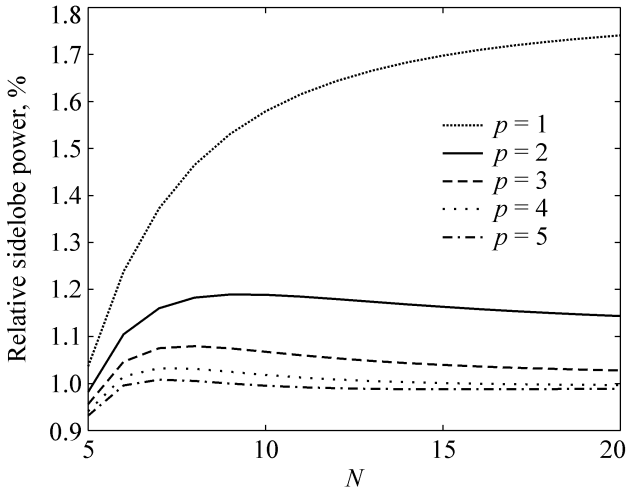

Figure 5. Relative sidelobe power obtained by *p*th-derivative Chebyshev arrays having N elements with spacing of $\lambda/2$, assuming minimum relative sidelobe attenuation is 20 dB.

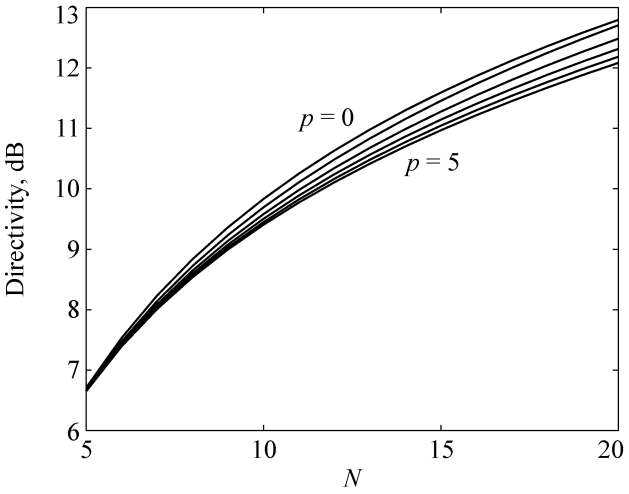

Figure 7. Directivities obtained by *p*th-derivative Chebyshev arrays having N elements with spacing of $\lambda/2$, assuming minimum relative sidelobe attenuation is 20 dB. Case $p = 0$ corresponds to Dolph-Chebyshev arrays.

The reduction of sidelobe power usually deteriorates dynamic range ratio. Figure 4 shows the ratios of the proposed arrays with $5 \le N \le 20$ and $R = 20$ dB, obtained for $1 \le p \le 5$. It is clear that increasing the derivative order causes an increase in the ratio. However, for the derivatives with $p \le 5$, the ratios less than 10 are obtained for $N \le 16$. Figure 5 shows the corresponding relative sidelobe power, assuming $d = \lambda/2$. It is clear that a significant power reduction is made for $p \le 3$. Moreover, for $N \ge 9$ and $p = 5$, the relative power is less than 1 %, thus resulting in the efficiency greater than 99 %.

Figures 6 and 7 show the 3dB-beamwidths and directivities of previously described arrays together with the beamwidth and directivity of the Dolph-Chebyshev counterpart, which are denoted as $p = 0$. Considering the derivatives up to the fifth order, slight deteriorations in the beamwidth and directivity are present for a small number of elements. However, for a large array, their degradations are more noticeable.

V. Conclusion

A straightforward method for the design of uniform linear arrays forming pencil beams was presented. The method is based on the polynomial approximation in which higher order derivatives of the first-kind Chebyshev polynomials are used. The arrays obtained bring decaying sidelobes, whose power is reducing by increasing the derivative order. Considering the beam with the minimum sidelobe level of 20 dB, the arrays having up to 16 elements, obtained by the derivatives up to the fifth order, provide relative sidelobe power less than 1.8 % and dynamic range ratio less than 10.

Appendix
MATLAB Code for Array Design

In this section, we provide an example of MATLAB code for calculating the coefficients of the symmetrical *p*th-derivative Chebyshev array. The function is called

pthder_cheby. Its input parameters are the number of elements N, $N > 1$, the derivative order p, $p > 0$, and the minimum relative sidelobe attenuation R expressed in decibels. The function returns the coefficients of the array.

```
function h=pthder_cheby(N,p,R)

% matrix of Chebyshev polynomial coefficients
C=zeros(N,N);
for n=1:N
 if n==1; c=1;
 elseif n==2; c=[0,1];
 else
  k=2; cN_2=1; cN_1=[0,1];
  while k<n
   c=2*[0,cN_1]-[cN_2,0,0];
   cN_2=cN_1; cN_1=c; k=k+1;
  end
 end
 C(n,:)=[c,zeros(1,N-n)];
end

% coefficients of Dn,p(x), where n=N-1
d=zeros(1,N);
for k=0:floor((N-1)/2)
 d=d+2^p*(N-1+p)*prod((k+1):(p+k-1))*...
   prod((N-k):(N-k+p-2))/prod(1:(p-1))*...
   C(N-2*k,:);
end
if mod(N,2)==1 % N-1 is even
 d(1)=d(1)-2^(p-1)*(N-1+p)/prod(1:(p-1))*...
      (prod(((N-1)/2+1):((N-1)/2+p-1)))^2;
end
d=fliplr(d);

% coefficients of Qn,p(x), where n=N-1
if N==2; q=[1;0];
else
 % first derivative of Dn,p(x)
 d1=d.*(N-1:-1:0); d1=d1(1:end-1);
 % maximum deviation, Dmax
 xmax=max(roots(d1));
 Dmax=d*xmax.^(N-1:-1:0)';
 % edge of ripple region, xp
 xps=roots([d(1:end-1),d(end)+Dmax]);
 xps=xps(real(xps)>0 & imag(xps)==0);
 xp=xps(abs(xps)==max(abs(xps)));
 % coefficients q=[qn ... q1 q0]'
 q=-d.*xp.^(N-1:-1:0)/Dmax; q=q(:);
end

% point x0
r=10^(R/20);
if N==2; x0=r;
else
 x0s=roots([q(1:end-1);q(end)-r]);
 x0s=x0s(real(x0s)>0 & imag(x0s)==0);
 x0=x0s(abs(x0s)==max(abs(x0s)));
end

% excitation coefficients
L=mod(N,2); M=(N+L)/2;
a=zeros(M,1);
a(M)=x0^(N-1)*q(1)/C(N,N);
for k=(M-1):-1:1
 ind=M:-1:(k+1);
 sk=a(ind)'*C(2*ind-L,2*k-L);
 a(k)=(q((N+1)-2*k+L)*x0^(2*k-L-1)-sk)/...
      C(2*k-L,2*k-L);
end
a(1+L:end)=a(1+L:end)/2;
h=[a(end:-1:(L+1));a];
```

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Noise improvement for different BP filter designs

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***Abstract* - In this paper an analysis of noise through four different approaches to filter design is performed. The voltage noise spectral density and root mean square (RMS) value of noise voltage for the simply designed (SD) active RC, noise optimized (NO) active RC, operational transconductance amplifiers (OTA-C) and switched capacitor (SC) filter design are calculated for fourth-order Chebyshev band-pass filter, with central frequency f_c=4kHz, bandwidth 1kHz and pass band ripple α_{max}=-0.1dB. For the achievement realization of all four designs a cascade of two second order sections are used. The analyses is performed using Matlab and SPICE (LTspice) programming tools.**

Keywords - band-pass filter; noise; SC filter

I. INTRODUCTION

There are different ways to achieve the desired transfer function of the filter. The most commonly used realization is with the operational amplifiers (OA) which gives a stable (solid) voltage point output and also low impedance output. On the other hand, if high impedance output is desired, then realization with general transconductance amplifier (OTA-C) sections will be used. Such design gives us a constant current source on output.

Likewise, one of the realization of the same transfer function can be with switched capacitors (SC) where resistors are replaced with switched capacitors [1, 2]. This realization is good for design in monolithic integrated technology, where the filter is completely implemented in chip using thick and thin film technology.

Except satisfaction of elementary specifications on amplitude and phase filter characteristics, there exist additional parameters of filter quality. One of them is noise. The goal is to reduce noise as much as possible, because with superposition of noise on observed signal the information that the signal transmits can be covered. Through the sections of the paper will be demonstrating how to design filters on above suggested approaches with the desire to reduce noise in filter.

II. REALIZATION

The normed transfer functions of the observed Chebyshev band-pass filter are given by:

$$H(s) = H_1(s) \cdot H_2(s), \tag{1a}$$

$$H_1(s) = \frac{0.4525s}{s^2 + 0.2456s + 0.7066}, \tag{1b}$$

$$H_2(s) = \frac{0.4525s}{s^2 + 0.3475s + 1.415}, \tag{1c}$$

$$H(s) = \frac{0.2048s^2}{s^4 + 0.5931s^3 + 2.207s^2 + 0.5931s + 1}. \tag{1d}$$

The transfer functions of fourth-order Chebyshev band-pass filter sections denormed on a frequency of 4kHz are given by:

$$H(s) = H_1(s) \cdot H_2(s), \tag{2a}$$

$$H_1(s) = \frac{-5.3542 \cdot 10^3 s}{s^2 + 4.1764 \cdot 10^3 s + 7.5469 \cdot 10^8}, \tag{2b}$$

$$H_2(s) = \frac{-6.3969 \cdot 10^3 s}{s^2 + 3.4956 \cdot 10^3 s + 5.2869 \cdot 10^8}, \tag{2c}$$

$$H(s) = \frac{3.4251 \cdot 10^7 s^2}{s^4 + 7.672 \cdot 10^3 s^3 + 1.2979 \cdot 10^9 s^2 + + 4.8462 \cdot 10^{12} s + 3.99 \cdot 10^{17}}. \tag{2d}$$

A. Continuous-time active-RC filters

In Fig. 1 the Single Amplifier Biquad (SAB) topology of the band-pass filter is given.

Realization is performed as a cascade of two second order sections. The circuit transfer function is given as:

$$H(s) = \prod_{i=1,2} H_i(s), \tag{3a}$$

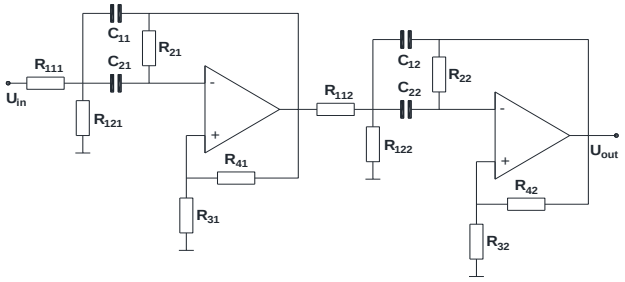


Figure 1. Fourth-order OA band-pass filter

TABLE I. ELEMENT VALUES OF SIMPLY DESIGNED (SD) AND NOISE OPTIMIZED (NO) CONTINUOUS ACTIVE-RC FILTERS [3]

	SD		NO	
	1st section	*2nd section*	*1st section*	*2nd section*
R_{11i}	53.1915 kΩ	44.5208 kΩ	21.3238 kΩ	21.3238 kΩ
R_{12i}	3.9075 kΩ	4.81995 kΩ	1.5299 kΩ	1.8538 kΩ
R_{2i}	3.6401 kΩ	4.3491 kΩ	9.2824 kΩ	11.0902 kΩ
R_{3i}	7.3529 kΩ	7.35294 kΩ	0.9866 kΩ	0.9866 kΩ
R_{4i}	3.9789 kΩ	3.9789 kΩ	3.9789 kΩ	3.9789 kΩ
C_{1i}	10 nF	10 nF	10 nF	10 nF
C_{2i}	10 nF	10 nF	10 nF	10 nF
k_i	1	1	2.55	2.55

$$H_i(s) = \frac{-\left(1+\frac{G_{4i}}{G_{3i}}\right)\frac{G_{11i}}{C_{1i}}s}{s^2 + s\left(\frac{G_{2i}}{C_{1i}} + \frac{G_{2i}}{C_{2i}} - \frac{G_{1i}G_{4i}}{C_{1i}G_{3i}}\right) + \frac{G_{1i}G_{2i}}{C_{1i}C_{2i}}}. \quad (3b)$$

Using given filter parameters, element values can be calculated by comparing equations (2a) to (2c) with (3a) and (3b) with assumptions $C_{1i}=C_{2i}$ and $R_{1i}=R_{2i}$. Values taken over from [3] are given in Table 1.

Fig. 2 shows the frequency responses of the filter. The simulated values of the frequency response are given by simulating circuit shown in Fig.1 using element values from Table 1. Unlike the former, frequency response of calculated values is given by the filter transfer function (2a) to (2c). In the zoomed inset of Fig. 2 there can be seen a minimal difference between these two characteristics (simulated-dashed, calculated-full).

B. OTA-C filter

Realization is performed as a cascade of two second order general transconductance amplifier sections. This circuit is shown in Fig. 3. The circuit transfer function is given as:

$$H(s) = \prod_{i=1,2} H_i(s), \quad (4a)$$

$$H_i(s) = \frac{\left(\frac{g_{m4i}}{C_{2i}}\right)s}{s^2 + s\left(\frac{g_{m3i}}{C_{2i}}\right) + \left(\frac{g_{m1i}g_{m2i}}{C_{1i}C_{2i}}\right)}. \quad (4b)$$

Comparing the equations (4a, 4b) with (2a-2c) element values of OTA-C filter were calculated and shown in Table 2. Frequency responses are shown in Fig. 4.

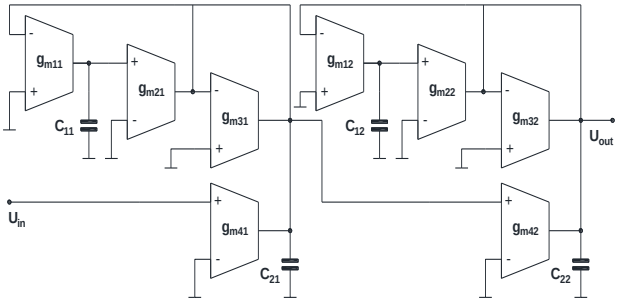


Figure 3. Fourth-order OTA-C band-pass filter

TABLE II. ELEMENT VALUES OF OTA-C FILTER

	1st section	*2nd section*
g_{m1i}	0.27472 mS	0.22993 mS
g_{m2i}	0.27472 mS	0.22993 mS
g_{m3i}	0.041764 mS	0.034956 mS
g_{m4i}	0.053542 mS	0.063969 mS
C_{1i}	100 nF	100 nF
C_{2i}	100 nF	100 nF

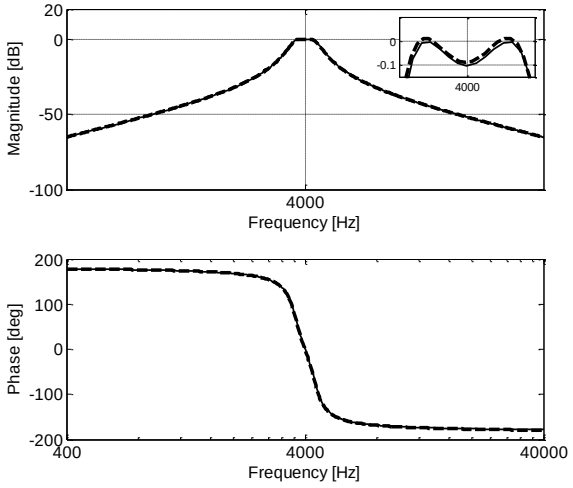


Figure 2. Frequency response of the Fourth-order continuous-time active-RC (SD) band-pass filter

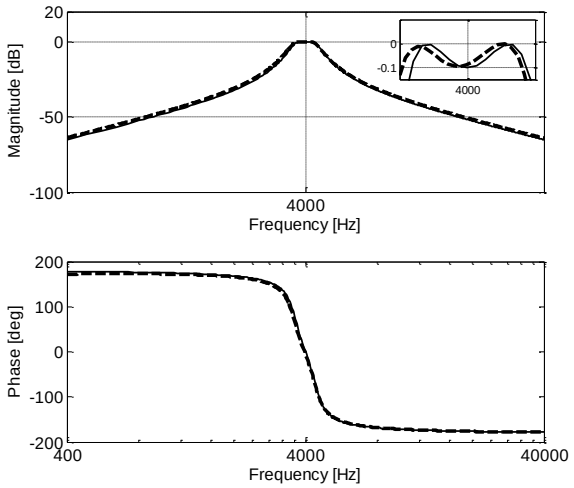


Figure 4. Frequency response of the Fourth-order OTA-C BP filter

C. Discrete time SC filter

The discrete time SC filter based on Sallen-Key (SAK) topology is shown in Fig. 5.

The forward Euler transformation ($s=>(z-1)/T_s$) was applied for calculation of the discrete time transfer function. Where T_s *($f_s=4900f_c$)* is a sampling time and which has been calculated as $T_s=1/f_s$.

$$H(z) = H_1(z) \cdot H_2(z), \tag{5a}$$

$$H_1(z) = \frac{5.8023 \cdot 10^{-4} \cdot (z-1)}{z^2 - 1.9997z + 0.9997}, \tag{5b}$$

$$H_2(z) = \frac{5.8023 \cdot 10^{-4} \cdot (z-1)}{z^2 - 1.9996z + 0.9996}, \tag{5c}$$

$$H(z) = \frac{3.3667 \cdot 10^{-7}\left(z^2 - 2z + 1\right)}{z^4 - 3.9992z^3 + 5.9977z^2 - \\ - 3.9977z + 0.9992}. \tag{5d}$$

The transfer function of discrete time SC filter based on Sallen-Key topology is given by:

$$H(z) = \prod_{i=1,2} G_i \cdot \frac{a_{1i} \cdot (z-1)}{a_{2i} \cdot z^2 - a_{3i} \cdot z + a_{4i}}, \tag{6a}$$

$$G_i = 1 + C_{4i} / C_{5i}, \tag{6b}$$

$$a_{1i} = C_{1i} C_{2i} C_{R1i}, \tag{6c}$$

$$a_{2i} = C_{1i}^2 C_{2i} + C_{1i} C_{2i} C_{R1i} + C_{1i}^2 C_{R2i} \\ + C_{1i} C_{2i} C_{R2i} + C_{1i} C_{R1i} C_{R2i} \\ + C_{2i} C_{R1i} C_{R2i} + C_{1i} C_{2i} C_{Rfi} \\ + C_{1i} C_{R2i} C_{Rfi} + C_{2i} C_{R2i} C_{Rfi}, \tag{6d}$$

TABLE III. ELEMENT VALUES OF SC FILTER

	1st section	*2nd section*
C_{R1i}	37.9 pF	53.7 pF
C_{R2i}	2.82 pF	2.52 pF
C_{1i}	120 nF	120 nF
C_{2i}	3.3 nF	3.3 nF
C_{Rfi}	125.5 pF	313.5 pF
C_{4i}	2.15 nF	1.53 nF
C_{5i}	2.55 nF	5.1 nF

$$a_{3i} = 2C_{1i}^2 C_{2i} + C_{1i} C_{2i} C_{R1i} + C_{1i}^2 C_{R2i} \\ + C_{1i} C_{2i} C_{R2i} + C_{2i} C_{R1i} C_{R2i} \\ + C_{1i} C_{2i} C_{Rfi} + C_{2i} C_{R2i} C_{Rfi} \\ + G_i C_{1i} C_{2i} C_{Rfi}, \tag{6e}$$

$$a_{4i} = C_{1i}^2 C_{2i} + G_i C_{1i} C_{2i} C_{Rf}. \tag{6f}$$

Comparing the equations (5a-5c) with (6a-6f) element values were calculated and presented in Table 3. From Fig. 6 and Fig 2. it can be seen that the Z-transformation hasn't got undesired effects on filter specifications.

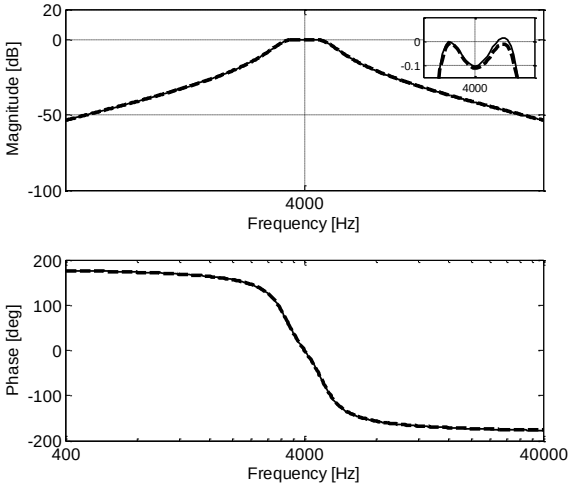


Figure 6. Frequency response of the Fourth-order SC band-pass filter

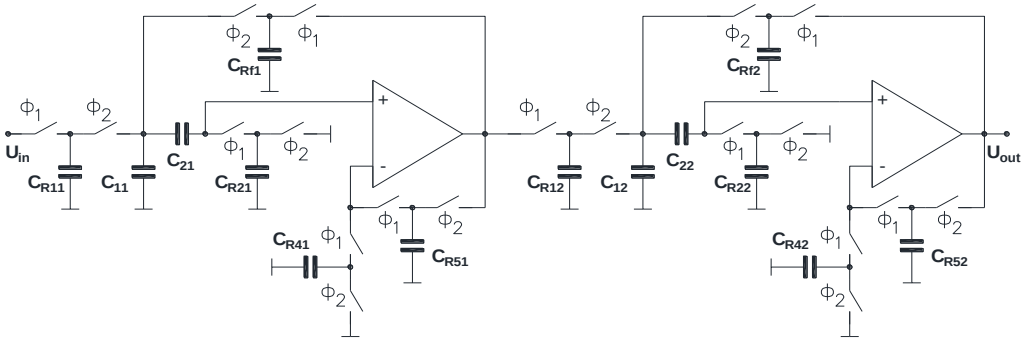


Figure 5. Fourth-order SC band-pass filter (SAK topology)

III. NOISE

A. Noise in filter with OA

Fig 7. shows an equivalent circuit of the active-RC filter for the calculation of the voltage noise spectral density. Parallel to the resistors have been added current noise sources: $I_{ni} = \sqrt{4kT/R_i}$, whilst to the voltage noise sources E_n = 2.5 nV/ √ Hz for LT1007 have been added at the input of the operational amplifiers. The input current noise source of operational amplifiers were neglected, because its values are much smaller than voltage noise sources, for instance I_n=0.4 pA/ √ Hz .

The voltage noise spectral density is calculated by the given equation [4]:

$$V_n^2(\omega) = \sum_{k=1}^{m} \left| T_{I,k}(j\omega) \right|^2 (I_{n,k})^2 + \sum_{l=1}^{n} \left| T_{V,l}(j\omega) \right|^2 (E_{n,l})^2 . \quad (7)$$

In this equation $T_{V,l}$ and $T_{I,k}$ represent the transfer functions of the voltage noise sources $E_{n,i}$ and the current noise sources $I_{n,i}$, respectively. Fig. 8 (a) shows the total voltage noise spectral density while Fig. 8 (b, c) shows noise components for both sections. The differences between simulated and calculated values can be considered as a result of using theoretical values based on thermal noise sources in calculations and real elements noise models using SPICE. The RMS value has been calculated by the equation:

$$(E_n^2)_{ef} = \int_{\omega_1}^{\omega_2} V_n^2(\omega) d\omega . \quad (8)$$

In the desire to reduce voltage noise spectral density of filter we used the optimization algorithm given in [3]. All element values are taken from [3], recalculated and tested in Matlab and SPICE in order to give us smaller noise results. The total voltage noise spectral density of NO filter design is shown in Fig. 9 (a). Noise components for both sections are given through the Fig. 9 (b, c).

Comparing the noise RMS values of filters, we can conclude that optimized filter gave smaller noise RMS value.

B. Noise in OTA-C filter

The equivalent circuit for the calculation of the voltage noise spectral density of the observed OTA-C filter is shown in Fig. 10.

Voltage noise spectral density (7) is calculated. The total voltage noise spectral density components are given in Fig. 11 (a). The differences between simulated and calculated values can be considered as a result of using theoretical values based on thermal noise sources in calculations using MATLAB and real elements noise models using SPICE.

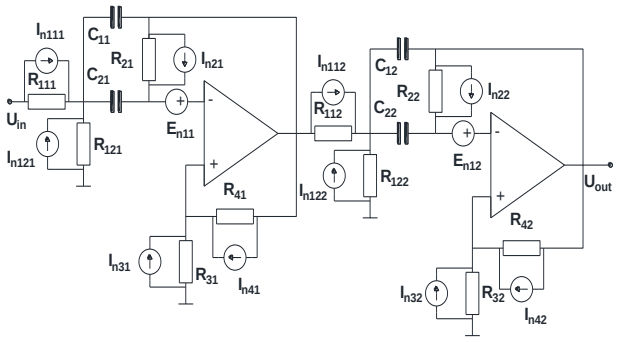


Figure 7. Equivalent electrical noise circuit of the Fourth-order SD and NO band-pass filter

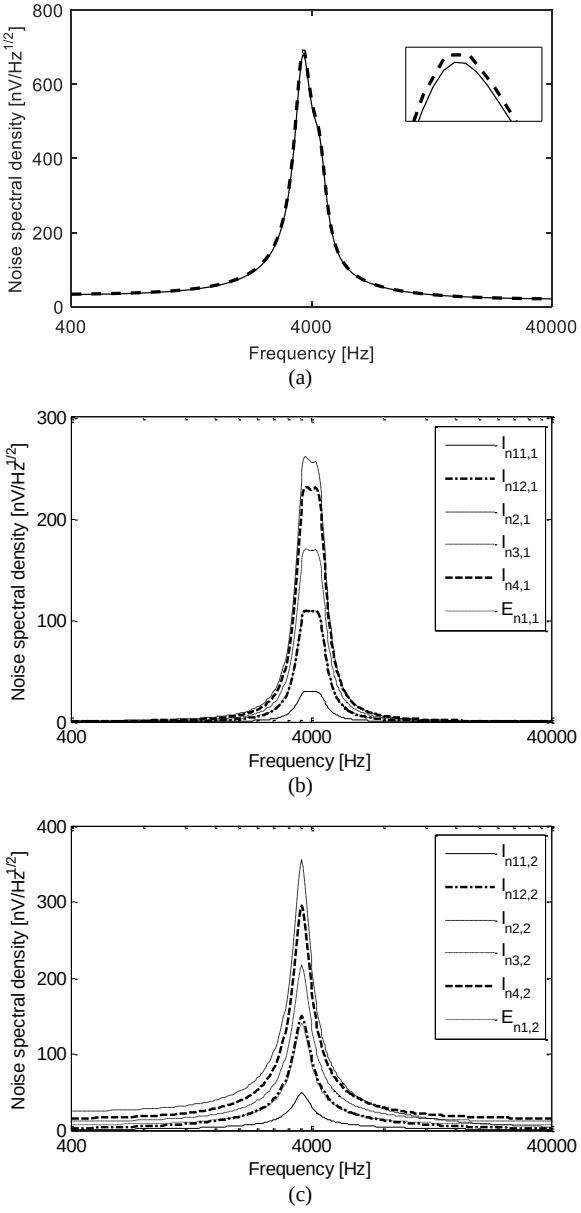
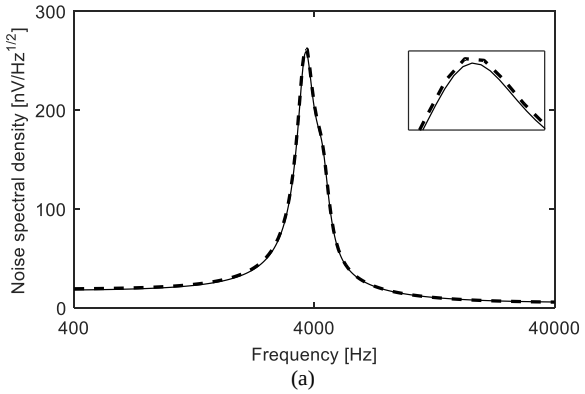
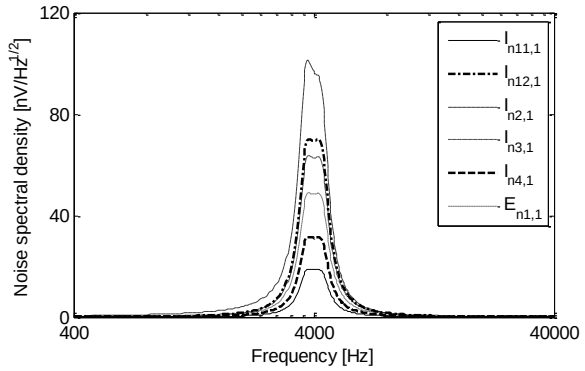


Figure 8. Noise voltage spectral density of Fourth-order SD band-pass filter and its components. (a) Total noise voltage spectral density: simulated (dashed) and calculated (full). Noise RMS value is E_n=54.556μV. (b) Section 1 noise voltage spectral density components. Noise RMS value is E_n=34.805 μV. (c) Section 2 noise voltage spectral density components. Noise RMS value is E_n=42.011 μV.

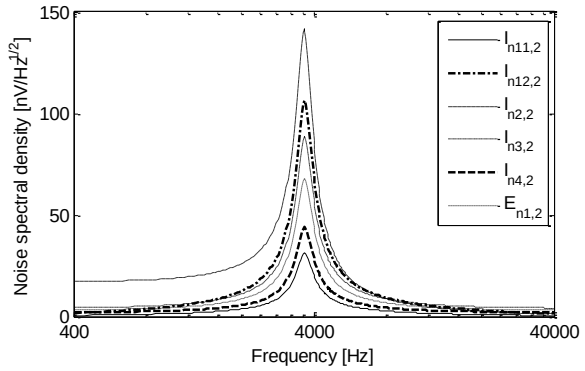
Fig. 11 (b, c) shows noise components for both sections.



(a)



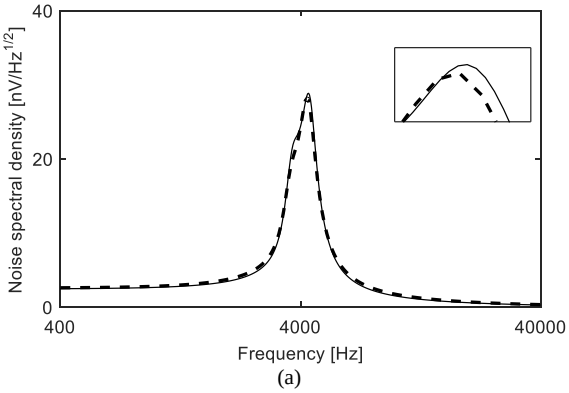
(b)



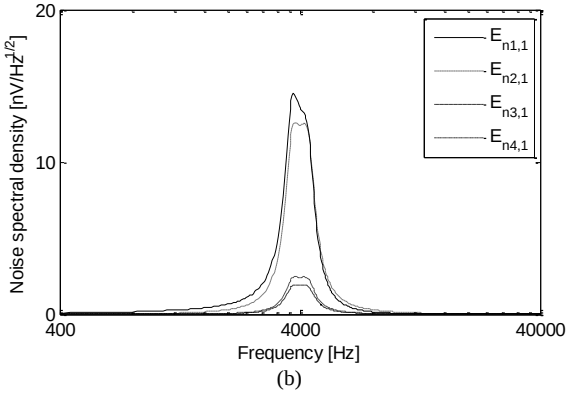
(c)

Figure 9. Noise voltage spectral density of Fourth-order NO band-pass filter and its components. (a) Total noise voltage spectral density: simulated (dashed) and calculated (full). Noise RMS value is E_n=20.412μV. (b) Section 1 noise voltage spectral density components. Noise RMS value is E_n=12.422 μV. (c) Section 2 noise voltage spectral density components. Noise RMS value is E_n=16.197 μV.

LT1228 was used as a transconductance amplifier in this design. The input voltage noise source of this



(a)



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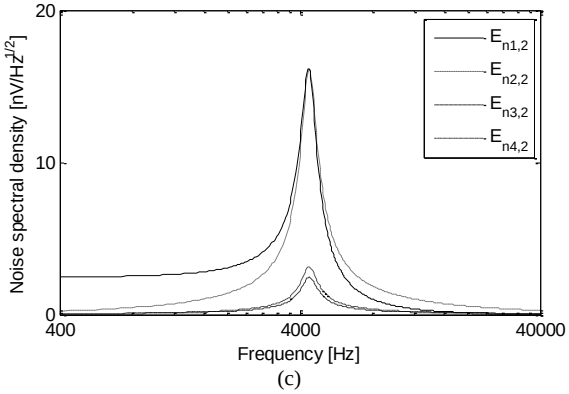

(c)

Figure 11. Noise voltage spectral density of Fourth-order OTA-C band-pass filter and its components. (a) Total noise voltage spectral density: simulated (dashed) and calculated (full). Noise RMS value is E_n=2.4384μV. (b) Section 1 noise voltage spectral density components. Noise RMS value is E_n=1.5715 μV. (c) Section 2 noise voltage spectral density components. Noise RMS value is E_n=1.8645 μV.

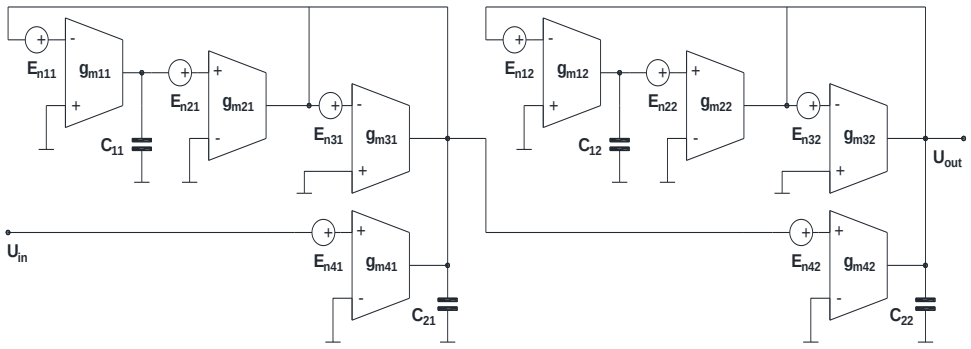

Figure 10. Equivalent electrical noise circuit of the Fourth-order OTA-C band-pass filter

transconductance amplifier is E_n=6 nV/ √ Hz and the input current noise source is I_n=1.4 pA/ √ Hz. The current noise source is much smaller and because of that it was neglected in calculation procedure.

C. Noise in SC filter

The fourth-order SC band-pass filter is shown in Fig. 5. The equivalent circuit for the calculation of voltage noise spectral density is based on [5]. Fig. 12 shows total voltage noise spectral density and its components.

D. Comparison

If the RMS voltage noise value is measured between 0.1fc to 10fc as the indicator of noise reduction,

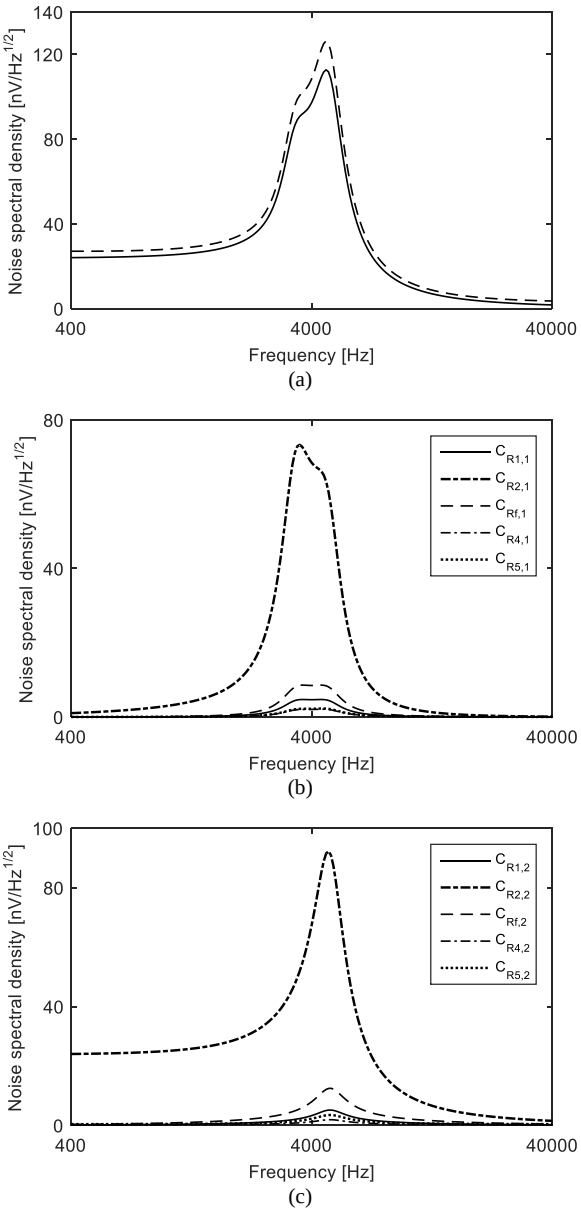

Figure 12. Noise voltage spectral density of Fourth-order discrete time SC band-pass filter and its components. (a) Total noise voltage spectral density: simulated (dashed) and calculated (full). Noise RMS value is E_n=5.3954 µV. (b) Section 1 noise voltage spectral density components. Noise RMS value is E_n=3.2451 µV. (c) Section 2 noise voltage spectral density components. Noise RMS value is E_n=4.3022 µV.

TABLE IV. NOISE RMS VALUE COMPARISON

	SD	***NO***	***OTA-C***	***SC***
E_n	54.556 µV	20.412 µV	2.4384 µV	5.3954 µV

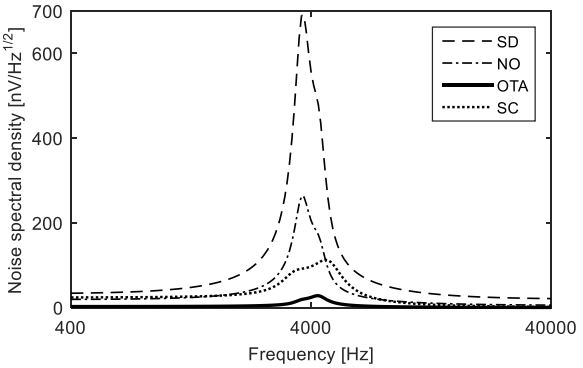

Figure 13. Noise voltage spectral density for: SD (dashed), NO (dashed-dot), OTA-C (full), SC (dot-dot)

comparison of noise in all presented designs is given in Table 4. Fig. 13 shows voltage noise spectral density for all filter designs which are discussed in this paper.

IV. CONCLUSION

In this paper, noise improvement using different filter designs is analyzed. Analyses of four different designs are done. As noise measure RMS voltage noise value is calculated between 400 Hz and 40 kHz. Noise analysis is done for SD and for NO design filters based on operational amplifiers. Noise improvement for NO is 2.5 times. Noise analyses for OTA-C and SC designs are also done. They gave improvement of more than 20 times for OTA-C design in comparison with SD and 10 times for SC design in comparison with SD. In the end, considering RMS voltage noise as a numeric indicator, it is shown that the OTA-C filter design gives the best noise reduction.

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Low-Noise and Low-Sensitivity Coupled Fourth-Order Low-Pass Filters

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***Abstract* - The output thermal noise and sensitivity of the low-pass fourth-order Butterworth filter are reduced by the effect of coupling. The structure as two coupled second-order biquads is compared to the two cascaded second-order biquads structure, where both realize the same low-pass transfer function. The manufacturing technology used to realize the coupled circuit is the same as that of the cascaded, non-coupled circuit. Physical circuits are designed as active-RC filters using multiple-amplifier biquads. The optimization by equating maximum voltage levels at the opamp outputs is presented. First, Pspice simulation investigates an optimum design of the coupled circuit with regard to minimum sensitivity and compares it to the cascaded realization. The sensitivity analysis is performed using Monte Carlo runs. Second, the measurements of the two circuits are performed on the PCB realizations in SMD technology using HP 4195A Network Analyzer in the laboratory setup. The measurement results proof the stability of the coupled filters, although they are using positive feedback. Output thermal noise of the two filter structures is then compared. Substantially reduced values of the output thermal noise is measured for the coupled case.**

Keywords - active filters; analog circuits; circuit synthesis; coupled low-pass biquads; filtering theory; feedback circuits; sensitivity, output thermal noise

I. INTRODUCTION

It has been known for a long time that the negative feedback in geometrically-symmetrical band-pass (BP) filters of fourth order reduce the filters sensitivity to the component tolerances and the output thermal noise [1][2]. In the case of BP filters, two identical blocks inside coupling provided minimum sensitivity and noise. In this paper the same concept is extended to low-pass (LP) filters of fourth order, referred to as "LP biquart". The new design is the first design of coupled LP fourth-order filters, using the same principles that have been applied to BP filters, only. The new design can easily be applied to designing fourth-order high-pass (HP) filters, as well.

It is presented in this paper that to reduce the LP filters sensitivity to passive components, positive feedback must be used. An example on which the sensitivity reduction is performed is Butterworth approximation. It was also shown that to realize the stable poles of the LP filter the positive feedback must be lower than (maximum) critical value, and special care must be taken in filter element calculations, otherwise the filter can become unstable.

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The simulation of filter realizability and stability is first demonstrated using Pspice. The sensitivity analysis was performed using Pspice Monte Carlo runs. The testing of the filter feasibility is then performed by measurements on the discrete component, printed-circuit board (PCB) realization in surface-mount devices (SMD) technology. It was demonstrated by measurements that the filters using positive feedback are stable. The active-RC filters considered, use opamps as active elements.

In the context of the new design of high-order (>>4th-order) filters, it is desirable to realize the noise and sensitivity reduction, if the two pairs of complex-conjugate poles, having highest pole-Q factors, i.e. the four most critical poles, were coupled.

II. POSITIVE-FEEDBACK LOW-PASS FILTERS

A. Cascaded Biquads (CA)

In this paper we construct fourth-order LP filter as a cascade in Fig. 1(a) with the transfer function in the form:

$$T_{CA}(s) = \prod_{i=1}^{2} T_{cai}(s)\,, \tag{1}$$

where $T_{ca1}(s)$ and $T_{ca2}(s)$ are the second-order biquadratic sections with LP voltage transfer functions given by

$$T_{cai}(s) = \frac{k_i \cdot \omega_{pi}^2}{s^2 + \left(\omega_{pi} / q_{pi}\right) \cdot s + \omega_{pi}^2};\ i = 1, 2. \tag{2}$$

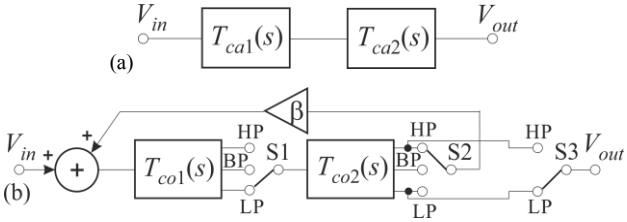

Figure 1. Fourth-order LP filter realization. (a) Cascade. (b) Coupled filter using general-purpose inner biquads (GP).

B. Coupled Biquads (CO)

Coupled biquads, realizing fourth-order LP transfer function will be realized by cascading two general-purpose (GP) biquads (of second-order) and applying a positive feedback, as shown in Fig. 1(b). GP biquads can

realize LP, BP and HP transfer functions, by using different outputs from the same filter block (see inner blocks in Fig. 1(b) with designated outputs LP, BP and HP). It is shown in Fig. 1(b) that in order to obtain overall fourth-order LP transfer function the switches have to be connected as follows: S_1 to LP output of the first biquad, S_2 in the feedback loop to HP, and the overall-output switch S_3 is in the position LP, at the output of the second biquad. In that way proper open-loop transfer function is realized and, as shown below, the positive feedback is needed. Some other combination of switches, such as S_1 to HP, S_2 to LP and S_3 to HP provide fourth-order HP transfer function with the same denominator and the same properties as that of the fourth-order LP filter.

The transfer function of the coupled fourth-order LP filter is in the form:

$$T_{CO}(s)=\frac{T_{co1LP}(s)T_{co2LP}(s)}{1-\beta T_{co1LP}(s)T_{co2HP}(s)}, \tag{3}$$

where $T_{co1LP}(s)$ and $T_{co2LP,HP}(s)$ are the second-order biquadratic sections with LP and HP voltage transfer functions given by

$$T_{coiLP,HP}(s)=\frac{N_{coiLP,HP}(s)}{s^2+\left(\omega_{coi}/q_{coi}\right)\cdot s+\omega_{coi}^2};\ i=1,2;$$
$$N_{coiLP}(s)=k_{coi}\cdot\omega_{cai}^2;\quad N_{coiHP}(s)=k_{coi}\cdot s^2. \tag{4}$$

The negative sign of the feedback gain β in (3) indicates a positive feedback.

Consider 4th-order low-pass Butterworth filter with parameters as in (2) defined by

$$\begin{aligned}&k_1=k_2=1;\\&\omega_{p1}=\omega_{p2}=1;\\&q_{p1}=0.5411961;\\&q_{p2}=1.3065630,\end{aligned} \tag{5}$$

corresponding to the closed-loop poles:

$$\begin{aligned}&s_{p1,2}=-0.3826834\pm j0.9238795;\\&s_{p3,3}=-0.9238795\pm j0.3826834.\end{aligned} \tag{6}$$

To design a LP coupled filter, we must equate (1) and (3), i.e. $T_{CA}(s)=T_{CO}(s)$. By comparing the denominators of (1) and (3) and if *we choose equal blocks inside coupling*, (as in BP case design in [1][2]) we obtain:

$$\omega_0=\omega_{co1}=\omega_{co2}=\omega_{p1}=\omega_{p2}; \tag{7}$$

$$q_{co}=q_{co1}=q_{co2}=\frac{\omega_{co1}+\omega_{co2}}{\omega_{p1}/q_{p1}+\omega_{p2}/q_{p2}}; \tag{8}$$

$$k_{co1}\cdot k_{co2}=k_1\cdot k_2; \tag{9}$$

$$\begin{aligned}\beta'&=\beta k_{co1}k_{co2}\\&=(\omega_{co1}+\omega_{co2})^2-(\omega_{p1}+\omega_{p2})^2+\omega_0^2\left(\frac{1}{q_{co}^2}-\frac{1}{q_{p1}q_{p2}}\right).\end{aligned} \tag{10}$$

Using (5) and from (7)–(10) we obtain the following solutions for open-loop pole parameters:

$$\begin{aligned}&k_{co1}=k_{co2}=1;\\&\omega_{co1}=\omega_{co2}=1;\\&q_{co1}=q_{co2}=0.765367;\\&\beta=0.292893,\end{aligned} \tag{11}$$

corresponding to double open-loop poles:

$$\begin{aligned}&s_{co1,2}=-0.653281\pm j0.757115;\\&s_{co3,4}=-0.653281\pm j0.757115.\end{aligned} \tag{12}$$

The root locus of the closed-loop poles from the denominator of (3), as a function of initial position of open-loop poles, as given in (12), and a *positive*-feedback factor β is shown in Fig. 2.

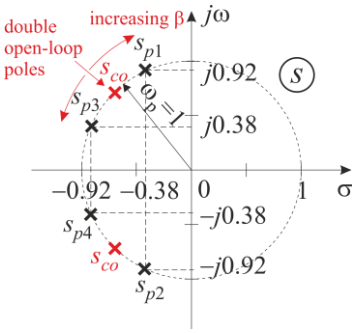

Figure 2. Root locus for the coupled structure in Fig. 1(b).

Increasing the positive feedback β from zero to 0.292893, the open-loop poles travel on the circle and become the closed-loop poles in (6). Because of realization of Butterworth poles, the locus is circular. It can be seen in Fig. 2 that for some large value of positive feedback a pair of poles would be on imaginary axis, and travel into the RHS *s*-plane. Thus, there exist a maximum value of the β_{max} for which the circuit becomes unstable, and the poles would exceed the wanted closed-loop poles.

C. Filter Realization

Tow-Thomas biquad, which is a GP section (having LP, BP, and with an addition of one opamp HP outputs) according to the designation in [3] is shown in Fig. 3.

The transfer function for this circuit is given by [4]:

$$T(s)=\frac{V_{out}}{V_{in}}=-k\frac{s^2+(\omega_z/q_z)\cdot s+\omega_z^2}{s^2+(\omega_p/q_p)\cdot s+\omega_p^2}, \tag{13}$$

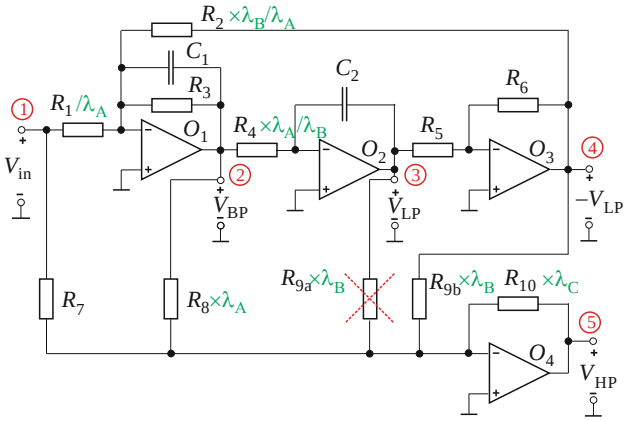

Figure 3. General purpose filter with 4 operational amplifiers.

where

$$\omega_p = \frac{1}{\sqrt{R_2R_4C_1C_2}}; q_p = R_3\sqrt{\frac{C_1}{R_2R_4C_2}};$$
$$k_{LP2} = R_2/R_1; k_{HP} = R_{10}/R_7; \quad (14)$$
$$\frac{\omega_z}{q_z} = \frac{\omega_p}{q_p}\left(1-\frac{R_7R_3}{R_8R_1}\right); \omega_z^2 = \omega_p^2\left[1+\left(\frac{R_7}{R_{9a}}-\frac{R_7}{R_{9b}}\right)\frac{R_2}{R_1}\right].$$

In our example the cut-off frequency is given f_0=1kHz. To design physical circuit, we perform a step-by-step design. Because of degrees of freedom we choose C_0=10nF, and R_0=10kΩ. Then, if we set C_1=C_2=C_0=10nF, R_2=R_0=10kΩ, from (14) we have for the first LP block in cascade the following element values:

$$R_4 = 1/(\omega_{p1}^2C_0^2R_2) = 25.3\text{k}\Omega;$$
$$R_3 = q_{p1}\sqrt{R_2R_4} = 8.6\text{k}\Omega; R_1 = k_{ca1}R_2 = 10\text{k}\Omega. \quad (15)$$

For the second LP block in cascade we use the same design equations (15).

For the two biquads inside coupling, besides the first, which is LP, we must calculate components of the second HP block, too, using (14). The additional elements of the HP realization are R_7 to R_{10}. For the HP block R_{9a} is not needed (see Fig. 3), and R_{9b} is designated by R_9 in the sequel. The feedback resistor (connected from the second-block opamp O_4 output node to the "–" input node of the first-block opamp O_1) is R_F=R_0/β=34.317kΩ. The obtained elements are in Table 1.

D. *Optimization of Filter's Dynamic Range D_R*

Dynamic range (D_R) optimization is described in [1] and [4]. In Fig. 4 an optimization procedure for maximum dynamic range for the filter in Fig. 3 is presented. The optimization is performed using signal-flow graph (SFG), by application of the rules for equal voltage maximums at the amplifier's outputs. Nodes of the SFG correspond to nodes in the filter circuit in Fig. 3. The transmissions of the branches entering the node are multiplied by the value λ by which we are going to scale node voltages. The outcoming branches are divided by that value. All nodes must have equal maximums, after optimization.

TABLE I. LP FILTER IN FIG. 1 ELEMENTS (C IN [nF], R IN [kΩ])

Elements	Cascade		Coupled	
	Biquad 1	Biquad 2	Biquad 1	Biquad 2
C_1=C_2	10	10	10	10
R_1	10	10	10	12.2127
R_2	10	10	10	10
R_3	8.6	20.8	12.15	12.2127
R_4	25.3	25.3	25.2	25.4613
R_5=R_6	10	10	10	10
R_7=R_8=R_{10}	-	-	-	12.2127
R_9	-	-	-	34.317

In Fig. 5(a) amplitude-frequency characteristics of the corresponding nodes are presented for cascaded filter. The values of scaling components λ follow from that plot and are calculated numerically using Pspice.

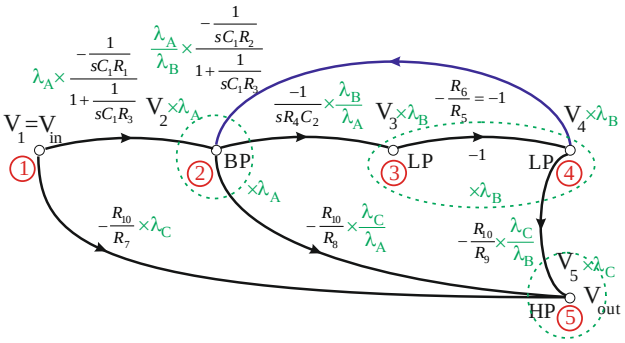

Figure 4. General purpose filter with 4 operational amplifiers.

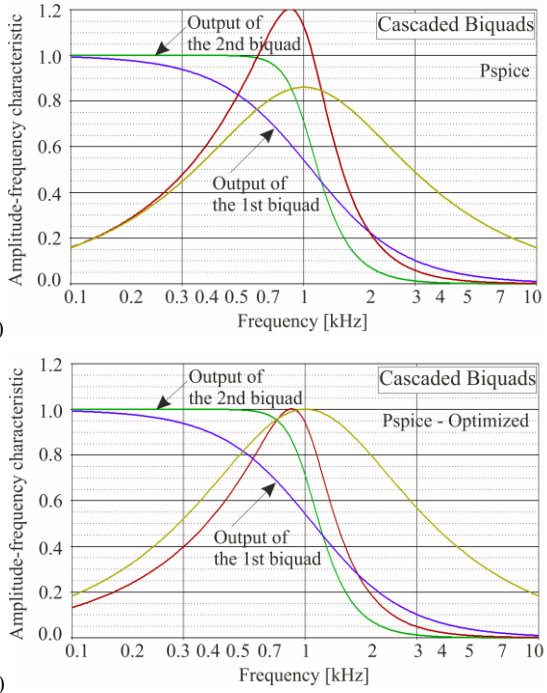

Figure 5. Amplitude-frequency characteristics of fourth-order LP filter cascade. (a) Non-optimized. (b) Optimized.

TABLE II. SCALING FACTORS λ FOR D_R OPTIMIZATION

Scaling factor	Cascade		Coupled	
	Biquad 1	Biquad 2	Biquad 1	Biquad 2
λ_A	0.86	1.2	0.6808	1.00732
λ_B	-	-	0.97411	1.221
λ_C	-	-	-	1.40251

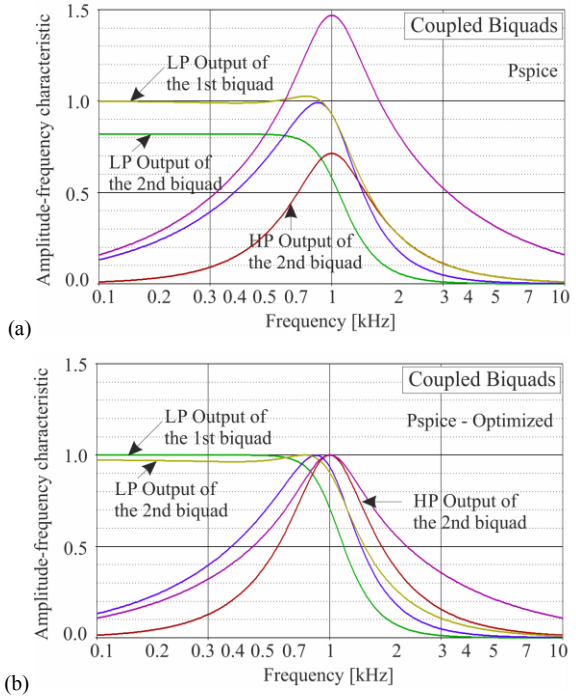

Figure 6. Amplitude-frequency characteristics of coupled fourth-order LP filter. (a) Non-optimized. (b) Optimized.

They are given in Table II. Then, according to Figs. 3 and 4, appropriate resistive values are scaled in order to equate output maximums. The scaling factor λ_A scales the value of node ② voltage, λ_B scales the nodes ③ and ④, and λ_C scales the node ⑤. The scaling factors for the cascade are λ_{A1}=0.86 for the first biquad and λ_{A2}=1.2 for the second biquad. Indices 1 and 2 determine biquad blocks. The optimization is performed by multiplying the corresponding resistances $R_2 \cdot (\lambda_B/\lambda_A)$, $R_4 \cdot (\lambda_A/\lambda_B)$, and $R_1 \cdot (1/\lambda_A)$, which is shown in Fig. 3. For the HP case we also must multiply $R_8 \cdot \lambda_A$, $R_9 \cdot \lambda_B$, and $R_{10} \cdot \lambda_C$. The feedback resistor R_F for the coupled case is scaled by $R_F \cdot (\lambda_{A1}/\lambda_{C2})$.

Then in Fig. 5(b) amplitude frequency characteristics of the filter inner nodes are presented for the optimized cascaded filter. The characteristics for coupled non-optimized and optimized filters are shown in Fig. 6. With dynamic range optimization, the filter circuit with four opamps works in the whole dynamic range, because all voltage maximums at the amplifier outputs are equal.

III. SENSITIVITY AND NOISE RESULTS

A. *Sensitivity Results by Pspice Simulations*

Comparing the sensitivities to component tolerances of two LP filters examples in Section II with Monte Carlo runs using PSpice, while assuming a zero-mean uniform

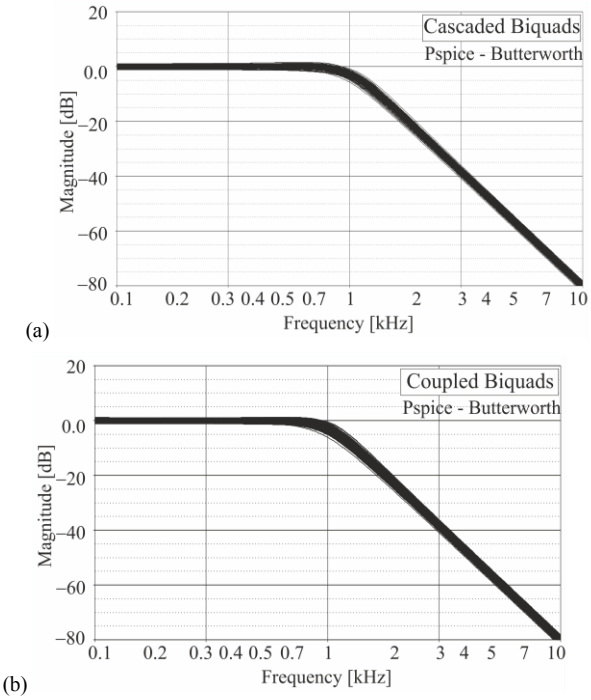

Figure 7. Simulated MC runs sensitivities of LP Butterworth filter examples using Pspice. (a) Cascaded case. (b) Coupled case.

distribution and 5% standard deviation for all components, we obtain the spread of responses shown in Fig. 7. Because, the larger spread represents higher sensitivity, we can conclude that the sensitivity for the cascade is very close to the sensitivity of the coupled case, the latter is with identical inner sections.

B. *Noise Results by Mesurements*

To perform measurements on the discrete-component filters using lab equipment, filters are realized on the printed circuit test boards using SMD technology as shown in Fig. 8. The filters under test are designated on the right-side of the boards inside white rectangle "opamp filter section". The measurements are performed using Network Analyzer HP4195A as described in [5].

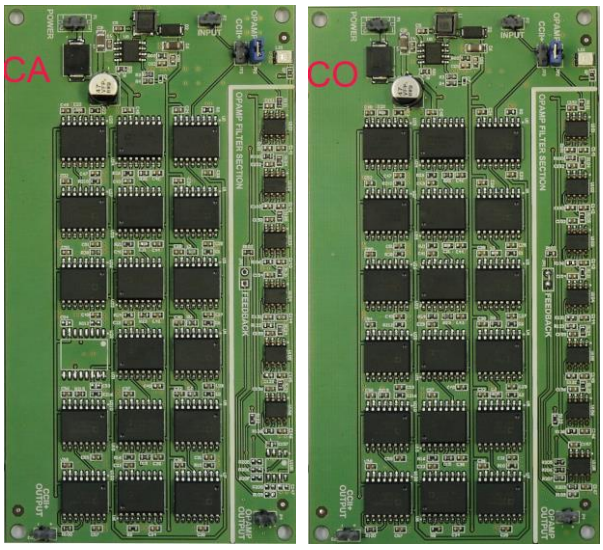

Figure 8. Discrete-component filters realized on SMD printed circuit board: (a) Cascaded case. (b) Coupled case.

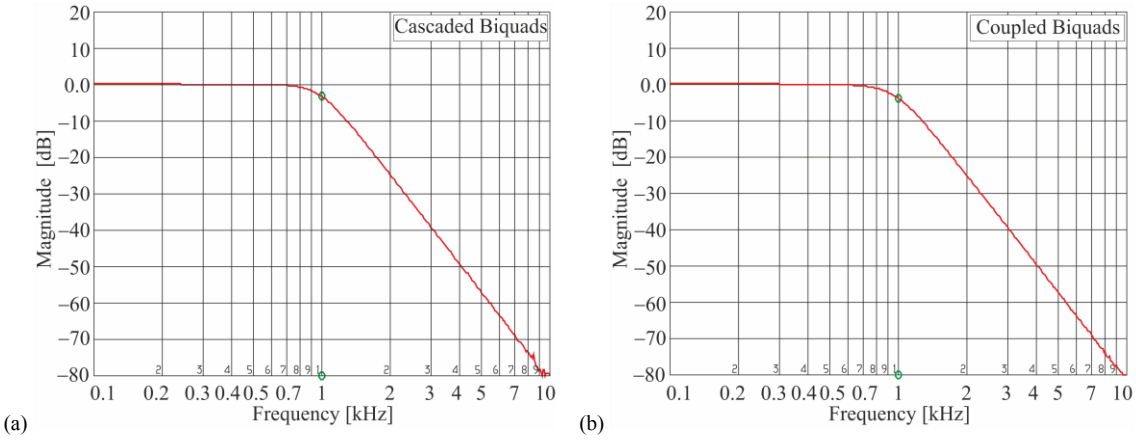

Figure 9. Measured amplitude-frequency characteristics of fourth-order LP filter. (a) Cascaded case. (b) Coupled case.

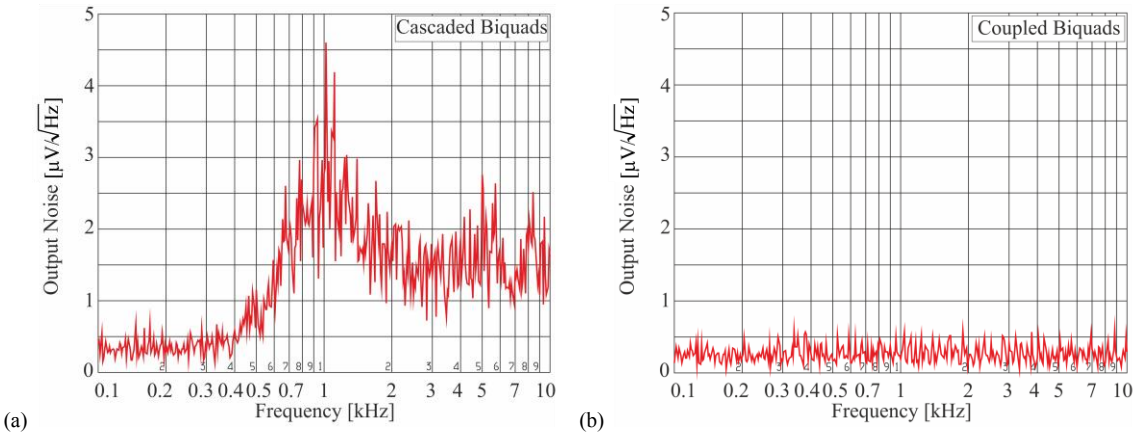

Figure 10. Measured output thermal noise spectral density of fourth-order LP filter. (a) Cascaded case. (b) Coupled case.

Observing measured magnitudes of the filters that are presented in Fig. 9, we can conclude, that although having positive feedback, coupled filter is stable and fully operable. It possesses the same magnitude as his cascaded counterpart. Furthermore, the measured output thermal noise spectral density is substantially reduced for the coupled case when compared to the cascaded case, which can be seen in Fig. 10.

It is well known that the output noise is proportional to the pole Q-factor [6][7]. The reduction of noise is a caused by reduction of the pole Q factor, due to feedback [q_{p2}=1.3065 in (5) >> q_{co}=0.7654 in (11)]. The analytical proof of noise reduction will be published shortly.

IV. Conclusion

In this paper we present a biquartic section, i.e. the section of fourth order realizing LP transfer function. The section is also capable of realizing HP transfer function with different positioning of switches. The biquartic sections studied so far have all realized BP transfer function by application of negative feedback. Thus, realizing coupled LP and HP biquartic section, using the same principles as for BP, is novelty, and the most important contribution of this paper. It was shown that the usage of positive feedback is needed for the LP (and also HP) section to be feasible. In this paper the biquad using four opamps is explored, in the future investigation single-amplifier biquads will be considered, because the latter consume less power.

Measurement results have proven that the new LP filter is stable, although having (limited amount) of positive feedback. The sensitivity analysis has shown that the novel section has retained low sensitivity by application of coupling. The most important result of the coupling is significant reduction of output thermal noise, which was demonstrated by measurements.

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Design of Magnetic Shielding from Space Radiation using Numerical Methods

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***Abstract*—Shielding the humans from space radiation is one of the most demanding challenges in manned space travel. The space radiation can be mitigated using passive and active shielding techniques. Passive shielding techniques use layers of materials which absorb the incoming radiation, while the active shielding techniques use electrical or magnetic fields to deflect the incoming radiation. This paper considers magnetic shielding which consists of a number of coils and forms a large magnetic field surrounding the spacecraft. The paper presents a numerical method of designing the configuration of the coils used in the magnetic shielding. The magnetic field of the coils is numerically evaluated using Biot-Savart law. The design parameters of the magnetic shielding are optimized w.r.t. the bending power of the generated magnetic field by using a random walk algorithm. The resulting optimal design of magnetic shielding is compared to reference design, i.e. the 'pumpkin' magnetic shielding design.**

***Keywords*—numerical modelling; space radiation; active shielding;**

I. INTRODUCTION

The great next steps in space exploration are a manned mission to Mars or a permanent base on the Moon. These are ambitious goals and their realization will have to address many economic and technical constraints. The principal technical challenge for a long-term, manned mission is the matter of the radiation risks.

There is a number of different solutions of radiation shielding which in general can be categorized as passive and active shielding [1]–[3]. The passive shields are based on sufficiently thick layers of materials which produce significant ionization losses and consequently stop the incident radiation. The active shields use static electric or magnetic fields to deflect the incoming charged particles. The main advantage of the active shielding is that it has reduced mass and material cost when compared to the passive shielding. The main drawback of the active shielding is that it only shields against charged particles, and not against EM radiation, e.g. gamma and X-rays.

In the case of long-term manned missions, the exposure to galactic cosmic rays are the most challenging type of radiation to account for in the shielding design. These rays are continuous and high-energy (~1 GeV). This case requires the application of one of the active shielding strategies and the magnetic shielding shows the most promise in this respect. The magnetic shielding consists of a static magnetic field which surrounds the spacecraft and it is generated by large superconducting magnets [4], [5].

Recently, a novel configuration of magnetic shielding was developed as a part of the EU FP7 project SR2S [6]. This shielding design is called the "pumpkin" magnetic shield and it is based on open toroids which are arranged with their axes perpendicular to the spacecraft [7]. This magnetic shielding design has a lower magnetic field at the superconductor and it is lighter when compared to other shielding designs with the same shielding power. Fig. 1 illustrates the "pumpkin" magnetic shielding surrounding a spacecraft.

In [8] it is stated that further optimizations of the "pumpkin" shielding design are possible and this paper examines how this magnetic shielding design can be optimized. The paper uses a parametrized numerical model of the magnetic field of the shielding design and an optimization algorithm to identify improved shielding designs.

The model of the magnetic shielding is built in Section II and then the model is used in the optimization of the magnetic shielding design which is described in Section III. The modelling and the optimization results are discussed in Section IV, while the conclusions are presented in Section V.

II. MAGNETIC SHIELDING MODELLING

A. *Magnetic field of a current loop*

The magnetic shielding consists of a number of separate coils, i.e. current loops and the magnetic field of the magnetic shielding is modelled by first modelling a current loop. The model of the current loop is then used to build

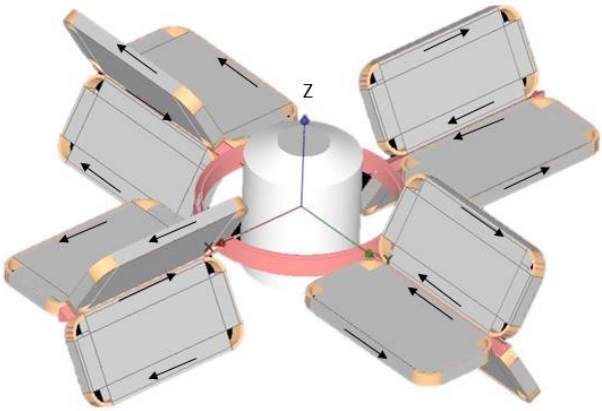

Figure 1. Illustration of the "pumpkin magnetic shield" surrounding a spacecraft [7].

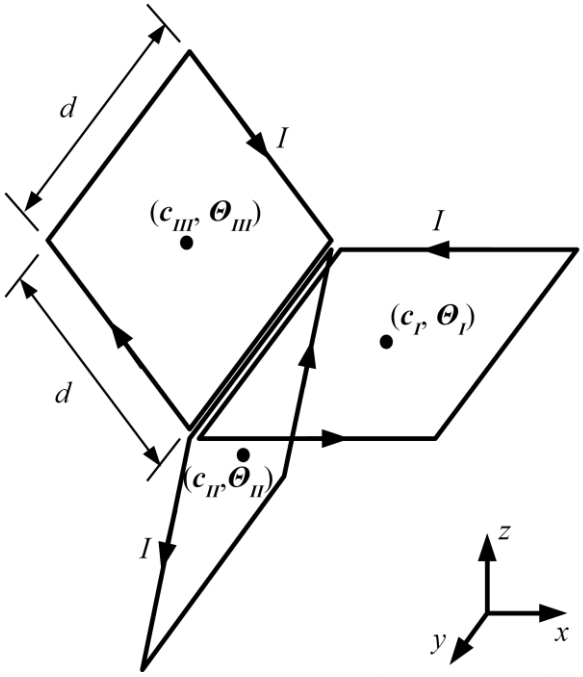

Figure 2. Schematic view of the one of the open toroids of the "pumpkin" magnetic shield design with its design parameters.

the model of the whole magnetic shielding.

The magnetic flux density $\boldsymbol{B}$ of a current loop is defined using the Biot-Savart law [9] as

$$\boldsymbol{B}(\boldsymbol{r}) = \frac{\mu_0 I}{4\pi} \oint_l \frac{d\boldsymbol{l} \times (\boldsymbol{r} - \boldsymbol{r}')}{|\boldsymbol{r} - \boldsymbol{r}'|^3} \tag{1}$$

where $\boldsymbol{r}' = \boldsymbol{r} - \boldsymbol{l}$ represents the displacement vector from the loop element $d\boldsymbol{l}$ to the evaluated point $\boldsymbol{r}$, I is the current of the current loop, l is the curve which represents the current loop and μ_0 is the magnetic permeability of vacuum. The magnetic flux density of a current loop is then defined as

$$\boldsymbol{B}(\boldsymbol{r}, I, \boldsymbol{P}) = \frac{\mu_0 I}{4\pi} \sum_{i=1}^{4} \sum_{l=\boldsymbol{p}_i}^{\boldsymbol{p}_{i+1}} \frac{\Delta\boldsymbol{l} \times (\boldsymbol{r} - \boldsymbol{r}')}{|\boldsymbol{r} - \boldsymbol{r}'|^3} \tag{2}$$

where $\boldsymbol{P}$ is a matrix consisting of the corner points $\boldsymbol{p}$ of the current loop and $\Delta\boldsymbol{l}$ is the current loop segment.

B. "Pumpkin" shield design

The "pumpkin" design serves as the reference model in this paper and it is shown in Fig. 1. The design consists of four open toroids arranged in a symmetrical manner and each open toroid consists of three current loops which are uniformly distributed.

The magnetic flux density of the system of current loops which represents the "pumpkin" shielding design is defined as

$$\boldsymbol{B}(\boldsymbol{r}) = \sum_{k=0}^{3} \sum_{j=1}^{3} \boldsymbol{B}(\boldsymbol{r}, I, \boldsymbol{P}_j\big|_{\gamma=\frac{\pi}{2}k}) \tag{3}$$

where the inner sum represents the magnetic flux density contributions of the individual current loops in the open toroids and the outer sum represents the sum of the open toroids which are mirrored, i.e. rotated around the z-axis in increments of $\pi/2$.

The symmetry of the shielding design simplifies the magnetic modelling and reduces the total number of design parameters which are used to define the shielding design.

Fig. 2 shows one of the four open toroids of the "pumpkin" shielding design. The open toroid consists of three current loops which are defined by their centre points $\boldsymbol{c_I}$, $\boldsymbol{c_{II}}$ *and* $\boldsymbol{c_{III}}$, and their rotations $\boldsymbol{\Theta_I}$, $\boldsymbol{\Theta_{II}}$ *and* $\boldsymbol{\Theta_{III}}$. The rotations are defined as two element vectors which represent the rotation around the x- and y-axis, while the initial current loop before the rotation is defined in the xy-plane, i.e. its orientation is in the direction of z-axis. The model uses matrix $\boldsymbol{P}$ which consists of the corner points $\boldsymbol{p}$ and they are defined based on the centre points and the appropriate rotations.

C. Bending power

The main purpose of the magnetic shielding is to divert the incident charged particles. The magnetic field of the current loops interacts with the charge of the particle and produces a force, i.e. the Lorentz force which diffracts the particle. The produced force is perpendicular to both the magnetic field and the direction in which the particle moves.

In [3] bending power Ξ is defined and it quantifies the power of a magnetic field to divert a charged particle from its path. The bending power Ξ is defined as

$$\Xi = \int_v \boldsymbol{B} \times d\boldsymbol{v} \tag{4}$$

where $\boldsymbol{B}$ is the magnetic flux density of the shielding and $\boldsymbol{v}$ represents the trajectory of the charged particle. The numerical model of the magnetic shielding uses the defined magnetic flux density in (2) to calculate the bending power for a linear particle trajectory as

$$\Xi = \sum_{\boldsymbol{r}=\boldsymbol{v}'}^{\boldsymbol{v}''} \boldsymbol{B}(\boldsymbol{r}) \times \Delta\boldsymbol{v} \tag{5}$$

where $\boldsymbol{v}'$ and $\boldsymbol{v}''$ are the starting and the ending points of the particle trajectory, while $\Delta\boldsymbol{v}$ is the trajectory segment.

The particles directed at the z-axis are the most penetrating [3] and the model considers a number of particle trajectories which are evenly spaced out in the xy-plane. These particle trajectories represent the worst case and the greatest threat to the crew on board the spacecraft. The trajectories start at an arbitrary distance and end at the origin point.

The model and the supporting functions are implemented in Python programming language. The numerically intensive core of the magnetic modelling is implemented in OpenCL language and runs on a local GPU using the Python module *pyopencl* [10].

III. DESIGN OPTIMIZATION

A. Multiobjective optimization

The magnetic shielding of the spacecraft has to have a large enough bending power in order to divert the charged particles away from the spacecraft. The bending power of the magnetic shielding also has to be relatively uniform with respect the different paths of the incident charged particles.

The magnetic shielding model is used to evaluate the bending powers for different particle paths and the resulting

TABLE I
THE DESIGN PARAMETERS OF THE REFERENCE SHIELD DESIGN.

Parameter name	Parameter value
Loop current I [A]	1.0
Dimension d [m]	0.1
Loop I geometry c_I [m], Θ_I [°]	(0.05,2.0,0), (0,0)
Loop II geometry c_{II} [m], Θ_{II} [°]	(-0.025,2.0,0.0433), (0,120)
Loop III geometry c_{III} [m], Θ_{III} [°]	(-0.025,2.0,0.0433), (0,-120)

bending powers constitute a sample which is statistically processed. The mean value of the bending powers Ξ_m represents the overall bending power of the magnetic shielding, while the standard deviation of the sample Ξ_σ represents the uniformity of the magnetic shielding.

The two defined statistical parameters of the bending powers sample constitute the Figures-of-Merit used in the multiobjective optimization process. The multiobjective optimization process uses a random walk algorithm in the space of the design parameters of magnetic shielding [11]. The random walk algorithm is used in the optimization process as it is assumed that the model of the Figures-of-Merit w.r.t. the shielding design parameters is not continuous and/or differentiable. One iteration of the random walk algorithm consists of randomly choosing a single shielding design parameter which is then randomly incremented or decremented by a fixed step Δs.

In order to keep the magnetic moment of the individual current loops constant throughout the optimization process, the current I and the dimension d is kept constant. This makes the generated magnetic shielding designs comparable in terms of the required operating power. Consequently, the space of the design parameters consists of the centres of the current loops $\boldsymbol{c_I}$, $\boldsymbol{c_{II}}$ and $\boldsymbol{c_{III}}$, and their orientations $\boldsymbol{\Theta_I}$, $\boldsymbol{\Theta_{II}}$ and $\boldsymbol{\Theta_{III}}$.

The multiobjective optimization process is subject to a number of limits. The optimization algorithm accepts only the designs of magnetic shielding which have improved values of the Figures-of-Merit compared to the initial design. The positions of the current loops are also limited to a space surrounding the spacecraft.

The co-optimization of the magnetic shielding is formulated as

$$\begin{aligned} &\text{maximize}\ \Xi_m(\boldsymbol{c},\boldsymbol{\Theta}) \\ &\text{minimize}\ \Xi_\sigma(\boldsymbol{c},\boldsymbol{\Theta}) \\ &\text{subject to}\ \Xi_m \geq \Xi_{m,i}, \Xi_\sigma \leq \Xi_{\sigma,i} \\ &2.0 \leq |\boldsymbol{c}| \leq 3.0 \end{aligned} \tag{6}$$

where $\Xi_{m,i}$ and $\Xi_{\sigma,i}$ are the mean and the standard deviation of the bending power of the initial, i.e. reference shielding design, while $|\boldsymbol{c}|$ are the distances of the three current loops from the origin point. It is assumed that the spacecraft has a radius R = 1.0 m and that the shielding has a clearance from the spacecraft, thus the lower limit of the loop centres is set at $|c| \geq 2.0$ m, while the upper limit is arbitrary. The random walk in the design parameter space examines each step and accepts it according to the rules in (6).

TABLE II
THE RESULTS OF THE MAGNETIC SHIELDING MODELLING.

	Mean bending power Ξ_m [Tm]	Std. dev. of bending power Ξ_σ [Tm]
Reference design	$8.18 \cdot 10^{-9}$	$5.14 \cdot 10^{-9}$
Optimal design	$15.4 \cdot 10^{-9}$	$1.73 \cdot 10^{-9}$
Rel. improvement	+88.5 %	-66.4 %

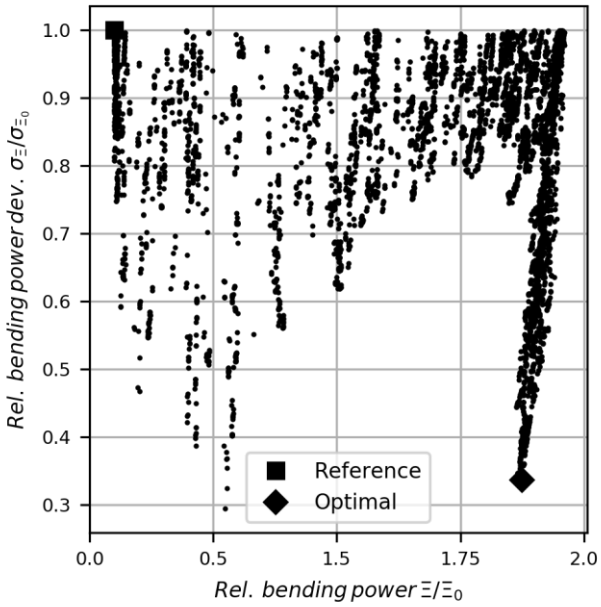

Figure 3. The optimization algorithm results in the Figures-of-Merit space, i.e. relative standard deviation w.r.t. relative mean bending power.

B. Reference design

The multiobjective optimization algorithm starts with an initial design of magnetic shielding and subsequently optimizes it with respect to the defined Figures-of-Merit. This paper uses the described "pumpkin" design of magnetic shielding as the initial design in the algorithm.

Table I shows the design parameters of the reference "pumpkin design of magnetic shielding.

C. Optimization results

The optimization algorithm, i.e. its random walk in the space of design parameters had a fixed step size of Δs = 0.01 and it was done for M = 10 000 iterations which produced a sample of N = 6 213 designs.

Fig. 3 shows the results of the multiobjective optimization process in the space of the Figures-of-Merit, i.e. the mean bending power and the standard deviation of bending power. Fig. shows the Figures-of-Merit in a relative manner w.r.t. the values of the initial, i.e. reference "pumpkin" design. The simulation results for the reference shielding design are marked with a square symbol, while the results of the optimal shielding design are marked with a diamond symbol. The shielding designs which are sampled by the optimization algorithm while searching for the optimal design are marked by dots.

Table II compares the simulation results, i.e. the Figures-of-Merit for the reference and the optimal shielding designs. The simulation results show that the optimal shielding design has 88.5 % larger mean bending power and 66.4 % smaller standard deviation of the bending power.

Fig. 4 illustrates the optimal shielding design identified by the multiobjective optimization algorithm, while Table

TABLE III
THE DESIGN PARAMETERS OF THE OPTIMAL SHIELD DESIGN.

Parameter name	Parameter value
Loop current I [A]	1.0
Dimension d [m]	0.1
Loop I geometry c_I [m], Θ_I [°]	(0.01,2.0,0), (-5.12,0)
Loop II geometry c_{II} [m], Θ_{II} [°]	(0.955,1.82,-0.317), (41.0,-155)
Loop III geometry c_{III} [m], Θ_{III} [°]	(-1.09,1.74,0.335), (129,166)

III shows the design parameters of the optimal design of magnetic shielding.

D. Magnetostatic model performance

The optimization process uses a random walk in the design parameters space which requires a large number of shielding design evaluations. This makes the execution speed of the model critical and thus the defined numerical model of the magnetic shielding was implemented in OpenCL programming language and was executed on a GPU.

The speed up in the execution of the model was evaluated by comparing the execution times for different implementations of the model and Table IV presents this comparison. The OpenCL implementation has an approx. 16 times shorter execution time than the single core implementation and an approx. 5 times shorter execution time than the multiple core implementation on a Core i7 PC with a discrete AMD Radeon graphics card.

IV. DISCUSSION

A. Multiobjective optimization results

The shielding designs in Fig. 3 at the far right have the highest mean bending power and form the front of Pareto optimal designs. The optimal design is identified as such because the front of Pareto optimal designs consists of shielding designs which have very similar mean bending powers, while the standard deviation varies greatly and thus the optimal design was selected as the shielding design with near-maximum mean value and the lowest standard deviation.

The identified optimal shielding design (Fig. 4) compared to the reference "pumpkin" design (Fig. 2) has a few notable differences. While the current loop I remains mostly unchanged, the current loops II and III significantly rotated and moved in z-axis direction. This change additionally open ups the toroids of the "pumpkin" design and links the magnetic fields of the neighbouring toroids.

The centres of all loops of the optimal shielding design have the same approx. distance from the origin point which is at the lower limit value. They are also equal to the distances of the loops of the initial "pumpkin" design. This confirms that the coils of the magnetic shielding should be as close as possible to the space craft.

TABLE IV
THE EXECUTION TIMES FOR DIFFERENT MODEL IMPLEMENTATION.

Model implementation	Execution time [s]
Single core	11.5
Multiple cores (4 cores)	3.52
GPU via OpenCL	0.72

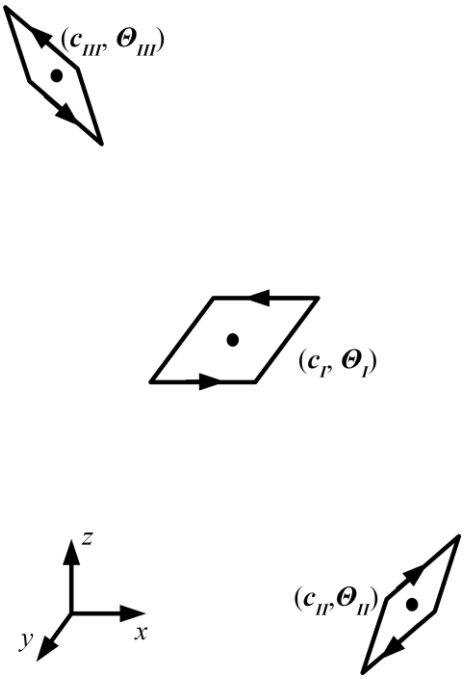

Figure 4. Schematic view of the optimal shielding design.

B. Future work

The optimization process identified an optimal shielding design w.r.t. the value and the uniformity of the bending power. The identified optimal design has to be examined whether it is structurally feasible. Also, there are additional requirements that can be included in to the multiobjective optimization process like the minimization of the magnetic forces between the individual coils and the minimization of the magnetic field generated in the spacecraft. E.g. the developed model shows that for the optimal shielding design the magnetic flux density at the origin point, i.e. inside the spacecraft is $|B| = 6.48 \cdot 10^{-9}$ T, which is somewhat larger when compared to the magnetic flux density of the reference model $|B| = 5.01 \cdot 10^{-9}$ T.

The developed magnetic model needs to be validated by comparing its results with a commercial solver, e.g. COMSOL Multiphysics. These results also need to be verified by measurements of the magnetic field of scale models of the shielding designs.

V. CONCLUSIONS

The space radiation poses a threat to the crews of manned spaceflight missions and developing effective shielding from the space radiation is critical. Recently, a novel magnetic shielding design was proposed which consists of multiple open toroids, i.e. the "pumpkin" shielding design and this paper examines whether its shielding power can be improved upon. The magnetic field of the "pumpkin" shielding design and its bending power are numerically modelled using the Biot-Savart law. The parametrized model is used to optimize the bending power of the magnetic shielding w.r.t. its value and uniformity. A random walk algorithm was used to identify the optimal shielding design and the numerical model was implemented in OpenCL in order to speed up the execution of the algorithm. The identified optimal shielding design has 88.5 % larger mean and 66.4 % smaller standard deviation

of the bending power which confirms that the "pumpkin" shielding designs can be indeed improved upon.

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A proposal for characterizing global light pollution using a LEO nanosatellite

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***Abstract*—Solid-state lighting (LED lighting) is an energy efficient alternative to conventional sodium, mercury and fluorescent outdoor lighting. The high spectral density of blue light emitted by nominally "white" LEDs has in recent years become an ecological and health concern. Monitoring the global presence of LED lighting as a fraction of total light pollution has hence become a parameter of interest to government organizations dealing with health and environmental protection. This work describes a planned low-earth orbit satellite mission with a low-cost technology and algorithms to provide light pollution images and estimates of the contribution of solid-state lighting relative to conventional illumination globally.**

***Index Terms*—Nanosatellite Earth observation, light pollution, spectrally-resolved light measurement.**

I. Introduction

Large fraction of Earth's population lives under light-polluted skies. Artificial lights overpower the darkness and the city skies glow at night, disrupting the natural day-night pattern and shifting the delicate balance of our environment. The negative effects of the loss of natural darkness are (*i*) the disruption of the ecosystem and wildlife, (*ii*) harming human health through disruption of the circadian rhythm [1], (*iii*) the disruption of astronomical observation [2] and finally (*iv*) wasted energy in illumination. The public concern about light pollution is rising as a growing number of scientists, homeowners, environmental groups and civic leaders are taking action to restore the natural night [3].

The purpose of this work is to describe a proposed nanosatellite mission to evaluate global light pollution and to determine, if possible, the global progress in solid-state lighting from space. Light pollution is generally monitored from Earth [4], [5] (see an example in Figure 1), while with the progress in satellite-based Earth observation, light pollution maps of the entire world are now available on the internet [6] (illustrated in Figure 2).

Solid-state lighting is being implemented worldwide as the alternative, more efficient and less toxic, light source (relative to mercury containing lamps) [7]. The key advantage of solid-state lighting, besides the low toxicity and size, is in that it offers a light source with luminous efficiency comparable to that of conventional outdoor lighting at a significantly better color rendering index (CRI) [1]. For example, a nominally-white LED bulb with CRI ≥ 80 can be obtained with luminous efficiency $\eta_\nu = 90$ lm/W, while a low-pressure sodium (LPS) bulb

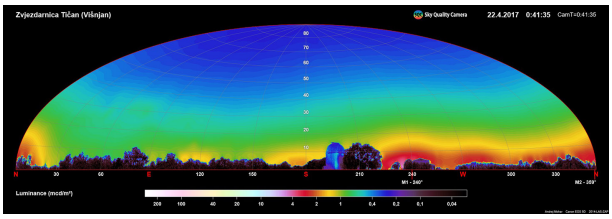

Fig. 1. Light pollution seen in west-pointing night photograph of Tičan observatory in Višnjan (Istria, Croatia), which shows light pollution coming Trieste/Italy at 360 degrees and from Poreč/Croatia at 240 degrees. Image taken by EOS Nikon Sky Quality Camera by Andrej Mohar, printed with permission.

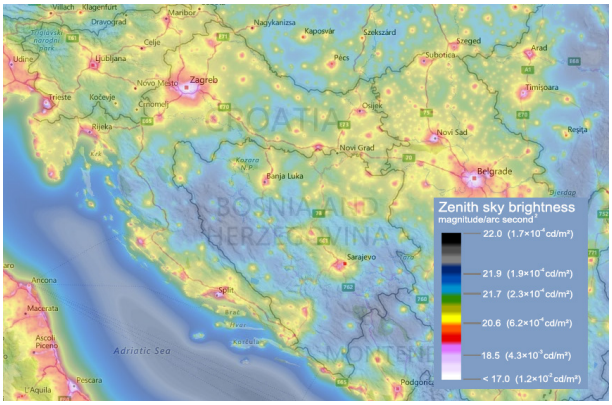

Fig. 2. Global light pollution map available on the internet [6].

will have luminous efficiency of $\eta_\nu = 160$ lm/W. However, the LPS emits light in a single yellow line at 589 nm and therefore has a very poor color rendering index (CRI $= -44$). Note that a modern halogen lamp in E27 base with CRI = 100 will have $\eta_\nu \approx 17$ lm/W.

Luminous efficiency η_ν is a measure of the efficiency of conversion of electrical energy (Watts) into luminous flux (lumens) and can be easily computed for any light source/bulb by dividing the luminous flux specified for the light bulb by the electrical power it consumes. Luminous efficiency η_ν is measured in lm/W, but is not to be confused with luminous efficacy K (also measured in lm/W) which characterizes the shape of the light emission spectrum. The relationship between these quantities is given with $\eta_\nu = \eta_e \cdot K$, where η_e is the efficiency of the device to convert electrical enegy into radiant flux (measured in W) [7].

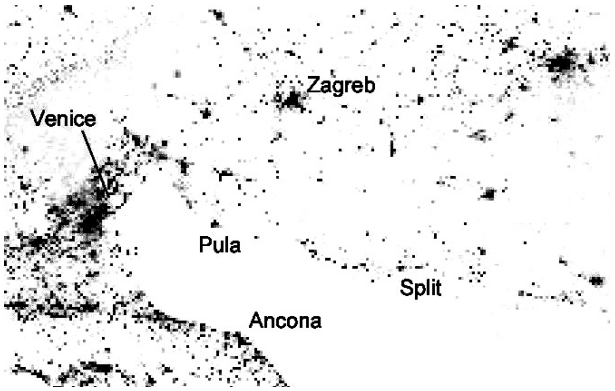

Fig. 3. Night-time light emission from Croatia and Italy taken April 14, 2019 in day-and-night band between 500 do 900 nm. The gray-scale image has been inverted to negative image and contrast increased to show dark where there is light and white where there is no light emitted (VIIRS).

Nominally white light-emitting diodes generate a combination of blue and yellow light that appears to the human eye as white of differing degree of "warmness". These light-emitting diodes are built as blue gallium-nitride-based LEDs emitting at ≈455 nm covered with a layer of yellow phosphor (peak of emission ≈590 nm) so that the blue light from LED excites the phosphor and the LED generates a combination of blue and yellow light. Phosphor is a chemical compound that emits light in a certain wavelength range when illuminated with light of shorter wavelength. The color of nominally white LEDs, marketed as "warm white" or "cool white", is controlled with the ratio of the power in the yellow relative to the blue part of the LED emission spectrum: more blue in the spectrum appears as colder white light.

Correlated color temperature (CCT) is a measure of a light source's color appearance defined by the proximity of the light source's chromaticity coordinates to the blackbody-emission locus, as a single number rather than the two required to specify a chromaticity [1]. The spectral power distribution of a blackbody radiator can be completely determined from its absolute temperature using Planck's radiation law. Practical light sources of different power spectral densities but identical chromaticities will also have identical CCTs. An incandescent light bulb with a tungsten filament may have a CCT of 2700 K, which can also be approximated with a "warm white" LED. Although an approximation, CCT is simple way to communicate the color appearance of a light source. However, it neglects that fact that two sources with same CCT may have vastly different emission spectra.

New regulations are being put in place worldwide to control light pollution while cost per lumen of solid-state light sources is reducing. As a result we expect to see conventional lighting, such as metal halide, mercury and sodium lighting reduce in time and solid-state lighting progress.

II. Earth light captured in space

Night-time images of cities and lighting from space have been available since the 1970-ies [8]. More recently, the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor launched in 2011 started providing high-quality night-time images of the Earth in the day-and-night band (DNB) 500 nm and 900 nm wavelength range with intensity resolution of 14 bits. A night-time image of a portion of Croatia and Italy downloaded as part of this work is shown in Figure 3.

In 2010, photographs from the International Space Station showed that cities around world appear to be lit by lighting of different color: images from space reported in [9] show that Tokyo appears blue-green resulting from mostly metal halide lamps, while Los Angeles and Las Vegas appear more yellow resulting from sodium lamps. The fact that these images were captured on a regular CCD camera, raised the question whether one could use a regular camera to determine the type of light source generating the light pollution [10] and has initiated this satellite mission: to estimate the fraction of LED lighting in the overall emission from the Earth using a CCD camera or a miniature spectraphotometer.

The objective of this work is to use satellite-based Earth observation to monitor, over a period of time, the fraction of solid-state lighting in the overall illumination in the world. Our approach is to acquire spectrally resolved night-time images of the Earth using a CubeSat, analyze the data and determine the fraction of the overall illumination that originates from solid-state lighting globally and locally in Croatia. To this end we first measure and discuss the emission spectra of nine different conventional and solid-state lighting sources. All of the presented discussion is preliminary and is subject to change once the optimal algorithm and hardware approach to reach the target functionality is identified.

III. Light-source emission spectra

We measured the emission spectra of representative bulbs for light-sources used in public illumination. They are listed in Table I.

TABLE I
Light sources characterized (all E27 base)

Code	Description	Power	CCT
HPS	High-pressure sodium	70 W	
MH3	Metal-halide	150 W	3000 K
MH4	Metal-halide	150 W	4000 K
HG	Mercury vapor	125 W	
LED3	806 lm, CRI>80	9 W	3000 K
LED4	806 lm, CRI>80	9 W	4000 K
LED6	806 lm, CRI>80	9 W	6500 K
LED0	1000 lm, CRI 90	11 W	2700 K
CFL	900 lm, CRI > 80	15 W	2700 K

The emission spectra were measured using Photon Control SPM002-CH spectraphotometer with < 0.6-nm resolution and spectral range between 350 nm to 1000 nm in



Fig. 4. Three of the discharge lamps tested, from left to right MH3, HPS, and HG bulbs.

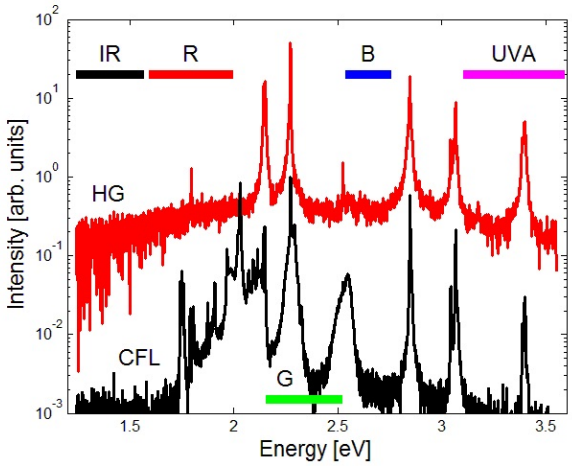

Fig. 5. Mercury bulbs, top shows mercury vapor high-intensity discharge bulb "HG", bottom graph shows compact fluorescent E27 bulb "CFL"

3560 pixels. The room in which measurements were done was dark and to reduce the noise in the measurement, we averaged 600 one-second scans for each bulb. The warm-up of each lamp was visually observed and measurements were taken after approximately 30 minutes after turn-on.

The measurements of emission intensities for all light sources are shown in Figures 5, 6, 7, and 8. The power spectral density is shown versus energy and on a logarithmic scale to accentuate the shape of the peaks in the emission and show how much they are above the noise. The intensities of various sources shown in the Figures have been normalized and shown in a logarithmic graph to reveal correlations in the emission peaks, hence, one should not associate the vertical value with the actual lamp intensity. To assist simple conversion to wavelength (more commonly used in illumination), the wavelength regions of near infrared (IR), red (R), green (G), blue (B), and soft ultra-violet (UVA) light are also shown. The boundaries between R, G, and B are taken from [7].

A. *Conventional light sources*

The measurements of emission power spectral density of conventional lighting sources (metal halide, mercury and high-pressure sodium lamps) are shown in Figures 5, 6, and 7.

Mercury is the staple metal of conventional high-intensity discharge and fluorescent lamps with high luminous efficacy. Excited mercury vapor emits strongly in the ultraviolet spectrum and is then efficiently used to excite a phosphor to downconvert the energy into the visible part of the spectrum. The emission spectra for a mercury vapor lamp "HG" and a compact fluorescent lamp "CFL" are shown in Figure 5. Inasmuch as both bulbs are based on mercury vapor to generate the ultraviolet light and appear to use similar phosphor, the correlation between the spectra is $C = 0.58$.

Metal halide lamps are also based on mercury discharge to generate the ultraviolet light, but metal halides are mixed in with the mercury vapor to produce a wide variety of lines as shown in Figure 6 and can hence be adjusted to have "warm" or "cool" white tint. The top and

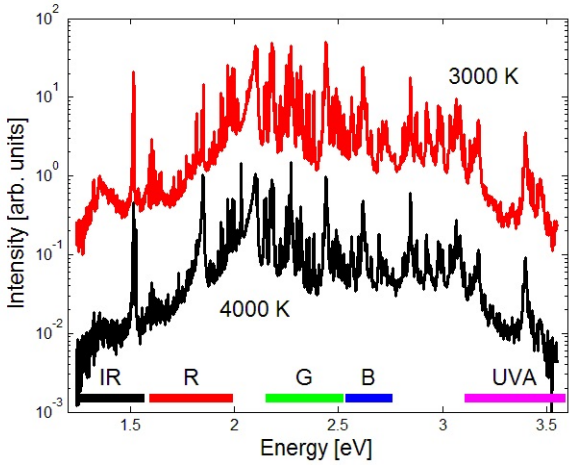

Fig. 6. Metal halide emission spectra: top chart has CCT = 3000K "MH3" and bottom chart CCT = 4000K "MH4".

bottom graphs correspond to the "MH3" and "MH4" bulbs, respectively. The correlation between the two spectra is $C = 0.85$. The difference from unity is the manifestation of a different CCT. The emission spectra of the metal halide lamps is rich with emission lines and hence gives a color rendering index acceptable for outdoor lighting (CRI > 65).

It is worth noting that, as shown in Figures 5 and 6, both metal halide and mercury vapor lamps emit some energy in the UVA region (315-400 nm). This portion of the UV spectrum is not absorbed by the ozone layer and therefore these spectral lines may be detectable from space.

High-pressure sodium lamps (HPS) contain mercury vapor with traces of inert gas, such as, xenon. They have a distinct yellow/orange tint to them resulting from majority of the emission coming around 589 nm, characteristic of sodium. The bottom graph in Figure 7 illustrates the emission spectrum. Low-pressure sodium lamps (LPS), not measured in this work, has only sodium vapor and only two lines: the dominant emission at 589 nm and smaller

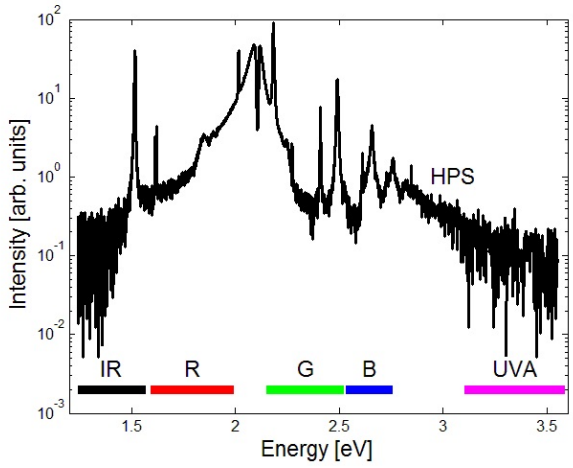

Fig. 7. High-pressure sodium lamp emission spectra.

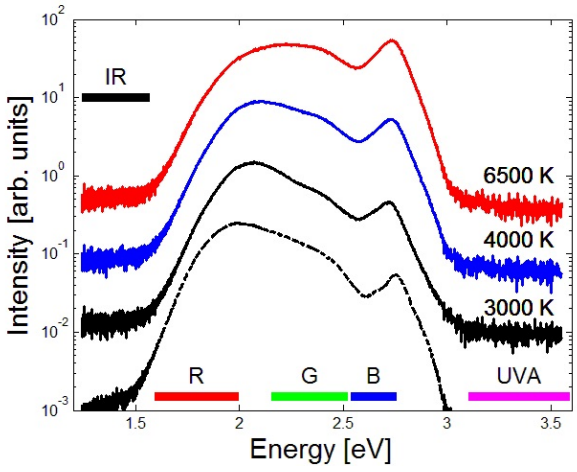

Fig. 8. Four nominally white light-emitting diode spectra. All bulbs are small household bulbs that fit into E27 base. From top to bottom we have CTT = 6500 K, CCT = 4000 K, CCT = 3000 K, and finally, CCT = 2800 K. The last (dashed line) is a houselhold lamp with CRI > 90

emission at 819 nm.

B. White light-emitting diodes

The CCT of nominally white light-emitting diodes is adjusted by controlling the thickness and type of phosphor deposited onto blue light-emitting diodes. The imperfect phosphor thickess control produces a spread of correlated color temperatures in the production process mandating product binning. Figure 8 show the spectra of four nominally white light-emitting diodes with different correlated color temperatures: the ratio between the intensity of the 2.75-eV blue peak (455 nm) and the yellow/orange peaks ranging from 2.20 eV (621 nm) to 2.25 eV (554 nm) increases with the CCT.

The high color-rendering index of LEDs comes from the fact that the yellow and blue spectra are continuous and smooth rather than exhibiting peaks like high-intensity discharge lamps. The LED emission spectra are very similar regardless of the CCT value: the correlation coefficient between 6500 K and 4000 K units is $C = 0.94$, between the 4000 K and 3000 K units $C = 0.97$, and between the 6500 K and 3000 K units $C = 0.83$.

C. Light source identification problem

The spectrum of night-time lights coming from the Earth is a mixture (an incoherent linear superposition) of many light sources. The photon flux from each of the light sources is first reflected from the ground surface with a magnitude reflection coefficient $R(E)$ that depends on the surface structure, angle of incidence and energy, and then transmitted through the atmosphere to the satellite. The transmission through the atmosphere is quantified with the transmission coefficient $T(E)$. The reflection spectrum $R(E)$ will be different for every installed light fixture, but for simplicity it makes sense to assume that $R(E)$ is a slow varying and smooth function of energy and that it represents an average over the angle of incidence and surface quality. Note that most of public illumination is installed over urban pavement and that an estimate of $R(E)$ can be determined experimentally. The transmission $T(E)$ can be determined from publicly available sources.

The spectra $P(E)$ (power spectral density) detected by the satellite may therefore be approximately written as,

$$P(E) = T(E) \cdot R(E) \cdot \sum_{k=1}^{n} c_k P_k(E) \qquad (1)$$

Here c_k is the power contribution of lamp type k in the view of the measurement equipment (e.g. camera pixel), while the number of possible emission sources is n. The task is to determine the c_k's with known $P_k(E)$ power spectral density for each lamp. If the power spectral densities of the sources $P_k(E)$ were orthogonal, this would be a relatively simple task, but the spectra exhibit a high degree of correlation as we confirmed in Figure 9. The bar graph in Figure 9 shows that the correlation between the 4000 K LED emission spectra and the other LEDs is high, but that the correlation with CFL and HG lamps are not small, which is what we would like to be able to extract one from the other. The lowest correlation is found between the LED4 and the HG mercury lamp. Clearly, a more sophisticated method for identifying the light source will have to be applied.

The analysis of commercially-used lamp emission spectra with the goal to identifying the type of light source from the emission has been successfully implemented by [10]. Their approach was to filter the spectrum captured from a mixture of lights into bands and the integral power in each band was used in a statistical correlation analysis to obtain the type of source with a certain confidence level. As we have seen in Figure 9, the fundamental difficulty in extracting the light-source type and hence the need for sophisticated statistical analysis stems from the fact that individual light-source emission spectra, and there are many, do not form an orthogonal set.

Another approach is to search for markers in the emission spectra. For example, low-pressure sodium (LPS) bulb has a strong emission at 589 nm and could be used to determine what fraction of the light is coming from LPS

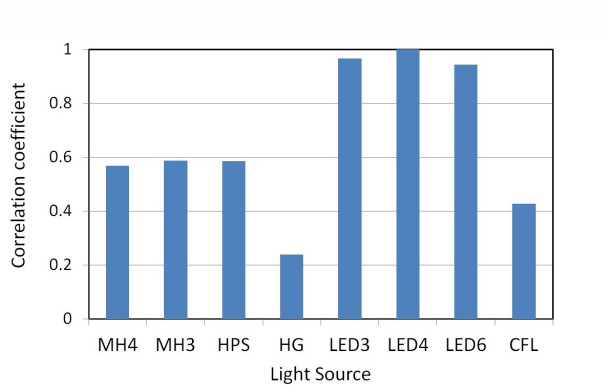

Fig. 9. The correlation coefficient between the LED4 and the selection of other sources.

by simply measuring emission strength in narrow bands below, around, and above the targeted marker and looking at the ratio of the three measured parameters.

A further difficulty arises from the product variability: not all metal halide, CFLs, and mercury vapor bulbs are the same. They vary between manufacturers and since their spectra depend on the chemistry of the halides and the phosphors, the emission spectra varies. As it is not clear how severe the variability is and this needs to be determined experimentally by collecting data on the light pollution spectra on the Earth and analyzing it to possibly develop an algorithm that will be imune to chemistry variation.

Finally, the spectral range of data collection is set to not wider than 350 nm to 1000 nm which can be accomplished with a silicon detector. An in-depth study of the spectra with a successful algorithm for identifying the type of light source was published by [10] and in that reference the authors made measurements with a spectrometer between 350 nm and 2400 nm, while the conclusion was that the wavelength range between 350 nm to 1000 nm is sufficient to reveal the spectra differences and identify the type of light source.

IV. Conclusion

Monitoring total light pollution from space has been active since the 1970-ies. The introduction of solid-state lighting and its associated blue-yellow emission spectrum have caused its own set of environmental concerns. Performing spectrally resolved night-time imaging of Earth is potentially a good approach to quantify the progress of solid-state lighting and light pollution on a global or local areas.

In this work we have shown measured emission spectra from conventional and solid-state light sources that one expects to see from space and discussed two potential approaches to detecting the origin of light pollution using spectrally resolved images from space.

V. Acknowledgement

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Application of the Combined Method for the Estimation of the RMS Measurement Error Caused by ADC Nonlinearity

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***Abstract* – Currently, digital methods are applied to measure the root mean square (RMS) of the signal in most cases. To obtain instantaneous values of the input signal in digital form, an analog-to-digital converter (ADC) is applied. Real ADCs have deviations (errors) of the conversion function from the linear one. These deviations can be presented as additive, multiplicative and nonlinear. Additive and multiplicative errors can be eliminated by zero adjustment and calibration of the measurement channel, respectively. To eliminate the nonlinearity of the ADC transfer function requires individual adjustment of the measurement channel of each device. This significantly increases the cost of the device. This article describes a technique ("combined" method of representation of the ADC nonlinearity), which allows to estimate of the RMS measurement error caused by the nonlinearity of the ADC transfer function. The analytical relations allowing to perform calculation of the error estimation are obtained. The proposed approach is compared with existing techniques. Simulation mathematical modeling is performed in Matlab and Simulink software packages. This allows to evaluate the correctness of the obtained analytical relations.**

Keywords – measurement error; root mean square; analog-to-digital converter; nonlinearity; approximation

I. INTRODUCTION

The root mean square value (RMS) is one of the most informative parameter of electrical network signals. The concept of RMS [1], [2] of periodical signal means the following value (definition of RMS):

$$X = \sqrt{\frac{1}{T_A}\int_{t_0}^{t_0+T_A} x(t)dt} = \sqrt{\sum_{i=0}^{K} X_i^2}\ , \qquad (1)$$

where $x(t)$ – input periodic signal; t_0 – start time of measurement; $T_A = mT$ – measurement interval; T – period of the input signal; X_i – RMS of the i-th spectral component of the input signal; K – number of considered spectral components.

In the case of digital measurement devices of RMS, an analog-to-digital converter (ADC) is applied to obtain the samples of input signal. The conversion function (CF) of the real ADC is nonlinear, which results to the measurement error of the signal samples and the RMS measurement error.

The form of ADC nonlinearity can be very different even within the same batch of ADC chips of the same type. To reduce the nonlinearity error, individual nonlinearity compensation [3] is required for each ADC. This results to a significant increase of the cost of the final measurement device and is not possible in practice. For this reason, it is important to develop effective analytical methods for estimating on the measurement error of RMS caused by the ADC nonlinearity. These procedures should be based on the use of the ADC parameters, specified by the manufacturer in ADC datasheet.

To estimate the RMS measurement error caused by ADC nonlinearity, there is a so-called "worst case" method [1], [4]. The main disadvantage of this method is a significant overstatement of the error estimation relative to its true value of error. The method based on the representation of nonlinearity as a random function [4] can be applied only to a limited number of ADCs, which are mainly based on successive-approximation register (SAR) architecture. In the case of pipeline or Sigma-Delta architectures, the application of this method results to an understatement of the error estimation. This paper is devoted to the application of the so-called "combined" method [5]-[7] of representation of ADC nonlinearity for estimation of the RMS measurement error. In the "combined" method, one of the error components refers to a random error. The results obtained earlier in [4] are used to estimate this component. The "combined" method can be successfully applied to ADCs of arbitrary architecture.

II. THE EFFECT OF ADC NONLINEARITY TO THE RMS MEASUREMENT ERROR

Digital RMS measurement device contains the ADC. The conversion function of the real ADC is not ideal: there are additive, multiplicative and nonlinear error components. In addition, there is a quantization error caused by the finite resolution of the applied ADC. Taking into account the ADC nonlinearity, the ADC output signal (given to the ADC input):

$$x_{real}(t) = x(t) + \Delta_{NL}(t)\ , \qquad (2)$$

where $\Delta_{NL}(t)$ – absolute value of the nonlinear component of the error of ADC CF; $x(t)$ – ADC input signal.

Substituting (2) into (1), we obtain:

$$X = \sqrt{X_{id}^2 + \frac{2}{T_A}\int_0^{T_A} x(t)\Delta_{NL}(t)dt + \frac{1}{T_A}\int_0^{T_A} \Delta_{NL}^2(t)dt}\ , \qquad (3)$$

where X_{id} – true (ideal) RMS value of the input signal.

Performing the decomposition of the square root function in Taylor series to two terms, the relative measurement error of RMS takes the following form:

$$\delta X = \frac{\Delta X}{X_{id}} \cong \frac{1}{T_A X_{id}^2}\left(\int_0^{T_A} x(t)\Delta_{NL}(t)dt + \frac{1}{2}\int_0^{T_A} \Delta_{NL}^2(t)dt\right). \quad (4)$$

For most forms of ADC nonlinearity the second term of (4) can be neglected.

III. Ways of Representing of ADC Nonlinearity

A. "Worst Case" Method

Since the form of ADC nonlinearity is unknown, there is a task of determining of the nonlinearity form, resulting to the maximum value of the RMS error. Regardless of the form of nonlinearity, is true:

$$-INL \cdot q \le \Delta_{NL}(t) \le INL \cdot q\ , \qquad (5)$$

where INL – maximal value of the ADC integral nonlinearity [8]; q – ADC least significant bit (LSB) [8].

The integral of the product $x(t)\cdot\Delta_{NL}$ (see (4)) will be maximum if the sign of this product is constant and its value is maximum for the entire integration interval. The RMS measurement error takes the maximum value when the following condition is true [8]:

$$\begin{cases} \Delta_{NL}(t) = INL \cdot q,\ for\ x(t) \ge 0, \\ \Delta_{NL}(t) = -INL \cdot q,\ for\ x(t) < 0. \end{cases} \qquad (6)$$

For the case of sinusoidal input (with amplitude – X_m; initial phase – α; angular frequency – $\omega = 2\pi f$), expression (4) takes the following form, taking into account of (6):

$$\delta X_{WC} = \frac{\Delta X_{WC}}{X_{id}} = \frac{4INL \cdot q}{\pi\sqrt{2}X_{id}}\ . \qquad (7)$$

It can be seen from the (7) that the obtained estimate of the RMS measurement error does not depend on the initial phase, measurement time and is additive in nature.

B. Approximation of the Polynomial Function

From the publication [9] it is known that the ADC nonlinearity can be approximated by a polynomial function of order D:

$$y(x) = P_D(x) = \sum_{i=0}^{D}\left(A_i F_i(x)\right), \qquad (8)$$

where y – ADC output signal (code); x – ADC input signal (voltage); A_i – i-th coefficient of approximating polynomial $P_D(x)$; $F_i(x)$ – i-th term of $P_D(x)$; D – polynomial order.

In the problem being solved, there is no possibility to perform additional researches of the form of ADC nonlinearity. Simulation results shows that the application of a third-order polynomial is effective for approximating the nonlinearity of most ADCs. The values of coefficients A_i of arbitrary order approximation polynomial $P_D(x)$ can be obtained by solving a equations system:

$$\mathbf{A} = \mathbf{X}^{-1}\mathbf{Y}\ , \qquad (9)$$

where $\mathbf{X}$ – matrix of input influences; $\mathbf{Y}$ – vector of ADC output responses (given to ADC input); $\mathbf{A} = (A_0 \ldots A_D)^{\mathbf{T}}$ – vector of coefficients of approximation polynomial.

For the case of a 3-rd order approximation polynomial:

$$\mathbf{A} = \begin{pmatrix} A_0 \\ A_1 \\ A_2 \\ A_3 \end{pmatrix}, \mathbf{X} = \begin{pmatrix} 1 & -x_N & x_N^2 & -x_N^3 \\ 1 & -x_L & x_L^2 & -x_L^3 \\ 1 & x_L & x_L^2 & x_L^3 \\ 1 & x_N & x_N^2 & x_N^3 \end{pmatrix}, \mathbf{Y} = \begin{pmatrix} 0 \\ -INL\ q \\ INL\ q \\ 0 \end{pmatrix}; \quad (10)$$

where x_L – the value of ADC input voltage for which the maximum value of the ADC nonlinearity is observed (to perform the correct approximation, select the position of the maximum of ADC nonlinearity $x_L = x_N / \sqrt{3}$); x_N – nominal (maximal) value of bipolar ADC input range.

When compiling the matrix $\mathbf{X}$ from (10), the nonlinearity should take zero values for the boundaries of the ADC input range (values $\pm x_N$). The x_L value should be chosen in such a way that it corresponds to the maximum of nonlinearity which is approximated by a third-order polynomial. This is achieved for the condition $x_L = x_N / \sqrt{3}$. For other x_L values the nonlinearity, value $INLq$ will be not reached for the maximum nonlinearity with the selected nonlinearity representation. In this case, for the input voltage values $\pm x_N / \sqrt{3}$, the nonlinearity value takes larger values (i.e., expression (5) is not satisfied). Values of polynomial coefficients for the case of the 3-rd order approximation polynomial:

$$\mathbf{A} = \begin{pmatrix} 0 & \dfrac{qx_N^2 INL}{(x_N{}^2 - x_L^2)x_L} & 0 & \dfrac{-qINL}{(x_N{}^2 - x_L^2)x_L} \end{pmatrix}^{\mathbf{T}}. \quad (11)$$

Substituting (8) with (11) into (4), we obtain a expression to estimate the RMS measurement error:

$$\delta X_{P3} = A_1 + 1.5A_3 X_{id}^2\ . \qquad (12)$$

C. Approximation by a Random Function (RF)

In the case of representing the ADC nonlinearity as a random function, the value of the nonlinearity is a random variable having one or another spectral distribution density. From the point of view of providing a metrological reserve, it is advisable to choose a uniform distribution density. The ADC nonlinearity is limited by the value of the integral nonlinearity (INL) of applied

ADC. The value of the nonlinearity of the considered method of approximation is determined by the expression:

$$\Delta_{NL}(x) = (rand(x)) \cdot INL \cdot q, \quad (13)$$

where *rand*(*x*) – random variable with a uniform distribution density in the range (-0.5 ÷ 0.5).

The results of simulation modeling shows that when representation the ADC nonlinearity by the form of a random function, the RMS measurement error depends on the limit value of the integral nonlinearity and the sampling rate of the input signal. And the dependence of the measurement error on the sampling frequency f_S is close to the parabolic curve. Then the dependence of the RMS measurement error from the ADC nonlinearity can be determined by applying the "worst case" method and additional approximating polynomial [4]:

$$\Delta X_N = \Delta X_{WC}\left(B_0 + B_1 (f_S)^{-1} + B_2 f_S\right), \quad (14)$$

where ΔX_{WC} – value of estimate of RMS measurement error obtained by the "worst case" method (see (7)); B_0, B_1, B_2 – coefficients of the approximating polynomial ΔX_N; f_S – sampling frequency.

The coefficients of the approximating polynomial ΔX_N were determined in [4] by simulation mathematical modeling in Matlab software package and their values for the sampling frequency range equal to (1 ÷ 20) kHz:

$$B_0 = 0.3425, \quad B_1 = 525.85954, \quad B_2 = -9.07 \cdot 10^{-6}. \quad (15)$$

An example of ADC with nonlinearity of considered type can be ADS8685 [10]. The typical nonlinearity of ADS8685 is shown in Fig. 2. The dependence of the ADC nonlinearity for most chips has a number of regularities. This results to the fact that the estimate of RMS measurement error by considered method is understatement relative to the true value of the error. To eliminate this disadvantage, a "combined" method is applied, which is described below.

D. "Combined" Method

In some publications [5]-[7] the so-called "combined" method for approximation and subsequent correction of ADC nonlinearity. The essence of this method is to represent the ADC nonlinearity in the form of a sum of three components: "smooth", "sawtooth" and having a "pseudo-random" behavior:

$$\Delta_{LIN}(x) = \Delta_S(x) + \Delta_L(x) + \Delta_N(x), \quad (16)$$

where $\Delta_S(x)$ – "smooth" component; $\Delta_L(x)$ – "sawtooth" component; $\Delta_N(x)$ – "pseudo-random" component.

This principle of representation of ADC nonlinearity is primarily applicable for of SAR and pipeline ADC architectures [6]-[7]. There is a method of determining the parameters of each of the components of the approximating function (16) by the values of the ADC nonlinearity obtained experimentally. The application of this technique requires extensive experimental data of the nonlinearity values of the considered ADC. For commercially available measurement devices, this is a significant drawback.

When describing the "pseudorandom" component, a random function is applied according to the principle described earlier in the section "*C. Approximation by a Random Function (RF)*". The "smooth" component is defined by a low order polynomial. The "sawtooth" component is represented by a piecewise linear function.

It is known [5]-[7] that the "sawtooth" component of the error is caused by the nonlinearity of the internal DAC, which is applied in SAR and pipeline architectures. The periodic piecewise linear function is applied for the analytical representation of this component of nonlinearity. For this reason, in each piecewise linear region, this nonlinearity can be approximated by a polynomial function of the first order. In the case of the approximation by *M* piecewise-linear plots, is true:

$$\begin{cases} b_i x + c_i = \Delta_L(x), \; for \;\; x_i \le x \le x_{i-1}, \\ b_i x_i + c_i = -0.5 \cdot q \cdot DNL, \\ b_i x_{i+1} + c_i = 0.5 \cdot q \cdot DNL, \\ x_i = x_{\min} + \Delta x \cdot (i-1), \; for \;\; i = 1 \div M; \end{cases} \quad (17)$$

where x_{min}, x_{max} – lower and upper limits of ADC input range; *M* – number of input subranges that can be distinguished from the experimental curve of ADC nonlinearity; x_{i+1}, x_i – upper and lower limits of *i*-th ADC input subrange; b_i, c_i – coefficients of the approximation polynomial for *i*-th ADC input subrange; $\Delta x = (x_{max} - x_{min}) / M$ – interval of ADC input subrange.

From the results of simulation it is known that the maximum RMS measurement error occurs at $M = 2$. Then (17) takes the form (under the condition of symmetry of the limits of ADC input range, $-x_{min} = x_{max} = x_N$):

$$\begin{cases} b_i = q \; DNL / x_N, \\ c_i = q \; DNL(1.5 - i), \; for \; i = 1 \div 2. \end{cases} \quad (18)$$

Since the slope coefficient of the approximating curve does not depend on the number of the subrange:

$$\begin{cases} b = b_i = b_j, \; for \; i, j = 1 \div M, \\ c = |c_i| = |c_j|, \; for \; i, j = 1 \div M. \end{cases} \quad (19)$$

The value of RMS measurement error caused by the "sawtooth" component can be obtained by substituting the (17) and (18) to (4):

$$\Delta X_L = 0.5(b_1 + b_2) X_{id} - (c_2 - c_1)\sqrt{2} / \pi. \quad (20)$$

A polynomial function is applied to analytically represent the "smooth" component (see (8)). This component of nonlinearity is caused by nonlinearity of internal sample-hold device, comparator, multiplexer (for multichannel ADCs) and input amplifier. It is known [5]-

[7] that a relatively low order polynomial is sufficient for approximation of "smooth" component. An example of ADC with dominant "smooth" nonlinearity component can be ADS1610 [11] (see Fig. 2).

To obtain the values of the coefficients $A_1 \div A_4$ of the "smooth" component, it is necessary to find the solution (9). However, since in this case the nonlinearity contains both "smooth" and "sawtooth" components, the solution will differ from (10). The values of nonlinearity at the boundaries of the ADC input range should be equal to zero. Therefore, the nonlinearity values of the "smooth" component should compensate the nonzero values of the "sawtooth" component for the boundary points of the ADC input range. The values of the **X** and **Y**:

$$\mathbf{X} = \begin{pmatrix} 1 & -x_N & x_N^2 & -x_N^3 \\ 1 & -x_L & x_L^2 & -x_L^3 \\ 1 & x_L & x_L^2 & x_L^3 \\ 1 & x_N & x_N^2 & x_N^3 \end{pmatrix}, \quad \mathbf{Y} = \begin{pmatrix} -0.5DNL\,q \\ -INL_S\,q \\ INL_S\,q \\ 0.5DNL\,q \end{pmatrix}. \quad (21)$$

As a result of the solution of (9) and (21):

$$\begin{cases} A_3 = -\dfrac{qx_N INL_S + x_L c}{(x_N{}^2 - x_L^2)x_N x_L} = -INL_S a_3 - \dfrac{c}{(x_N{}^2 - x_L^2)x_N}, \\ A_0 = A_2 = 0, \\ A_1 = \dfrac{x_L^3 c + qx_N^3 INL_S}{(x_N{}^2 - x_L^2)x_N x_L} = \dfrac{x_L^2 c}{(x_N{}^2 - x_L^2)x_N} + INL_S a_1; \end{cases} \quad (22)$$

where INL_S – integral nonlinearity of the "smooth" component; c – coefficient value from (18) and (19); to simplify (21) the replacement is made $a_1 = q\ x_N^2/(x_N^2 - x_L^2)\ x_L$; $a_3 = q/(x_N^2 - x_L^2)\ x_L$.

Thus, to determine the coefficients A_1 and A_3, the values of parameters x_L and INL_S are necessary. In the ADC datasheet is not enough information to uniquely assess the parameters of all three nonlinearity components. For this reason, three modifications of the ADC nonlinear representation by the "combined" method will be considered:

– nonlinearity is represented by "pseudo-random" and "sawtooth" components (CM_(L+N));

nonlinearity is represented by "smooth", "pseudo-random" and "sawtooth" components (CM_(S+L+N));

– nonlinearity is represented by "smooth" and "sawtooth" components (CM_(S+L)).

IV. The Application of the "Combined" Method for Estimation of the RMS Measurement Error

A. Representation of Nonlinearity by "Pseudo-random" and "Sawtooth" Components

In this approach, the maximum value of the ADC integral nonlinearity is the sum of the "pseudo-random" and "sawtooth" components. In (16) the parameter Δ_S corresponding to the "smooth" component of nonlinearity is equal to zero. This approach is effective for the ADC, which is not observed significant changes in the provisions of the piecewise-linear ("sawtooth" component) plots of the nonlinearity.

The value of the relative measurement error of RMS is determined by (4) taking into account (16) (component $\Delta_S = 0$). Since the "pseudo-random" component of error is determined by (14), and the "sawtooth" error component is determined by (7) and (20), the total RMS error:

$$\delta X = \frac{4INL_N q}{\pi\sqrt{2}X_{id}}\left(B_0 + B_1\frac{1}{f_S} + B_2 f_S\right) + b - \frac{2\sqrt{2}c}{\pi}, \quad (23)$$

where coefficients B_0, B_1, B_2 are determined by (15), and coefficients b, c are determined by (18) and (19); INL_N – integral nonlinearity of the "pseudo-random" component.

The value of INL_N is determined for the value of the input signal range at which the "sawtooth" component takes the greatest value:

$$INL_N = \Delta_{LIN}(x)\big|_{\max} - \Delta_L(x)\big|_{\max} = INL - 0.5 \cdot DNL. \quad (24)$$

The "sawtooth" component can be considered to be located symmetrically with respect to the zero value.

B. Representation of Nonlinearity by "Smooth", "Sawtooth" and "Pseudo-random" Components

The value of ADC integral nonlinearity is determined by (16), and at this approach we believe that all three components of nonlinearity are nonzero. The parameters of the "sawtooth" component are determined according to (18) and (19). The values of integral nonlinearity related to the "smooth" component (INL_S) can be determined by the typical dependence of nonlinearity, which is specified by the ADC manufacturer in datasheet. To determine this parameter, the difference of maximums of the "sawtooth" component (Δ_{PL}) can be calculated:

$$P_3(x_{i,\max}) - P_3(x_{i+1,\max}) = \Delta_{PL}, \quad (25)$$

where $x_{i,max}$, $x_{i+1,max}$ – positions of maximums of the "piecewise linear" component; $P_3(x)$ – a third-order polynomial which is applied to approximate a "smooth" component (see (8), (21)); i – number of maximum.

Performing substitution of (8) and (9) in (25), and performing simplifications, we obtain:

$$INL_S = \frac{\Delta_{PL}}{a_1 \cdot (x_{i,\max} - x_{i+1,\max}) + a_3 \cdot (x_{i,\max}^3 - x_{i+1,\max}^3)}. \quad (26)$$

If the "sawtooth" component prevails over the "smooth" component, then the value of integral nonlinearity related to the "pseudo-random" component is determined (see (24)):

$$INL_N = \Delta_{LIN}(x)\big|_{\max} - \Delta_L(x)\big|_{\max} = INL - 0.5 \cdot DNL, \quad (27)$$

otherwise, the expression can be applied:

$$INL_N = INL - \Delta_S(x_L) - \Delta_L(x_L). \quad (28)$$

In any case, from the INL_N values obtained by (27) and (28), the smaller should be chosen. The total RMS measurement error is determined by the sum of the errors from each of the considered nonlinearity components. Since the "smooth" component error is determined by (12), the "sawtooth" component error is determined by (20), and the "pseudo-random" component error is determined by the (14), the total RMS measurement error:

$$\delta X = A_1 + \frac{3}{2} A_3 X_{id}^2 + 2b - \frac{2\sqrt{2}}{\pi} c + \frac{\Delta X_N}{X_{id}}, \quad (29)$$

where coefficients A_0 – A_3 are determined by (21); coefficients of b, c are determined by (18) and (19); INL_S value is determined by (26); the error ΔX_N is determined by (14); the values of B_0, B_1, B_2 are determined by (15).

C. *Representation of Nonlinearity by "Smooth" and "Sawtooth" Components*

Simulation results shows that for three considered nonlinearity components, the "pseudo-random" one has the least impact on the RMS measurement error. If the "pseudo-random" component of nonlinearity (component Δ_N in (16)) equals to zero, then this will provide some metrological margin in nonlinearity representation. In this case the RMS relative error can be calculated by using a formula similar to (29) with ΔX_N component equal to zero. The value of INL_S parameter should be equal to:

$$INL_S = \Delta_{LIN}(x)\big|_{\max} - \Delta_L(x_x)\big|_{\max} = INL - bx_L - c. \quad (30)$$

V. Simulation Modeling

Comparative analysis of the effectiveness of the RMS measurement error estimating methods are presented in Table I. When performing the analysis were discussed three different ADC: ADS8685 [10]; ADS8472 [12] (architecture of both chips – SAR) and ADS1610 [11] (architecture – Sigma-Delta). Manufacturer of all chips – Texas Instruments company. A typical dependence (top) of the ADCs nonlinearity are shown in Fig. 2. This figure is based on datasheets information provided by manufacturers [10]-[12]. The rows of Table I present the results of simulation in the software package Matlab for estimation methods of RMS error that have been discussed earlier. Simulation modeling is performed with the following parameters: sinusoidal input voltage of unit amplitude ($X_{id} = 1 / \sqrt{2}$); frequency – 50 Hz; interval of measurement – 0.02 sec; sampling frequency – (5 ÷ 17) kHz; initial phase – 0 rad. The dependences of the ADCs nonlinearity, which are used in the simulation, are shown in Fig. 2 (below). The simulation results are obtained for the input signal with the amplitude corresponding to the ADC input range. This situation is most typical for the case of voltage measurement, the dynamic range of which is small. For the current, large changes in the amplitude value are possible, which is usually eliminated by the application of a programmable gain amplifier (PGA).

The dependence of the RMS relative measurement error (caused by the ADC nonlinearity) by the amplitude of the sinusoidal input signal is shown in Fig 1. It should be noted that the distortions of the ADC output signal spectrum, resulting to the appearance of harmonic distortion are taken into account when calculating the RMS measurement error. For the case of ADCs with a significant "pseudo-random" nonlinearity component, the relative error has a sharply uneven nature and have a tendency to increase with a decrease of amplitude of the input signal. This is due to the fact that for such ADC type, the absolute value of nonlinearity can reach a maximum value for any point of the input range. In the case of Sigma-Delta ADCs, the dependence of the RMS error is smoother. For the considered form of nonlinearity, the relative error at first tends to increase (the value of nonlinearity increases), and then to decrease (after the nonlinearity reaches its maximum value).

VI. Conlusion

Based on the stated material, the following conclusions can be drawn.

The "worst case" method gives highly significant overstatement of the RMS error estimate in comparison with all other considered methods. The method based on the approximation of the signal by a 3-rd order polynomial can be applied to estimate the nonlinearity of the ADC having a relatively smooth nonlinearity curve (for example, for the Sigma-Delta ADC architecture).

Three modifications of the "combined" method of approximation of ADC nonlinearity are considered. Depending on the form of the ADC nonlinearity, one or another method of approximation can be applied. If the behavior of ADC nonlinearity is close to random, the representation of the nonlinearity in the form of random function or the "combined" method in the modification CM_(L+N) are most effective. If the nonlinearity of the ADC contains an explicit "smooth" nonlinearity component (for example, for ADC ADS1610), the most effective is a "combined" method in the modification CM_(S+L+N). The modification of CM_(S+L) of the "combined" method yields to overstatement of the error estimate compared to the modification of CM_(S+L+N). However, the application of modification CM_(S+L) to obtain the RMS error estimate in practice is easier.

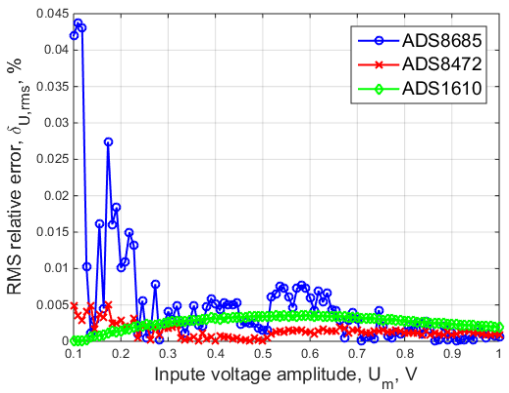

Figure 1. The dependence of the RMS measurement error from the amplitude value of a input sinusoidal signal

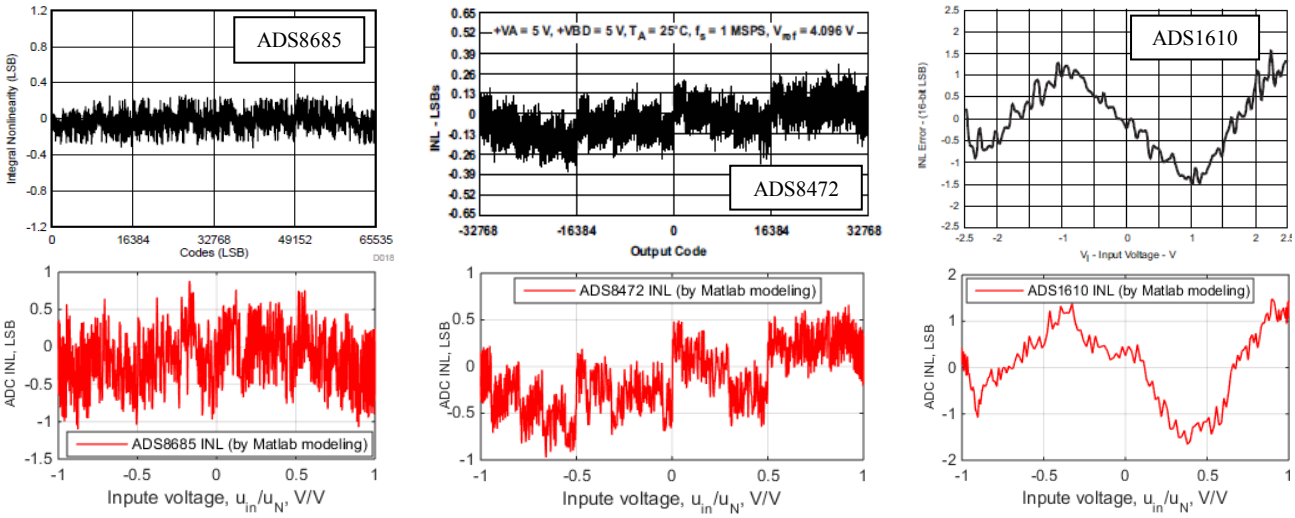

Figure 2. The typical dependences of ADC nonlinearity (top, from left to right) and results of ADC nonlinearity modeling of in matlab (bottom, from left to right) of ADS8685 [10], ADS8472 [12], ADS1610 [11]

TABLE I. THE VALUE OF RELATIVE MEASUREMENTS ERRORS OF RMS (IN PERCENT) BY DIFFERENT ESTIMATION METHODS

ADC	Parameter			Method of error estimation, expressions for calculation	Sampling frequency, kHz				
	N, bit	*INL, LSB*	*DNL, LSB*		5.0	8.0	11.0	14.0	17.0
ADS8685	16	1.2 (max)	0.7 (max)	Experimental (modeling)	$1.2\ 10^{-3}$	$1.1\ 10^{-3}$	$9.3\ 10^{-4}$	$5.1\ 10^{-4}$	$6.8\ 10^{-4}$
				"Worst case" – (7)	$4.7\ 10^{-3}$	$4.7\ 10^{-3}$	$4.7\ 10^{-3}$	$4.7\ 10^{-3}$	$4.7\ 10^{-3}$
				Polinomial, 3-rd order – (12)	$2.4\ 10^{-3}$	$2.4\ 10^{-3}$	$2.4\ 10^{-3}$	$2.4\ 10^{-3}$	$2.4\ 10^{-3}$
				RF – (14), (15)	$1.9\ 10^{-3}$	$1.6\ 10^{-3}$	$1.4\ 10^{-3}$	$1.2\ 10^{-3}$	$9.5\ 10^{-4}$
				CM_(L+N) – (23), (24)	$2.6\ 10^{-3}$	$2.3\ 10^{-3}$	$2.1\ 10^{-3}$	$1.9\ 10^{-3}$	$1.8\ 10^{-3}$
				CM_(S+L+N) – (26)-(29)	$2.6\ 10^{-3}$	$2.3\ 10^{-3}$	$2.1\ 10^{-3}$	$2.0\ 10^{-3}$	$1.8\ 10^{-3}$
				CM_(S+L) – (29), (30)	$3.1\ 10^{-3}$	$3.1\ 10^{-3}$	$3.1\ 10^{-3}$	$3.1\ 10^{-3}$	$3.1\ 10^{-3}$
ADS8472I	16	1.0 (max)	0.75 (max)	Experimental (modeling)	$1.4\ 10^{-3}$	$1.4\ 10^{-3}$	$1.2\ 10^{-3}$	$1.1\ 10^{-3}$	$8.9\ 10^{-4}$
				"Worst case" – (7)	$3.9\ 10^{-3}$	$3.9\ 10^{-3}$	$3.9\ 10^{-3}$	$3.9\ 10^{-3}$	$3.9\ 10^{-3}$
				Polinomial, 3-rd order – (12)	$2.0\ 10^{-3}$	$2.0\ 10^{-3}$	$2.0\ 10^{-3}$	$2.0\ 10^{-3}$	$2.0\ 10^{-3}$
				RF – (14), (15)	$1.6\ 10^{-3}$	$1.3\ 10^{-3}$	$1.1\ 10^{-3}$	$9.8\ 10^{-4}$	$8.5\ 10^{-4}$
				CM_(L+N) – (23), (24)	$2.3\ 10^{-3}$	$2.1\ 10^{-3}$	$1.9\ 10^{-3}$	$1.8\ 10^{-3}$	$1.6\ 10^{-3}$
				CM_(S+L+N) – (26)-(29)	$2.4\ 10^{-3}$	$2.1\ 10^{-3}$	$2.0\ 10^{-3}$	$1.9\ 10^{-3}$	$1.8\ 10^{-3}$
				CM_(S+L) – (29), (30)	$2.7\ 10^{-3}$	$2.7\ 10^{-3}$	$2.7\ 10^{-3}$	$2.7\ 10^{-3}$	$2.7\ 10^{-3}$
ADS1610	16	1.5 (max)	0.5 (max)	Experimental (modeling)	$2.6\ 10^{-3}$	$2.4\ 10^{-3}$	$2.2\ 10^{-3}$	$2.0\ 10^{-3}$	$1.9\ 10^{-3}$
				"Worst case" – (7)	$5.8\ 10^{-3}$	$5.8\ 10^{-3}$	$5.8\ 10^{-3}$	$5.8\ 10^{-3}$	$5.8\ 10^{-3}$
				Polinomial, 3-rd order – (12)	$3.0\ 10^{-3}$	$3.0\ 10^{-3}$	$3.0\ 10^{-3}$	$3.0\ 10^{-3}$	$3.0\ 10^{-3}$
				RF – (14), (15)	$2.3\ 10^{-3}$	$2.0\ 10^{-3}$	$1.7\ 10^{-3}$	$1.5\ 10^{-3}$	$1.3\ 10^{-3}$
				CM_(L+N) – (23), (24)	$2.8\ 10^{-3}$	$2.5\ 10^{-3}$	$2.2\ 10^{-3}$	$2.0\ 10^{-3}$	$1.8\ 10^{-3}$
				CM_(S+L+N) – (26)-(29)	$3.1\ 10^{-3}$	$2.8\ 10^{-3}$	$2.6\ 10^{-3}$	$2.5\ 10^{-3}$	$2.4\ 10^{-3}$
				CM_(S+L) – (29), (30)	$3.5\ 10^{-3}$	$2.8\ 10^{-3}$	$2.6\ 10^{-3}$	$2.5\ 10^{-3}$	$2.4\ 10^{-3}$

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Sizing CMOS operational transconductance amplifiers applying NSGA-II and MOEAD

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***Abstract*—Sizing analog integrated circuits (ICs) is a challenge due to the many trade-offs among their target specifications. For example, it has been shown that the operational transconductance amplifier (OTA) has a huge plethora of applications in analog electronic circuits. It can be designed using complementary metal-oxide-semiconductor (CMOS) IC technology. However, as CMOS technology scales down to the nanometer regime, many design problems arise to accomplish target specifications, and this task become impossible to mitigate when performing traditional manual design. In this manner, this article shows the usefulness of applying multi-objective optimization to size CMOS OTAs. NSGA-II and MOEAD are well-known evolutionary algorithms that can be applied to optimize CMOS ICs, and they are applied herein using CMOS technology of 350 nanometers. Both optimizers are tested using four indicators, namely: hypervolume, Δ_p, spacing and coverage. It is highlighted that NSGA-II is better than MOEAD, and it generates feasible solutions providing gains higher than 80dB and bandwidths in the range of MHz.**

***Index Terms*—OTA; sizing; optimization; CMOS; NSGA-II, MOEAD**

I. Introduction

The automatic design of analog circuits is challenging because the IC technology changes every year to accomplish target specifications imposed by modern applications [1]–[3]. In analog circuits, the optimal sizing can reduce the encoding of the design variables [4], because some transistors can have the same sizes and others can have scale values. However, the optimization process will include huge search spaces of the design variables, and the target specifications must accomplish many performances like high-gain and frequency response of an amplifier, wide dynamic range of signal processing, minimal noise and distortion, and so forth. In this manner, some contributions are focused on reaching high frequency responses using silicon-based technology [5]. In the majority of analog designs, complementary metal-oxide-semiconductor (CMOS) IC technology is good enough, and it is useful to accomplish high frequencies [6]. Nanometer CMOS technology requires the estimation of parasitics that generate undesirable effects in analog and RF ICs, and it is not a trivial task as shown in [7]. In this manner, multi-objective optimization approaches have demonstrated to be good methods for the optimal sizing of CMOS ICs [8], and some works include statistical variation analyses [9]. Other contributions introduce hybrid sizing tools [10], which can be very useful for estimating ranges of voltages and current biases, and of the search spaces of the design variables.

In this article we show the application of two metaheuristics for sizing OTAs, namely: the non-dominated sorting genetic algorithm (NSGA-II [11]) and multi-objective evolutionary algorithm with decomposition (MOEAD [12]). Both metaheuristics are applied to size an OTA using CMOS technology of 350 nanometers, and linking the circuit simulator ngspice [13]. We compare the feasible sized solutions provided by both algorithms using four indicators: hypervolume, Δ_p, spacing and coverage. We show the best feasible solutions combining all generations, and also we apply MOEAD adding rules from NSGA-II to handle the constraints on optimizing the OTA. Both metaheuristics have the objectives to maximize gain (measured in dB) and bandwidth (measured in Hz at -3 dB roll-off frequency). In this manner, the sizing is formulated as a bi-objective problem. The constraints accomplish that all MOS transistors work in the saturation mode.

The rest of this article is organized as follows: In Sect. II, NSGA-II and MOEAD are described to perform multi-objective optimization in the sizing of an OTA. Section III details the CMOS OTA and the encoding of the design variables, and formulates the sizing as a bi-objective optimization problem. Numerical results provided by the metaheuristics are given in IV. Finally, the conclusion is given in V.

II. NSGA-II and MOEAD

Optimization refers to finding the best possible solution to a problem given a set of constraints [14]. For a multi-objective optimization problem (MOP), one encounters conflicting objectives that provide a set of feasible solutions. In this work, the sizing problem of an OTA is formulated as a bi-objective problem subject to constraints that are associated to the bias conditions of every MOS transistor.

A MOP with k objectives can be formulated as [15]:

$$\begin{aligned} &\min_{x\in\Omega} F(x), \\ &\text{s.t. } g(x) \leq 0 \\ &\quad h(x) = 0. \end{aligned} \tag{1}$$

In this case, $F : \Omega \to \mathbb{R}^k$ is defined as the vector of the objective functions

$$F(x) = (f_1(x), \ldots, f_k(x))^T, \tag{2}$$

where $f_i : \Omega \to \mathbb{R}$ denotes the i-th objective associated to a target specification. The domain of F is defined as

$$D := \{x \in \Omega \ : \ g(x) \leq 0 \text{ and } h(x) = 0\}. \tag{3}$$

The optimality of a MOP is defined by the concept of *dominance*.

(a) Let $v, w \in \mathbb{R}^k$. Then the vector v is *less than* w ($v <_p w$), if $v_i < w_i$ for all $i \in \{1, \ldots, k\}$. The relation $\leq_p$ is defined analogously.
(b) A vector $y \in D$ is *dominated* by a vector $x \in D$ ($x \prec y$) with respect to (1) if $F(x) \leq_p F(y)$ and $F(x) \neq F(y)$, else y is called non-dominated by x.
(c) A point $x \in D$ is called *(Pareto) optimal* or a *Pareto point* if there is no $y \in D$ which dominates x.
(d) The set P_D of all Pareto optimal solutions is called the *Pareto set* and its image $F(P_D)$ the *Pareto front*.

NSGA-II is a domination-based multi-objective evolutionary algorithm, and directly applies the Pareto dominance relation and an elitism strategy to preserve the best individuals along the optimization process. The elitism operator is incorporated via a special parent selection based on two mechanisms: fast-non-dominated-sort and crowding distance. The former, conserves best individuals based on the Pareto dominance relation, whereas the latter is used to promote the preservation of the diversity. The pseudocode of NSGA-II is listed in Algorithm 1.

Algorithm 1 Pseudocode of NSGA-II

Require: Population size (P_s), ProblemSize ($size$), crossover probability (P_c), mutation probability (P_m)
Ensure: Children
0: Population ← `InitializePopulation`(P_s, ProblemSize)
0: `EvaluateAgainstObjectiveFunctions`(Population)
0: `FastNondominatedSort`(Population)
0: Selected ← `SelectParentsByRank`(Population, P_s)
0: Children ← `CrossoverAndMutation`(Selected, P_c, P_m)
0: **while** ¬StopCondition() **do**
0: `EvaluateAgainstObjectiveFunctions`(Children)
0: Union ← Merge(Population, Children)
0: Fronts ← `FastNondominatedSort`(Union)
0: Parents ← ∅
0: $Front_L \leftarrow \emptyset$
0: **for** $Front_i \in$ Fronts **do**
0: `CrowdingDistanceAssignment`($Front_i$)
0: **if** Size(Parents)+Size($Front_i$) $> P_s$ **then**
0: $Front_L \leftarrow i$
0: **break**
0: **else**
0: Parents ← Merge(Parents, $Front_i$)
0: **end if**
0: **if** Size(Parents)¡P_s **then**
0: $Front_L \leftarrow$ `SortByRankAndDistance`($Front_L$)
0: **for** P_1 **to** $P_{P_s-\text{Size}(Front_L)}$ **do**
0: Parents ← Pi
0: **end for**
0: **end if**
0: Selected ← `SelectParentsByRankAndDistance` (Parents, P_s)
0: Population ← Children
0: Children ← `CrossoverAndMutation`(Selected, P_c, P_m)
0: **end for**
0: **end while**
0: **return** Children =0

MOEAD is part of the Decomposition-Based Evolutionary Algorithms, which transform the original multi-objective optimization problem into a set of single-objective optimization problems that are simultaneously solved. In particular, this method takes a set of weights to define neighborhoods. The set of nearest weights defines one neighborhood and the best individuals are selected based on the value of a certain aggregative function. MOEAD considers the weighted aggregation of objectives as an elitism mechanism. Furthermore, the neighborhood structure promotes the mating of close solutions. Different aggregative functions can be used with the MOEAD framework. In this work we employ the Tchebycheff function, which is the most popular approach. The pseudocode of MOEAD is listed in [12].

III. Sizing an OTA applying metaheuristics

The OTA can be described by the circuit symbol shown in Fig. 1. The ideal characteristic of this device is described as $I_o = g_m(V_1 - V_2)$, where I_o is the output current, g_m is the transconductance gain, and V_1, V_2 denote the non-inverting input voltage and the inverting input voltage, respectively.

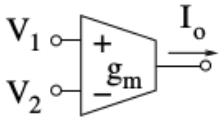

Fig. 1. Electrical symbol of the OTA.

The OTA can be designed using a single or a set of MOS transistors arranged by stages. In this work, the OTA is designed by two stages and is optimized using CMOS IC technology. The OTA is taken from [16] and consists of 12 MOS transistors, as shown in Fig. 2. As one sees, the MOS transistors are connected in a symmetrical way to provide two current outputs I_o that are considered as negative or positive ones. The OTA has six P-type MOS transistors (represented by M_{Pi} , for $i = 1, 2, \ldots, 6$), and six N-type MOS transistors (denoted by M_{Ni}, for $i = 1, 2, \ldots, 6$).

Each MOS transistor has a width (W) and length (L) sizes of its gate-channel. However, from the IC design point of view, and considering the symmetry of the OTA, the sizes W/L of M_{N3} and M_{N4} must be equal because they form a differential pair. Another building block is the current mirror, that is present in this OTA in the groups of MOS transistors M_{P1}, M_{P2}, M_{P3} and M_{P4}, M_{P5}, M_{P6} for the P-type and in the groups M_{N2}, M_{N5} and M_{N1}, M_{N6} for the N-type. In order to simplify the analysis, the sizing problem is established to have the same L for all MOS transistor, so that the encoding of the design variables are listed in Table I, and then, the design variables vector becomes $[W_1, W_2, W_3, W_4, W_5, I_{bias}]$. Therefore, the metaheuristics are applied to find optimal Ws with the constraint that all MOS transistors must work in the saturation mode.

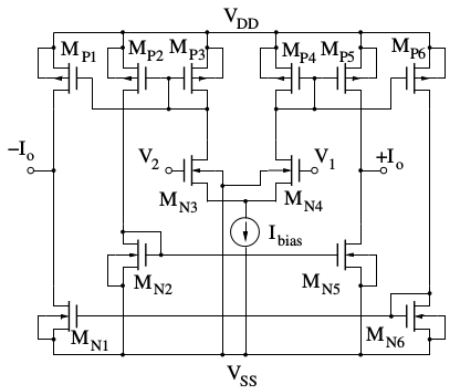

Fig. 2. CMOS OTA taken from [16].

TABLE I
ENCODING OF THE DESIGN VARIABLES OF THE OTA SHOWN IN FIG. 2.

Design Variable	MOS transistors
W_1	M_{P2}, M_{P3}, M_{P4}, and M_{P6}
W_2	M_{P1} and M_{P5}
W_3	M_{N3} and M_{N4}
W_4	M_{N2} and M_{N6}
W_5	M_{N1} and M_{N5}
I_{bias}	Bias to all transistors

The objective functions of the OTA are associated to the Bandwidth (f_1) and Gain (f_2) that are maximized. However, since NSGA-II and MOEAD run with normalized minimization functions, then f_1, f_2 are normalized [0,1], and for the minimization process they become $f_1 = -Bandwidth/\left|max(Bandwidth) - min(Bandwidth)\right|$, and $f_2 = -Gain/\left|max(Gain) - min(Gain)\right|$. In both metaheuristics the population is evolved until a determined number of generations, and each individual is evaluated by performing the following steps:

1) Generate a text file suitable for ngspice
2) Execute ngspice to evaluate individuals and generate output text-files listing the objectives (G and BW)
3) Extract from the text-file the values of G and BW, and verify the working conditions of the MOS transistors. This task is performed by extracting the gate-to-source voltage $V_{gs}^{(j)}$, the threshold voltage $V_{th}^{(j)}$, and the drain-to-source voltage $V_{ds}^{(j)}$, of the j-th MOS transistor. The constraint is assigned to r_j in (4), which ensures that each MOS transistor works in the saturation region.

$$r_j = \begin{cases} 1, & \text{if } |V_{gs}^{(j)}| > |V_{th}^{(j)}| \text{ and} \\ & |V_{ds}^{(j)}| > |V_{gs}^{(j)}| - |V_{th}^{(j)}|, \\ -1, & \text{otherwise.} \end{cases} \quad (4)$$

Since the source codes of both NSGA-II and MOEAD are freely available in C, we decided to use the `fork()`, `execve()`, and `waitpid()` C schemes to launch ngspice. Some steps can be programmed in the scripting languages Perl or Python to parse the text-files. We also used the constraint handling building inside NSGA-II and we adapted MOEAD with the same feasibility rules.

IV. NUMERICAL SIMULATION RESULTS

For the NSGA-II parameters we use 100 generations, 50 individuals, crossover probability of 0.7, mutation probability of 0.25, $\eta_c = 15$, and $\eta_m = 20$. Same parameters are used for the MOEAD with the additional parameter of neighborhood size, which was equal to 10. The search space for the first variable was the interval [1,10], and [1,1000] for the rest of variables, except for the variable that codes the biases. We used voltage bias of $V_{DD} = -V_{SS}$=1.5 V and $I_{bias} = 50\mu A$.

Three runs with different seeds for the random number generator were performed. The Pareto fronts of the three runs are shown in Fig. 3. As some of the results are equal on the three fronts, then we believe that the feasible solutions reach the true Pareto front. In Table II, we compare the feasible sized solutions provided by both algorithms using four indicators: hypervolume, Δ_p, spacing and coverage. We show the best feasible solutions combining all generations, and also we applied MOEAD adding rules from NSGA-II to handle the restrictions on optimizing the OTA.

We choose a solution with gain G=48.18 dB, and bandwidth BW=1 MHz. The corresponding design variables values is the vector [3, 353, 136, 4, 424, 50], which leads the values $W_p = 13.2\mu m$ for transistors M_{P2} , M_{P3}, M_{P4}, and M_{P6}; $W_p = 1553.2\mu m$ for M_{P1}, and M_{P5}; $W_n = 136.0\mu m$ for M_{N3}, and M_{N4}; $W_n = 4.0\mu m$ for M_{N2}, and M_{N6}; $W_n = 424.0\mu m$ for M_{N1}, and M_{N5}; and bias current $I_{bias} = 50\mu A$. The transconductance gain of this OTA is $g_m = 56mA/V$. One can choose another feasible solution, which will have different sizes and electrical characteristics. For example, selecting the appropriate sized OTA for a specific application requires to verify statistical variation analyses, power consumption, noise, slew rate, distortion, layout area [9], and so on.

There are three sets of feasible solutions as shown in Fig. 3, the ones provided by NSGA-II and MOEAD, and the ones that are the best, which were obtained after combining all generations. The comparison of the solutions was done using four indicators: hypervolume, Δ_p, spacing and coverage, and they are listed separately when executing NSGA-II and MOEAD, as shown in Table II. In this case one can appreciate that for the sizing problem of the OTA, NSGA-II is better than MOEAD. In fact, looking at Fig. 3, it can be appreciated that the feasible solutions provide gains higher than 80dB and bandwidths in the range of MHz.

V. CONCLUSION

We showed the application of NSGA-II and MOEAD in the multi-objective optimization problem associated to sizing an OTA. This problem was formulated to have two objectives, 12 constraints (all MOS transistors working in the saturation region), and 6 design variables associated to the widths of the MOS transistors and the current bias. Solving the sizing problem with NSGA-II and MOEAD, a critical step was to choose a correct representation and meaning of the design

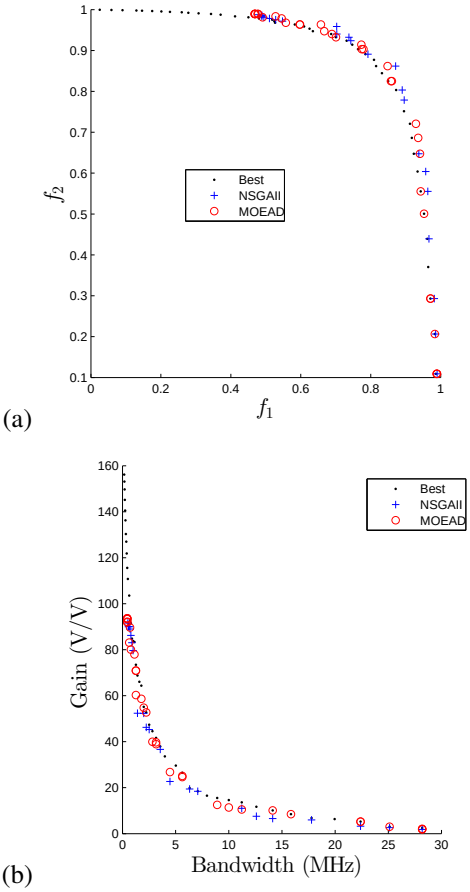

Fig. 3. Feasible sized solutions trading gain and bandwidth of the OTA applying NSGA-II and MOEAD.

TABLE II
VALUES FOR HYPERVOLUME, Δ_p, SPACING AND COVERAGE FOR THE BIOBJECTIVE PROBLEM. THE VALUES MINIMUM, MEAN (WITH STANDARD DEVIATION) AND MAXIMUM ARE SHOWN. (p-VALUE FOR THE WILCOXON TEST ON THE HYPERVOLUME 0.000111, WE CAN CONCLUDE THAT NSGA-II IS BETTER THAN MOEAD FOR THIS PROBLEM.)

Indicator	**NSGA-II**	**MOEAD**
Hypervolume	0.0400	0.0076
	0.0562 (0.007484)	0.0369 (0.020232)
	0.0680	0.0740
Δ_p	0.0831	0.0497
	0.2071 (0.065354)	0.2520 (0.060429)
	0.3445	0.3453
Spacing	0.0083	0.0045
	0.0280 (0.008434)	0.0141 (0.007438)
	0.0539	0.0385
Coverage	0.00 %	0.00 %
	29.09 % (19.8573)	18.95 % (22.3151)
	85.00 %	68.42%

variables. We showed the encoding considering five design variables associated to the Ws of the MOS transistors, and one to the bias current. The objective functions were associated to maximize gain and bandwidth, and the metaheuristics provided a gain higher than 80dB and bandwidth in MHz. In this paper MOEAD was applied through adding rules from NSGA-II to handle the constraints on optimizing the OTA. As a result, we showed the best feasible sized solutions combining all generations, and also the corresponding feasible solutions for each metaheuristic, which comparison was done using four indicators: hypervolume, Δ_p, spacing and coverage.

ACKNOWLEDGMENT

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A New Nonlinear Dynamical Model with Three Quadratic Nonlinear Terms and Hidden Chaos

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***Abstract*—A new nonlinear dynamical model with three quadratic nonlinear terms is introduced in this work. Lyapunov exponents are calculated to discover properties such as dissipativity and chaotic behavior. It is also established that there is no rest point for the proposed nonlinear plant signifying that the dynamical model undergoes hidden chaotic behavior. The proposed hidden chaotic system is implemented using electronic devices, which simulation results are in good agreement with MATLAB simulations.**

***Index Terms*—Chaos, chaotic systems, hidden attractor, nonlinear plant, dynamical systems, circuit model.**

I. Introduction

Nowadays, chaotic systems have a new classification that can be performed according to their nonlinear dynamics, so that one can distinguish two kinds of attractors: self-excited attractor and hidden attractor. In the former case, the attractor has a basin of attraction that is excited from unstable equilibrium point. As already mentioned in [1], the classical systems under this category are the classical nonlinear systems such as Lorenz's, Rössler's, Chen's, Lü's, or Sprott's systems. However, nowadays systems with hidden attractors have received great attention from both the theoretical and practical point of views. Self-excited attractors can be localized straightforwardly yet applying manual calculations. In contrast, one must develop specific computational procedures to identify a hidden attractor because the evaluation of their equilibrium points is difficult and they do not help in their localization.

Chaotic systems have a variety of engineering applications, as in the transmission of data. For example, Liu in [2] is proposing a direct acquisition algorithm using chaotic sequences to improve the communication systems based on chaotic DSSS signals, which aids in overcoming difficulties in different acquisition problems. Gohari et al. [3] proposed an algorithm for 3-D planning using chaotic maps for the motion planning and regulation of a quadrotor for boundary surveillance applications. For secure systems, Wang and Li [4] devised a color image encryption method which is constructed using Hopfield chaotic neural network. Hua *et al.* [5] dealt with the image encryption problem by proposing a cosine-transform-based chaotic system, which is useful in cryptography. Naseer *et al.* [6] proposed a new approach to improve the security of multimedia systems using a chaotic map. Zarebnia *et al.* [7] investigated the image encryption problem for gray scale images with a numerical algorithm based on hybrid chaotic dynamical systems. Nasr *et al.* [8] investigated the problem of workspace coverage for mobile robotic motion with a flatness controller and multi-scroll chaotic attractor. Karakaya *et al.* [9] proposed a memristive chaotic circuit and discussed also FPGA implementation and TRBG based on it. Wang and Dong [10] discussed a 4-D autonomous quadratic hyperchaotic system from the classical Lorenz system and built an electronic circuit design. As one sees, the development of new chaotic systems opens the possibility of improving such kinds of applications.

This research work introduces a new nonlinear dynamical model with three nonlinear terms of quadratic polynomial type. To ensure that the proposed dynamical model is chaotic, Lyapunov exponents are calculated using time-series of the solutions, which also help to discover properties such as dissipativity and chaoticity. The dynamical analysis shows that there is no rest point for the proposed nonlinear plant, in this sense one can say that this new nonlinear dynamical model undergoes hidden chaotic behavior [1].

Section II introduces the new nonlinear dynamical model, which dynamical analysis confirms that the attractor is hidden. Numerical simulations are performed to observe the corresponding attractor in different phase-space portraits. Section III shows the scaling of the original new nonlinear dynamical model, in order to perform a circuit simulation using MultiSim. Finally, the conclusions are given in Section IV.

II. A New Nonlinear Hidden Chaos Model

The new nonlinear dynamical model with three quadratic nonlinear terms is given in (1). It can be appreciated that is has three state variables ξ_1, ξ_2, ξ_3.

$$\begin{cases} \dot{\xi}_1 = \xi_2 \\ \dot{\xi}_2 = a\xi_1\xi_3 + b\xi_2^2 - c\xi_2 - \xi_2\xi_3 \\ \dot{\xi}_3 = \xi_2^2 - 1 \end{cases} \quad (1)$$

In the plant modeled by the dynamical equations from (1) one can see three coefficients a, b and c. The appropriate values of these parameters to produce a positive Lyapunov exponent to confirm chaotic behavior are $(a,b,c) = (0.1, 0.1, 0.15)$. In this manner, the three Lyapunov exponents of (1) are estimated in MATLAB after $T = 1E5$ seconds for and $\xi(0) = (0.2, 0.2, 0.2)$. It results in $(LE_1, LE_2, LE_3) = (0.0536, 0, -0.1829)$. Therefore, in view of the signs $(+, 0, -)$ of the Lyapunov exponents and having a negative sum, it follows naturally that this new nonlinear dynamical model exhibits dissipative chaotic motion.

The equilibrium or rest points of the new chaotic model given by (1) are evaluated from the following equations:

$$\xi_2 = 0 \quad (2a)$$

$$a\xi_1\xi_3 + b\xi_2^2 - c\xi_2 - \xi_2\xi_3 = 0 \quad (2b)$$

$$\xi_2^2 - 1 = 0 \quad (2c)$$

From (2a), $\xi_2 = 0$, which contradicts (2c). In this manner, one concludes that there is not a defined rest point for this 3-D nonlinear dynamical model, and then it signifies that the model given by (1) exhibits hidden chaos motion [1].

The different phase-space portraits 2D views of this hidden chaotic attractor are shown in Figures 1, 2, and 3, and a 3D view is given in Fig. 4. The numerical simulations can be performed using the fourth order Runge-Kutta Method in MATLAB. In all cases the simulations were performed setting the parameters $(a,b,c) = (0.1, 0.1, 0.15)$ and using the initial conditions $\xi(0) = (0.2, 0.2, 0.2)$.

The mathematical model given in (1) can be implemented using embedded systems, as detailed in [11], or it can be implemented using analog circuits, as shown in the following Section.

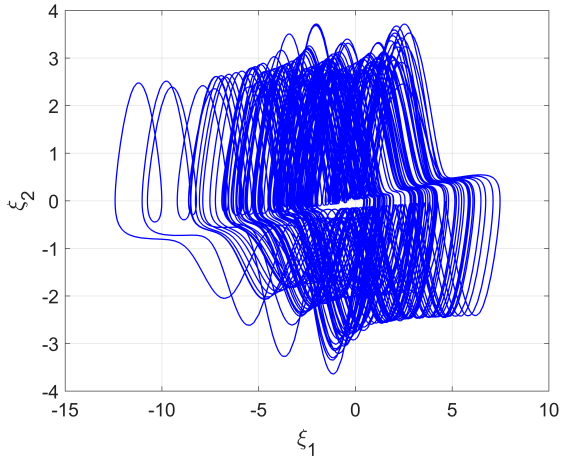

Figure 1. Computer plot of the 2-D projection view of the hidden attractor (1) in (ξ_1, ξ_2) – plane.

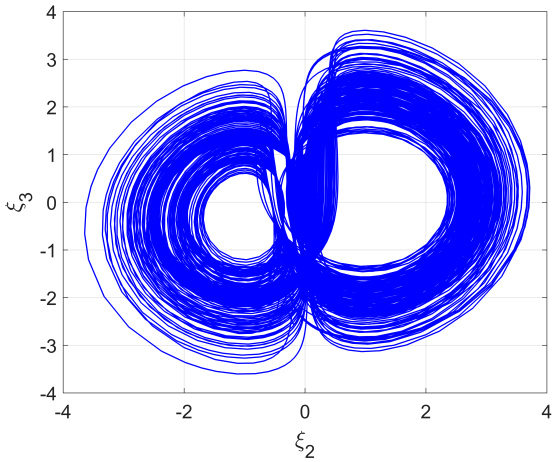

Figure 2. 2-D phase-space projection view of the hidden attractor (1) in (ξ_2, ξ_3) – plane.

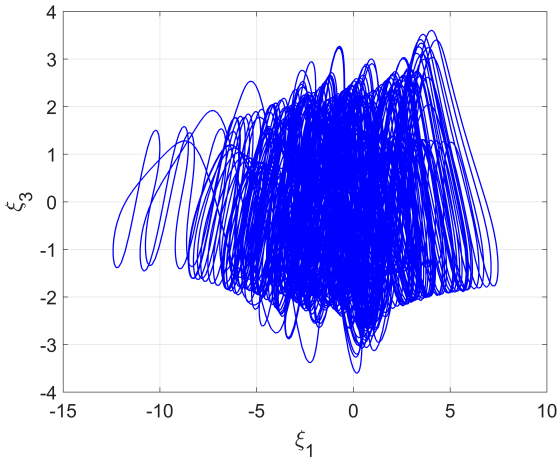

Figure 3. 2-D phase-space projection view of the hidden attractor (1) in (ξ_1, ξ_3) – plane.

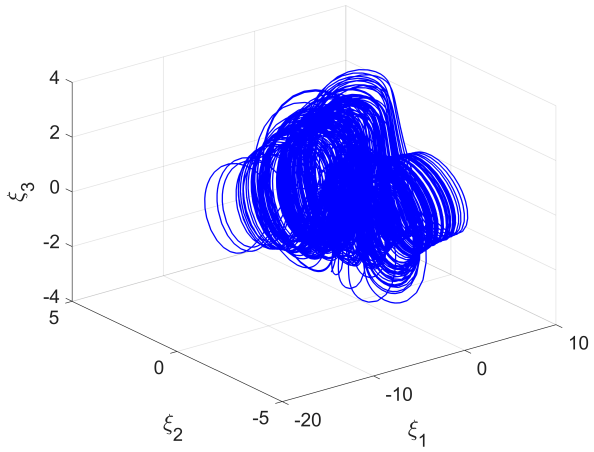

Figure 4. Computer plot of the 3-D view of the hidden attractor (1)

III. MULTISIM CIRCUIT MODEL OF THE NEW NONLINEAR DYNAMICAL PLANT WITH HIDDEN CHAOS

The new nonlinear dynamical model given in (1), which dynamical analysis confirms that the attractor is hidden, can be simulated using commercially available electronic devices that can be modeled in the circuit simulator called MultiSim. In this manner, this Section shows the scaling of (1), as given by (3), and these equations are synthesized by multipliers, amplifiers and passive resistors and capacitors. It leads us to the circuit sketched in Fig. 5.

$$\begin{cases} \dot{\xi}_1 = \xi_2 \\ \dot{\xi}_2 = \dfrac{a\xi_1\xi_3}{4} + \dfrac{b\xi_2^2}{2} - c\xi_2 - \dfrac{\xi_2\xi_3}{4} \\ \dot{\xi}_3 = \xi_2^2 - 4 \end{cases} \tag{3}$$

Applying Kirchhoff's current and voltage laws to Fig. 5 one gets (4), which associates the equations given in (3). Still ξ_1, ξ_2, ξ_3 are the states variables but they are representing the voltages across the capacitors C_1, C_2 and C_3, respectively.

$$\begin{cases} \dot{\xi}_1 = \dfrac{1}{R_1C_1}\xi_2 \\ \dot{\xi}_2 = \dfrac{1}{R_2C_2}\xi_1\xi_3 + \dfrac{1}{R_3C_2}\xi_2^2 - \dfrac{1}{R_4C_2}\xi_2 - \dfrac{1}{R_5C_2}\xi_2\xi_3 \\ \dot{\xi}_3 = \dfrac{1}{R_6C_3}\xi_2^2 - \dfrac{1}{R_7C_3}V_1 \end{cases} \tag{4}$$

The values of the circuit elements in Fig. 5 are selected as: $R_1 = R_6 = 400$ kΩ, $R_2 = 16$ MΩ, $R_3 = 8$ MΩ, $R_4 = 2.7$ MΩ, $R_5 = 1.6$ MΩ, $R_7 = R_8 = R_9 = R_{10} = R_{11} = 100$ kΩ, $V_1 = 1$ V_{DC}, $C_1 = C_2 = C_3 = 1$ nF. The multiplier and amplifier are commercially available, and the power supplies of all active devices are set to ±15 Volts.

The simulation results of the chaotic attractors using MultiSim are shown in Figures 6, 7 and 8, which are in good agreement with the simualtion results shown in Figures 1, 2 and 3, respectively.

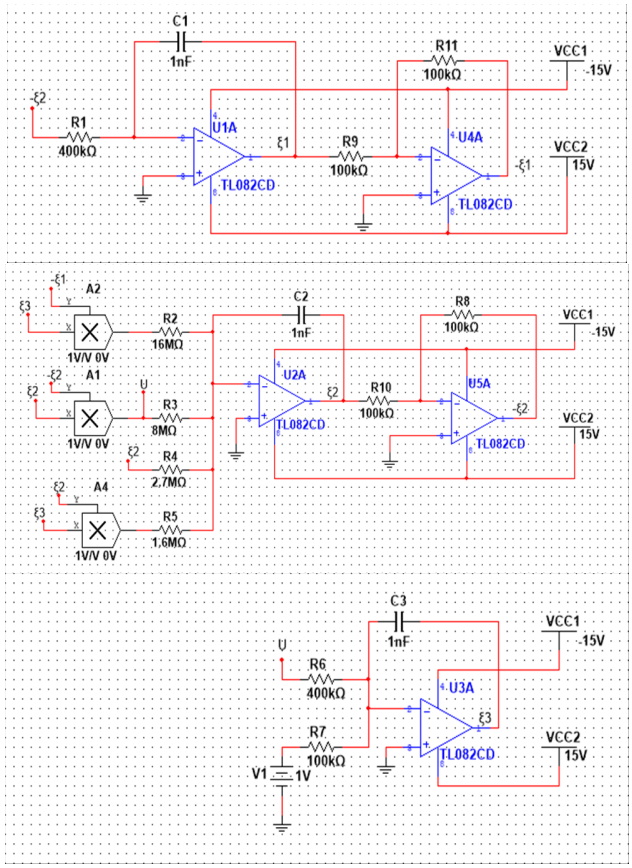

Figure 5. MultiSim circuit of the new dynamical model with hidden chaos.

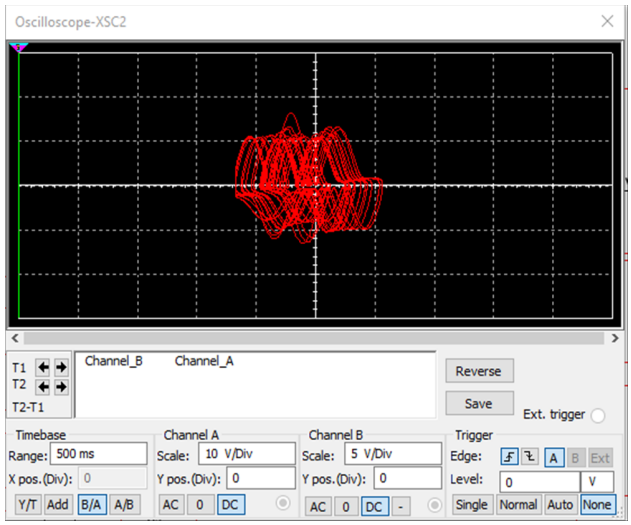

Figure 6. MultiSim circuit simulation result of the new dynamical model with hidden chaos in ξ_1- ξ_2 plane.

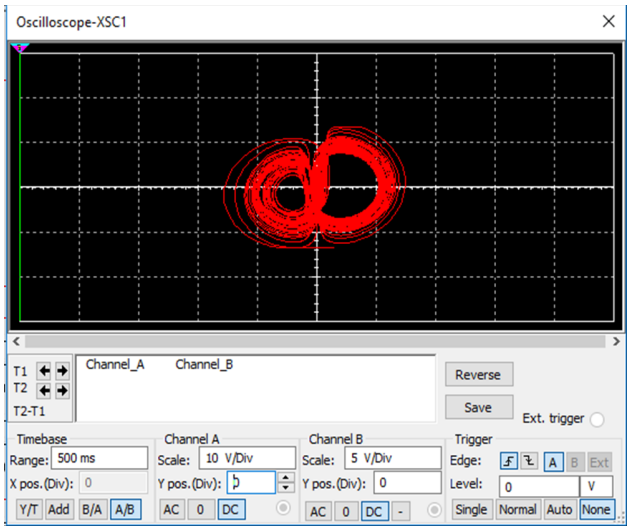

Figure 7. MultiSim circuit simulation result of the new dynamical model with hidden chaos in ξ_2- ξ_3 plane.

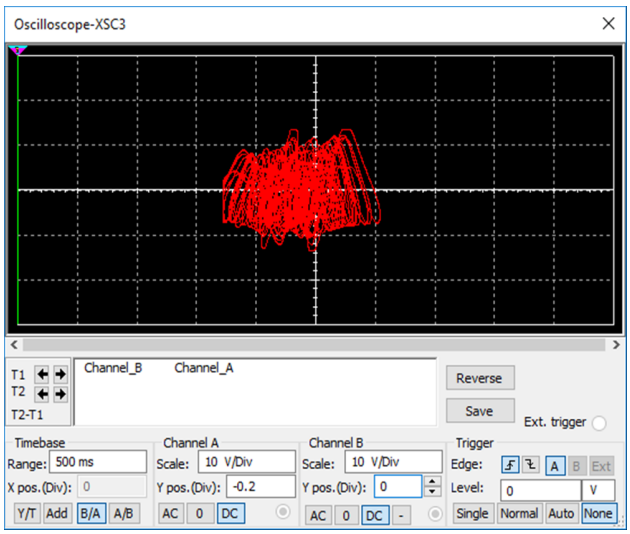

Figure 8. MultiSim circuit simulation result of the new dynamical model with hidden chaos in ξ_1- ξ_3 plane.

IV. CONCLUSION

We have shown the numerical and circuit simulation results of a new 3D dynamical model with hidden chaos. Lyapunov exponents were calculated to confirm that the system exhibits chaotic behavior, and the dynamical analysis showed the hidden attractor characteristic. The significant research contribution of this paper is the discovery of a new nonlinear dynamical model with three quadratic nonlinear terms exhibiting dissipativity and hidden chaoticity. The good agreement of the results between MATLAB and MultiSim confirmed the generation of hidden chaos.

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Detection Threshold for TVWS Spectrum Occupancy Determination in Urban Environments in Kosovo

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Abstract - **It is known that determination of TV white space (TVWS) availability, in absence of geo-location databases, can be based on sensing and applying a detection threshold. In this paper we assess the availability of TVWS spectrum, using on site measurements in urban environment in Kosovo, obtained with NARDA SRM 3006 spectrum analyzer in the UHF and VHF bands. The measurement locations are chosen such as to represent various types of environments within the city of Prishtina. Results show that using a fixed low threshold setting for detection of TV signal presence, i.e., -95 dBm or lower, may heavily underestimate the TVWS spectrum potential. On the other hand, setting the threshold too high may result in misdetection of TV broadcasting, and potentially lead to harmful interference to the primary user. Thus, we propose an adjustable threshold-sensing algorithm to be implemented during data processing for spectrum availability determination. To improve the accuracy and have a more reliable picture of spectrum occupancy, we apply different sensing thresholds for different channels and use a double adaptive thresholding technique to enhance the performance of the detection mechanism.**

Keywords - TV bands, UHF, VHF, measurement, sensing threshold

I. INTRODUCTION

The widespread use of wireless smart devices, such as smartphones, tablets and various other smart gadgets, has dramatically increased the demand for spectrum access. Adequate management of this prized resource has become a major issue, especially as a significant amount of literature on the topic has shown that a substantial portion of the frequency spectrum is in fact heavily under-utilized [1]. This fact is especially apparent in the frequency bands commonly allocated to TV broadcasters.

In this scenario, Cognitive Radio (CR) emerges as a promising solution as an enabling tool for the optimization of modern wireless networks and services. The operating principle of a CR system is based on allowing so-called unlicensed, secondary users to access to spectrum bands that are not being used, without interfering with the primary user who has the right (i.e., is licensed) to operate in a specific frequency channel [1].

The under-utilized portion of the TV bands is referred to as TV White Space (TVWS) and is of great interest due to the superior signal propagation characteristics. However, since the allocation and usage of TV bands can vary from country to country, an assessment of TV band utilization must be first performed to identify potential white spaces.

To do so, spectrum measurements need to be performed over the VHF band (174-230 MHz) and UHF band (470-860 MHz). In this paper we present the results from spectrum measurements over TVWS in Prishtina, the capital of Republic of Kosovo. Once the measurements are performed an assessment regarding the availability of the spectrum must be instigated. The simplest way is to compare the measured values to a predefined threshold. The design of the threshold, however is an important task on its own. On the one hand, if set too low, it can easily underestimate the true availability of the frequency spectrum, while on the other hand, if set too high it can fail to detect the presence of primary users, colluding thus with one of the core principles of cognitive radio.

The assessment of spectrum availability, and therefore the design of accurate detection mechanisms, have been studied carefully in the literature. A comprehensive review on characterizing and modelling the availability of white spaces is provided in [2]. The estimation of the detection threshold without prior knowledge about signal and noise characteristics is addressed in [3]. The use of iterative algorithms based on impulse suppression principles for spectrum sensing purposes is proposed in [4, 5]. The authors in [6, 7, 8] propose instead the application of adaptive double thresholds to enhance the performance of sensing process. In our previous work [9], we also addressed the availability of TVWS, using a single fixed threshold, however as we argue in this work, a fixed predetermined threshold is not flexible enough to provide an accurate picture of the TVWS availability. In this work, instead, we adopt several of the techniques proposed in the literature and apply them to obtain an accurate and realistic overview of the spectrum availability in the TV bands, in the urban area of Prishtina, Kosovo.

It should be noted that TV broadcasting in Kosovo has not yet fully transitioned from analog to digital broadcasting, therefore the analysis presented in this work paints the current spectrum landscape in this country. Although our results show that spectrum availability already is substantial, it is expected that the amount of TVWS will further increase once the transition is completed [10]. This implies that repeat measurement campaigns, at the end of transition, will need to be conducted to calibrate threshold levels and draw availability maps, however, the methods for assessing the availability as well as setting the detection threshold,

presented in this work, can be used without any modification in future measurement campaigns, as they are not conditioned by the broadcasting technology in use.

TABLE 1. MEASUREMENT LOCATIONS

ID	Location	Environment	Type
1	Faculty of Engineering	1.1. Ground floor/ Inside	School/Residential
		1.2. Ground floor/ Outside	
2	RTK building	2.1. Ground floor/ Inside	Urban/Residential
		2.2. Ground floor/ Outside	
3	Taukbahqe	Ground/ Outside	Park
4	Vneshta	Ground/ Outside	Park
5	KESCO building	5.1. Ground floor/ Inside	Urban/High-rise buildings
		5.2. Ground floor/ Outside	
		5.3. 12th floor / Inside	
		5.4. 12th floor / Outside	
6	Mother Teresa boulevard	6.1. Ground floor/ Inside	City centre
		6.2. Ground floor/ Outside	
7	Albi Shopping Center	7.1. Ground floor/ Inside	Shopping centre/ Outside of city
		7.2. Ground floor/ Outside	
		7.3. 4th floor / Inside	
		7.4. 4th floor / Outside	
8	Rruga B	8.1. Ground floor/ Inside	Residential/High-rise buildings
		8.2. Ground floor/ Outside	
		8.3. 12th floor / Inside	
		8.4. 12th floor / Outside	

The rest of the paper is organized as follows: Section II describes the details of the spectrum measurement setup. The detection of spectrum availability and the various threshold setting mechanisms are described in section III. An overview on how the data collected during the measurement campaign was processed using the techniques described in Section III is provided in Section IV. Finally, numerical results are provided in Section V.

II. MEASUREMENTS SETUP

The analog terrestrial TV broadcasting in Kosovo is allocated in the following spectrum bands: VHF 174-230 MHz (8 channels, each 7MHz wide) and UHF 470 – 860 MHz (48 channels, each 8MHz wide), according to data obtained from Kosovo Independent Media Commission [11]. A list of TV transmitters, their coordinates, antenna height and transmit power are also provided in their website [11].

To assess the utilization of these bands in downtown Prishtina, measurements were performed at 8 different locations using the NARDA Selective Radiation Meter SRM-3006, using the spectrum analysis mode, a frequency resolution of 100 kHz, and sweep time of ~200 ms.

To account for losses from signal propagation, at most of the locations, measurements were performed both for indoor and outdoor environments. Measurement locations are listed in Table I.

The locations were chosen to represent the various types of environments present within the Prishtina urban area. Where possible, in areas with taller buildings, measurements were taken in the ground floor and higher floors.

As shown in Table 1, measurements were taken in three urban residential areas: at a school building (location 1) situated in an uphill terrain and partially shadowed; at a residential area near the city center surrounded mainly by low-rise buildings and little shadowing (location 2); and a residential area surrounded by high-rise buildings and shadowed by a hill (location 8).

Within the city center measurements were taken in two different locations: the main city boulevard (location 6), which is a pedestrian street surrounded by medium-rise buildings (4-6 stories tall); and at a high rise building in the city center (location 5), surrounded by lower-rise buildings and situated in an uphill terrain. Measurements were also taken at two different parks, one within the city itself (location 3) and the other one in the outskirts of the city (location 4).

III. DETECTION OF SPECTRUM AVAILABILITY

A. Problem Statement

In order to analyze whether a portion of spectrum is available or not, sensing is performed to detect the presence of a primary signal. If no signal is present, the portion of spectrum is considered as available. One of the most common approaches to detect the presence of a signal in a channel is to apply what is often called the energy detection technique [2,12]. In order to detect a signal applying this technique, the energy of the sensed samples is calculated and compared to a fixed pre-defined threshold. Its drawback is that it is very vulnerable to noise, which can lead to high rates of *false alarms* (the case of detecting a signal where there is none) or high number of *misdetections* (the case of not detecting a signal where there is one), depending on the threshold. While various sensing methods have been proposed in the literature [13], with different tradeoffs between required sensing time, complexity and detection capabilities, the energy detector has proven to be the most popular due to its simplicity, and the fact that it requires no prior information regarding the characteristics of the signal or the noise, which is most often the case. It is especially appropriate for the cases where only the power measurements of the spectrum under evaluation are available.

Given the values of the measured power level for the portion of spectrum under evaluation, the energy detector takes a binary decision, regarding the presence of a

primary signal. Let P_n be the measured signal power. Then the classical detection problem can be expressed as [12]:

$$\delta = \begin{cases} 1 & \text{if } P_n > \gamma \\ 0 & \text{if } P_n \leq \gamma \end{cases} \quad (1)$$

where γ is the predetermined detection threshold and δ is the binary decision variable. It should be noted, that the design of the detection threshold requires particular attention. If set too low, the detector will be biased towards detecting the presence of a signal, even when there is only noise, an event referred to as false alarm. A high rate of false alarms can lead to significant underestimation of the availability of the spectrum, rendering the process useless. On the other hand, a high threshold, can underestimate the presence of the primary signal, i.e. TV signal, therefore increasing the risk of causing harmful interference to the primary user.

The goal is therefore to design a threshold such that it strikes a balance between the opportunistic potential of licensed bands and protection of the primary users, i.e. licensees.

B. Threshold setting

The most straightforward way to approach the threshold setting problem is to estimate the noise floor, or the mean value of the noise power. This can be significant task on its own, as it is shown that the noise level can change both as a function of time [12], and frequency [3]. In this paper we adopt the approach proposed in [3], also referred to as PFA method, as it does not require any *a priori* knowledge about the characteristics of noise. Assuming a sufficiently static situation, this method relies on estimating the noise level from samples that are known to be noise-only. The threshold is directly linked to the targeted probability of false alarm Pr_{fa}. Namely, once we set the desired Pr_{fa}, we find the threshold that our noise-only sample set exceeds with that probability. The values of Pr_{fa} can be in range from 10^{-4} to 0.1 [3,12].

It is important to note that the noise level may vary with frequency [3], therefore the threshold should be estimated for each frequency bin or, at least, for each frequency channel.

1) Threshold adjustmentg applying FCME

The forward consecutive mean excision (FCME) algorithm originally proposed to suppress outlier samples in time domain [4], has also been applied in literature to detect narrowband information signals for spectrum sensing purposes [5]. Its appeal lies in its computational simplicity and effectiveness. Before the algorithm is started, the samples are sorted in ascending order, and a number of the lowest values (e.g. the 10% lowest values [4]) are included in the original clean set, denoted as *Q*. An initial threshold parameter, *T*, is also set using the expressions provided in [9]:

$$T = -\ln(Pr_{fa}) \quad (2)$$

The procedure is further described in Fig. 1.

Once the two parameters are defined, the algorithm iteratively calculates the mean of the clean set:

$$\mu_Q = \frac{1}{|Q|}\sum_{P_n \epsilon Q} P_n \quad (3)$$

where $|Q|$ is the cardinality of Q. In each iteration the rest of the samples are compared to temporary threshold T_{temp}, and included in the clean set Q if they are below the threshold. The algorithm stops once there are no more samples to be included in the clean set. The final threshold is set to the temporary threshold of the last iteration, $\gamma = T_{temp}$. The FCME algorithm is quite fast and in our simulations typically converges in 3-4 iterations.

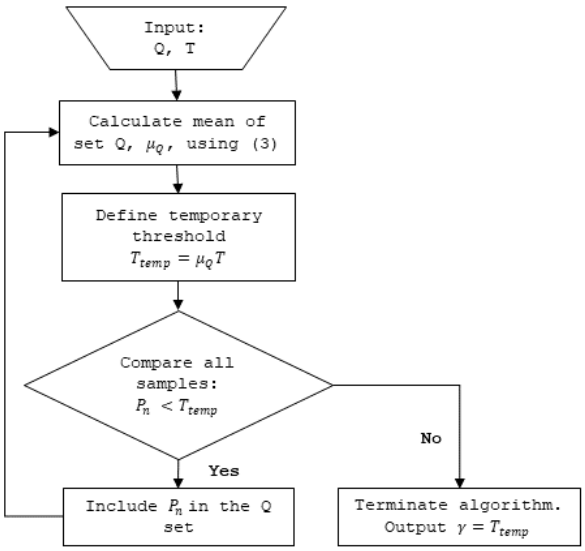

Figure 1. The FCME algorithm

As the authors in [5] note, (2) is derived assuming the noise exhibits, at least approximately, a Gaussian distribution, which is a reasonable assumption if there is no prior knowledge about noise characteristics. If the nature of noise in known, (2) can be adjusted accordingly.

Also it should be noted that in case the samples are compared in logarithmic scale [dBm], then *T* should also be converted to logarithmic scale, i.e., $T_{dB} = 10log_{10}(-\ln(Pr_{fa}))$.

C. Detection using double adaptive thresholding

In addition to properly setting the detection threshold, several papers have also proposed using double thresholds to improve the detection process [6, 7]. The idea is to apply a lower and an upper threshold, namely γ_l and γ_u , both of which can be derived independently using the PFA and FCME techniques. The detector works as follows: if the measured samples are above the upper threshold, then a signal is detected; if the samples are below the lower threshold, then no signal is detected. If the samples are

between the two, then further processing is required. The detection problem is then converted to:

$$\delta = \begin{cases} 1 & \text{if } P_n > \gamma_u \\ \text{apply clustering} & \text{if } \gamma_l < P_n \leq \gamma_u \\ 0 & \text{if } P_n \leq \gamma_l \end{cases} \quad (4)$$

An additional step is therefore required to reach a definite decision when measured samples are in the ambiguous region. In this work we follow the examples of the authors in [6, 12], and apply a simple clustering technique to make a final decision. Initially all decisions in the ambiguous region are assigned "1"s. Then the decisions are clustered so that any gap within a cluster smaller than 3, is disregarded. Namely, say the decisions for each frequency bin in a frequency channel are as follows: "1110111001". Because none of the gaps between the "1"s, are bigger than two, the sequence is transformed to "1111111111". Finally, a cluster of "1"s is considered as "1", only if at least one of the samples in the cluster exceeds the upper threshold. If not, the samples are considered noise.

IV. Analysis of Measured Data for TV Bands in Kosovo

In this section we analyze the data collected during the measurement campaign described in Section II. Availability analysis of TV band spectrum using a single fixed detection threshold has been a topic of our previous work [9]. Previous analysis showed that indeed using a low threshold, could vastly underestimate the availability of the spectrum, while a high threshold risked misdetection of primary signal.

At every location, the measurements were conducted inside and outside, and at different floors where applicable. Since we also have the list of active TV transmitters [2], we were able to calculate the distance between each transmitter - location pair, and identify for each location whether it falls under the service area of any of the transmitters.

The received power was measured in dBm over the entire TV band, in bins of 100 kHz. We denote the power received in bin b of channel c as $P_{b,c}$. The power levels detected in the individual bins within each channel band can then summed to obtain the received power level at the specific channel:

$$P_c = 10\log 10 \sum_{b=1}^{B_c} 10^{\frac{P_{b,c}}{10}}$$

where B_c is the number of bins in channel c. Note that B_c depends on the channel bandwidth and can vary from channel to channel.

Measurements were performed even in those channels that do not have active transmitters, according to the official list of TV transmitters [11]. These measurements were used to estimate the frequency dependent noise floor. The noise floor for active channels was then extrapolated from the obtained values.

A. Per bin vs. channel wide thresholds

The described techniques for threshold setting can be applied both at the bin and channel level. A per bin threshold implies that each bin value will compared to specific bin threshold. Our analysis shows that threshold variations within a channel are small, and indeed the per bin thresholds could be replaced by a single channel-wide threshold. When applying a single threshold method, decisions can be taken either at the bin or channel level. When decisions are taken at the bin level, by applying either the per bin or the channel-wide threshold, the decisions are combined to take a decision regarding the channel availability. When decisions are taken at the channel level, the per bin thresholds are summed to obtain a single per channel threshold for detection.

When applying the double threshold method, decisions are taken at the bin level and clustering is performed as described in Section III.C on the obtained per-bin decisions.

V. Numerical Results

The numerical results, obtained through processing of measurement data with MATLAB software are shown in this section. It should be noted that the measured values are randomly split into two sets: the first set is used for setting the thresholds while the second set is used for evaluating the occupancy using the derived thresholds.

First we look at how the estimation of noise floor changes with the frequency according to the PFA method. In Fig. 2, we show the Pr_{fa} curves for three different channels, namely channel 5, 32 and 65, which are inactive. The figure shows clearly that the noise floor estimate shifts to the right with increasing frequency (channel number). This implies that in order to keep a constant rate of false alarm, the noise threshold needs to be increased with frequency.

Next, we look at the estimation of the noise floor using the PFA method, applying $Pr_{fa} = 0.03$. In Fig. 3 and Fig. 4, we show the obtained per-bin and channel wide noise level values, for the VHF and UHF channels, respectively. The blue bars are the estimates obtained from noise-only channels (inactive channels), while the orange bars represent the noise floor values obtained through extrapolation for the active channels.

In Fig.5 and Fig. 6 we show the derived thresholds at the bin level using the FCME algorithm, with $Pr_{fa} = 0.03$, for VHF and UHF channels, respectively. Here we also note that FCME threshold increases with frequency, and tend to be slightly higher for active channels.

In the next figures we show the calculated occupancy ratios obtained by processing the evaluation set of the measurement data. First we compare the single threshold methods, by applying the PFA method and FCME method independently. We also differentiate between cases where the decision is taken at the bin level (denoted as per-bin), and the case where the decision is taken at the channel level (denoted as per-channel).

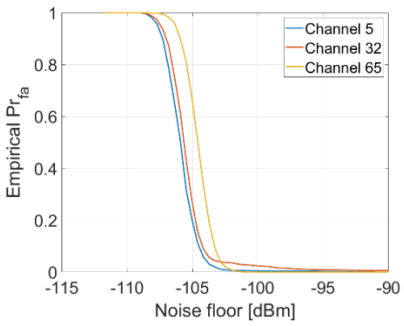

Figure 2. The empirical Pr_{fa} curves for channels 5, 32 and 65.

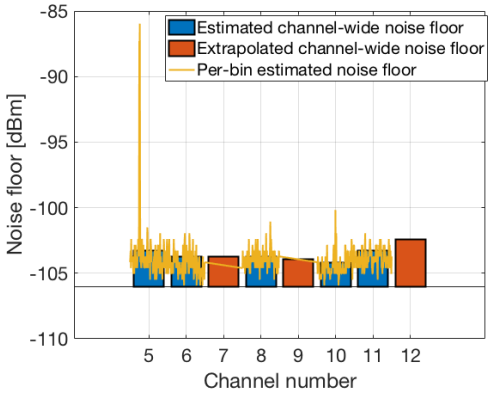

Figure 3. Noise floor estimation for VHF channels using PFA method

When the decisions are taken at the bin-level, channel decisions are made using the OR rule. When the decision is taken at the channel level, the channel threshold is calculated as follows:

$$\bar{\gamma}_c = 10\log10 \sum_{b=1}^{B_c} 10^{\frac{\gamma_c}{10}}$$

where γ_c is the channel wide per-bin threshold.

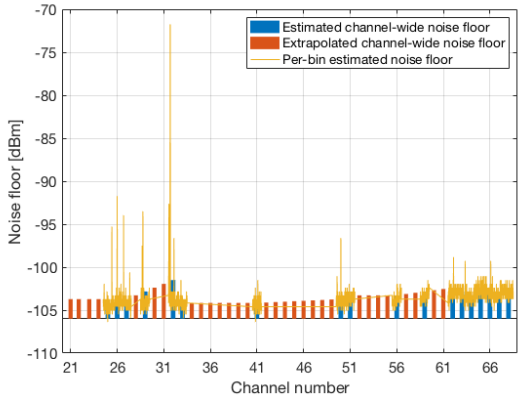

Figure 4. Noise floor estimation for UHF channels using PFA method

In addition we compare the above mentioned methods to the fixed threshold case, with $\gamma = -85\ dBm$.

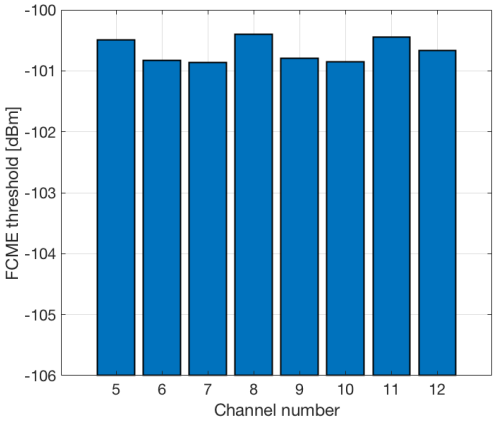

Figure 5 FCME thresholds for VHF channels

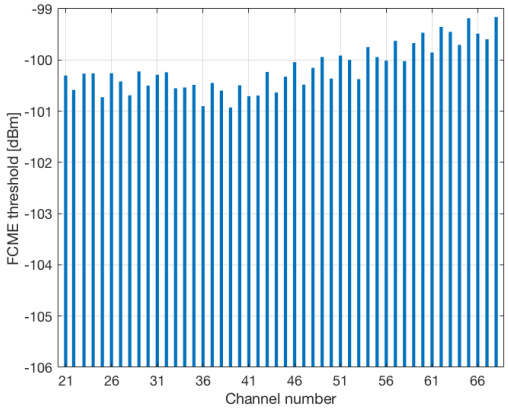

Figure 6. FCME thresholds for UHF channels

According to the official list of TV broadcasters [2], 43% of channels are currently not active, therefore at any given location, occupancy should not be above 57%, which is not the case with the fixed threshold. Applying the adaptive techniques such as PFA or FCME, we can immediately see a drop in occupancy ratios, which we expect to be much closer to the reality. We also note that PFA in general provides higher values of occupancy ratio than FCME, indicating that it provides more protection to the primary user. It should be noted that both FCME and PFA were performed applying $Pr_{fa} = 0.03$.

Finally, in Fig.8 we compare between the single and double threshold methods. The double thresholds were calculated using FCME, and by applying $Pr_{fa} = 0.01$, for the upper threshold and $Pr_{fa} = 0.03$ for the lower threshold [7]. We note here that the double threshold shows positive occupancy ratios for all locations, and in general provides values higher than the single threshold method. This indicates that higher protection for the primary users is ensured. But more importantly, it also seems to provide more realistic values in those locations where other methods were not able to detect a signal at all (e.g., location 6 and 7). This is important, since we know that all chosen locations were inside/or close to the urban area of Prishtina, and are undoubtedly under the service area of at least 3 national broadcasters.

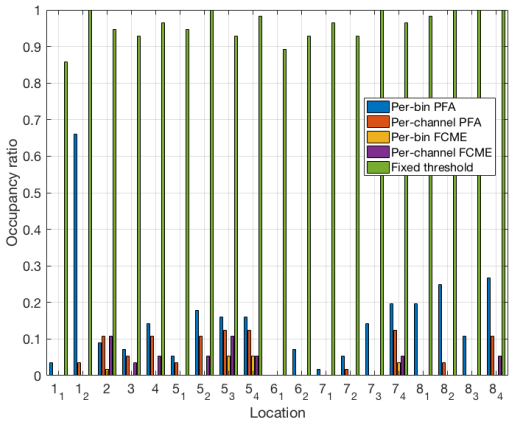

Figure 7. Occupancy ratios for the various locations applying the different single threshold methods

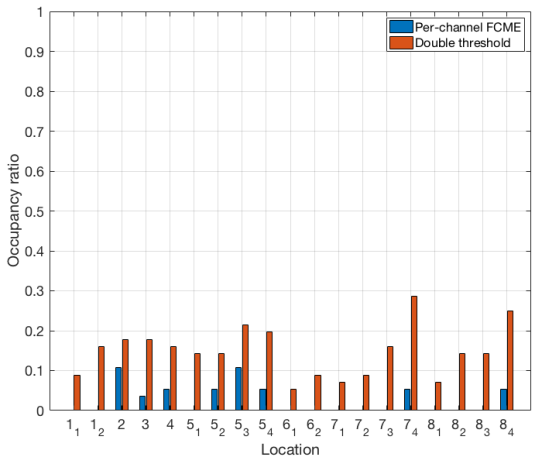

Figure 8. Occupancy ratios for the various locations applying the FCME based single threshold, and the adaptive double threshold

Although it has been shown that the application of adaptive thresholds improves the performance of the energy detector in low SNR regions [7], at this stage we cannot yet present the dependency of the performance of proposed algorithms with respect to SNR, since we only possess the measurements of received power level, and not the actual values of experienced SNR, which cannot be calculated without an accurate channel model.

CONCLUSION

Assessment of TV band utilization is an important step in identifying the so called TV white spaces, which could potentially be opened up for opportunistic use. It especially becomes important when no geo-location databases are available for a specific area. In such cases, it is important to have in place detection mechanisms that would correctly estimate the occupancy and availability of the TV channels. Applying a single threshold during detection of TV signals, has been shown to be ineffective as it largely underestimates the availability of the TV channels. In this paper compare between different adaptive thresholds algorithms proposed in literature by applying them to TV band spectrum measurement data collected in the urban area of Prishtina. Our results show that applying adaptive thresholds significantly improves the detection process, providing more realistic values. In addition, our results show that the occupancy ratio varies from 0 to 0.3. This implies that the amount of under-utilized spectrum in these bands is significant, and there is ample room for potential cognitive radio operations in TVWS in Kosovo. Future work is planned to extend the measurement campaigns over the entire territory of the country, to obtain a comprehensive picture of TVWS availability and potentially initiate the compilation of a TVWS database for Kosovo.

ACKNOWLEDGMENT

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Quality assessment of system for automated multi-node environmental water parameter monitoring

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***Abstract* - This paper presents a system for automated multi-node environmental water parameter monitoring and makes an assessment of its measurement quality. Using this system, by constant monitoring of water quality in wetlands and surrounding areas, and analysis of long-term measured data can yield key and useful information for environmental protection and biodiversity actions and plans. The system is built as a network of independent measurement nodes, each equipped with probes for measurement several key physicochemical parameters. Acquired data are sent using commercially available communication networks to a central data-center for further processing, analysis and presentation. The system was tested in laboratory condition. Measurement results of water samples taken from wetlands are compared to results obtained by physicochemical laboratory analysis, resulting in the quality assessment of the designed system.**

***Keywords* wetlands monitoring, sensors, multi-node, water quality**

I. INTRODUCTION

One of the largest industrial pollutants are food, chemical and metal industry. The negative effects of intensive agricultural production on the environment are particularly evident in rural areas, as most of their territory is used for the food production. Agrochemicals, such as pesticides, fertilizers and salts, have the greatest impact on the environment. Only 10-15% of the applied pesticides reach the target pests and the rest ends up in the air, water and soil. Therefore, it is clear that the increase in the agricultural productivity and the development of industry has a significant impact on environmental pollution, especially on the river and underground waters [1]. Consequently, water quality is significantly important since this parameter facilitates the rational and efficient use of the water reserves.

There are several approaches to inspect water quality. Traditional methods involve the manual collection of water samples from different locations and at different time intervals. Then, laboratory analyses are conducted in order to determine the water quality. This approach has many drawbacks [2] – [4], such as repetitive departures to the field in inaccessible places in order to take a sample. Furthermore, the sample changes its chemical characteristics until it is being processed in the laboratory surrounding. Additionally, laboratory analyses can take significantly long time and can be very expensive.

On the other hand, optical methods [5] for remote measuring water quality offer high sensitivity, good diagnostic potential, compact and robust instrumentation. These methods use several techniques based on the spectral analyses of the transmitted and scattered light. Disadvantage of the measurement systems based on this principle is demand to regularly maintain the probes in order to achieve good optical visibility, which is a requirement for good results. Also, the instrumentation used for these methods is very expensive.

Water measurement systems used in water purification facilities are one of the most accurate commercially available methods for measuring water quality [6] – [7]. These systems are robust, have proper security protocols in order to prevent failures and provide extremely accurate results. Such systems are very expensive, require trained personnel to handle and include regular replacement of probes, as well as their calibration.

Information technologies in the conjunction with the development of sensors and electronic circuits provide the possibility of on-line monitoring of essential parameters that determine the quality of the water. One of the solutions that uses a low-cost and holistic approach to the water quality monitoring problem is described [8]. This system is portable, which means it must be brought to the appropriate locations, and it is not suited for autonomous operation.

Solution presented in this paper are designed so it can be placed almost anywhere, it is battery powered with years long battery life, and needs minimum maintenance. Presented solution will be used in building system for monitoring and measuring key factors and existing risks in the protection of biodiversity. The result of the project will be implemented, integrated and functional continuous supervision and measurement system for controlling the quality of the surface water in the capacity of the unified data system with international aspects. Locations predicted for implementation are Tompojevački Ritovi, municipality Tompojevci, Mikluševci and Grabovo in Croatia and lake Zobnatica, municipality Bačka Topola in Serbia. Most of the measurement nodes will be placed in shallow boreholes surrounding wetlands in this area, and some will be placed directly in open water area.

II. MEASUREMENT SYSTEM

Multi-node environmental water parameter monitoring system is consisted of several measurement nodes placed in measurement locations shown in Fig. 1.

The water parameters measured with this system are: pH, temperature, dissolved oxygen, conductivity, nitrate (NO3-). The water level is also measured and this information is used for determination of direction of groundwater flow in order to calculate quantities of groundwater which flows into the lake. For pH measurement, standard pH probe with glass electrode is used, combined with reference electrode. Measurement range of this probe is 0− 14 pH. PT-1000 type of sensor is used for temperature measurement. Electrical conductivity probe consists of two measurement electrodes, and it is designed for measurement in range of 0.07 to 50,000 µS/cm. Dissolved oxygen is measured with galvanic probe consisted of Teflon sensing membrane, measurement range is from 0 to 100 mg/L. Selected nitrate probe is ion-selective type with solid state electrodes, like pH probe this probe also needs reference electrode, it uses the one from pH probe. Measurement range of selected nitrate probe is 0.6 to 31000 mg/L.

Since some boreholes are 10 meters deep and the water level in borehole can vary more than 3 meters during different seasons, the measurement node is divided in two part, CONTROL unit and PROBES unit.

In CONTROL unit a GSM module is placed, along with system battery and additional hardware. PROBES unit is placed on the floating cork with functions related to the probe managing and conditioning. In this way GSM module is on surface in order to minimize the length of the antenna cable. PROBES unit is floating on the water, so it is always on the same distance from the water level. Water pump is used to pump water up to the water sample box, where the measuring tips of all probes are inserted. If electronics of the PROBES unit were placed on surface, together with electronics in CONTROL unit, all the cables from the probes would need to be around 10 meters long. This probably wouldn't be a significant problem for integrity of signals from probes since their outputs are low changing voltage signals, although electromagnetic interference could have significant influence to the signal because of its low amplitude, in order of millivolts. More important problem with long probe cables is the fact that water level can vary about 3 meters, and they can be easily tangled up when the water level is high. By splitting hardware in the two units, only one 4-wire cable is needed between these units so possibility of entanglement of cables is very low.

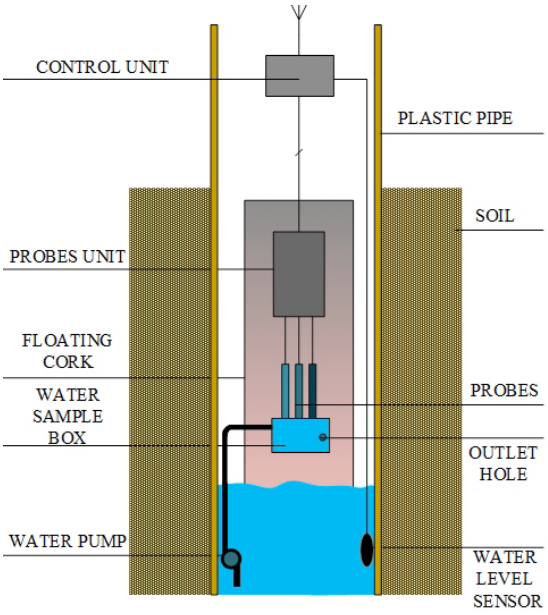

Figure 1. Structure of measurement node in borehole

A. *CONTROL unit*

Structural schematic of surface, CONTROL unit is shown on Fig. 2. Selected microcontroller is low cost 8-bit ATMEGA328P, there was no need for more powerful MCU since no significant computation is required in these units. As supply for whole system a non-rechargeable Lithium Thionyl Chloride battery LSH20 is used, with nominal capacity of 13 Ah and nominal voltage of 3.6V. Because of its high capacity and small dimension, low self-discharge rate and wide operating temperature range (-60°C/+85°C), it is ideal for outdoor battery-powered systems. Also, selected battery has high drain/pulse capability of 4 A, so it can be directly used for powering GSM and similar modules. The most of the batteries of this type have much lower current capabilities, around 10-20 times lower, so they have to be combined with the supercapacitor to be able to power such type of modules.

To achieve overall system low-power consumption, ultra-low-power timer TPL5110 is used. Consuming only 35 nA, this timer drastically reduce the stand by current during the sleep time of the system. No other component in the system consumes power (expect RTC clock) during sleep time since output of TPL5110 switches of power to the rest of the system. For additional power saving, microcontroller controls three individual power switches for: GSM, all the other internal electronic and power send to the underground unit, so it can power off part of the system which is not currently used.

Measurement data is send via GSM/GPRS module which was selected for data transfers because the most of measurement nodes will be placed in rural locations with large distances between them, so no other communication network is available. If GSM communication is unavailable for prolonged periods of time, data is saved in I2C serial eeprom chip with 512 kB of data, where data from six months of measurement can be saved.

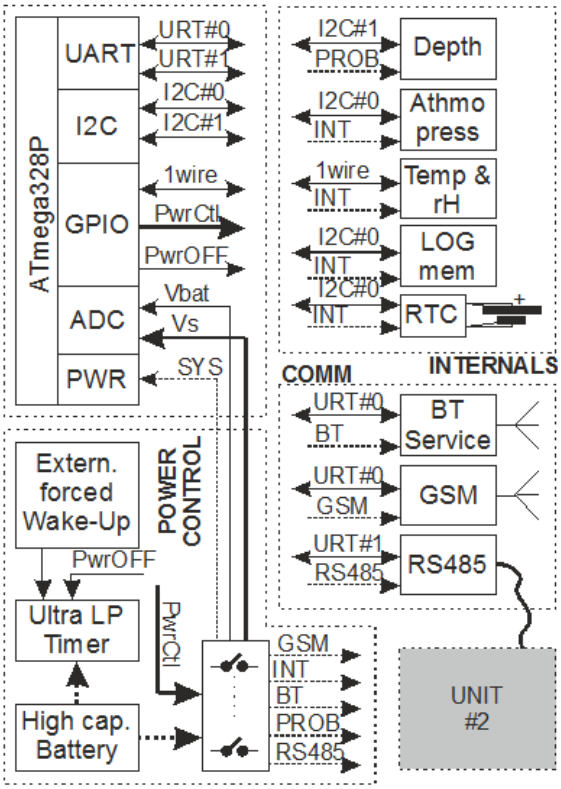

Figure 2. Structural schematic of CONTROL unit

Humidity and temperature sensor is placed on CONTROL unit PCB, this sensor is used for monitoring status of the air inside surface unit enclosure. Since measurement nodes will be placed into borehole tube which will be closed on the top, there will be significant condensation inside. Therefore, sensor is placed to be sure that humidity and temperature inside enclosure are within limits appropriate for the electronic hardware.

Water level probe is based on the differential pressure sensor with analog output. Since level sensor has to be on fixed level below the water it is connected to surface unit, unlike all other probes which are connected to moving underground unit.

For testing of the system in-situ extern forced wake up hardware is used. Since whole system is powered on every two hours for short period of time, the operator has to have possibility to check functioning of the whole system when nodes are placed on the field. For this purpose a reed relay is used, connected to the input of the TPL5110, so the operator can power on the system just by bringing magnet in proximity to reed relay, which is placed on the wall of the CONTROL unit enclosure. In such a way there is no need for operator to open enclosure every time the system need to be tested, which will shorten testing time since opening and closing enclosure is time consuming task. Enclosure is IP66 protected and properly closing its lid is delicate process, especially when it is done on field during poor weather conditions. For communication needs between the CONTROL unit and the operator, CONTROL unit is equipped with the BT module to receive test commands and send data to the operator.

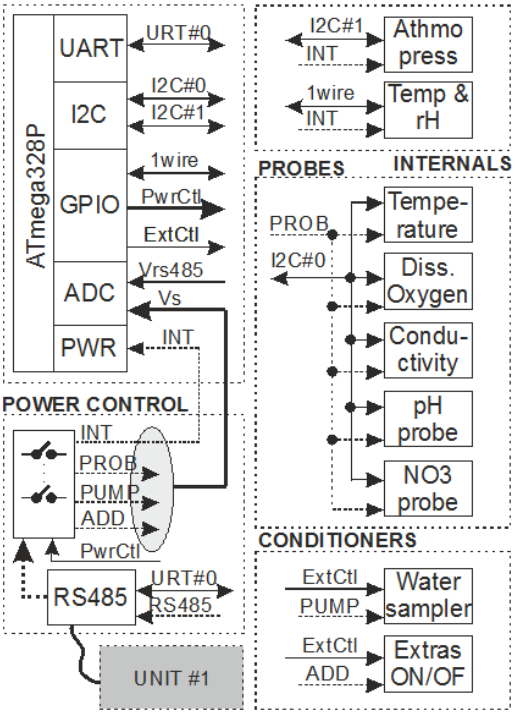

Figure 3. Structural schematic of PROBES unit

Communication between CONTROL unit and the PROBES unit is done via RS-485 communication, in some deeper boreholes distance between units is above 10 meters, so simple RS-232 communication could cause data loss in case of electromagnetic interference.

B. PROBES unit

Structural schematic of underground, PROBES unit is shown on Fig. 3. All probes for water parameter monitoring are acquired with custom electronic boards which communicates with MCU via I2C communication. These electronic boards process signals from probes, digitalize it and send measurement data to MCU. They can be also used for calibrating of the probes. Three I2C isolators are used in combination with the probes, primarily because of influence of probes to each other when placed in same water sample, which then acts as the low resistance current path between probes. Probe that has to be galvanic isolated are conductivity, dissolved oxygen and pH with NO_3- probe. Like mentioned before, pH probe is used as reference probe to NO_3- probe, so they have to be grounded together. As I2C isolators ADUM3260 is used, which also provides galvanic isolated power supply to the probes. Temperature probe does not need isolation, since its housing isolates temperature probe from surrounding environment.

Like on CONTROL unit, there is humidity and temperature sensor on probe unit PCB, to check conditions inside the enclosure. Also, there are power switches for powering off part of the system currently not used, and I2C isolators have enable input so they can power off the probes when the measurements are completed.

Average current consumption of whole system during measurement process is up to 150 mA, and duration of measurements is below 1 minute. During data transfer, continuous current consumption of GSM module is up to 500 mA, and data transfer can last up to 1 minute, mostly because of time needed for establishing the communication. For one measurement cycle and data transfer per day, battery life should be around 3 years. This estimation is made for worst case conditions, GSM module will in most cases have smaller consumption. Real current consumption of GSM module will depend of needed GSM transmitter signal strength which will be different for every location of measurement nodes, and will also vary for every data transfer since propagation of signal changes on daily bases.

III. SYSTEM LEVEL PROGRAM STRUCTURE AND SUPPORT

The software solution for this system is divided into two separate solutions. The term solution here represents all necessary software algorithms, development environments and hardware deployment tools used to create control, managing and processing algorithms. One of solutions is tailored for system that is placed above the ground (surface station / CONTROL unit) and serves as data sharing center with control ability in manner of managing the whole system operations. The second solution is made for system that is designed to be sensor hub (PROBES unit). This sensor hub is placed underground, in direct contact with measuring media. Also, the underground station serves operations related to the probes maintenance and data preconditioning, preparation and translation (conversion) into meaningful domain, preparation for raw transport to the main data center. Simplified functional layout of implemented algorithm is given in Fig 4. Also, all tools for programming and deploying are used according GNU and GPL principles.

The main targets that are accounted into core of implemented algorithms are oriented to achieve following objectives:

- to acquire raw probe measurements according probe specifications and rules for proper acquisitions (probe conditioning and readout),
- to condition and interpret raw measured data and translate into meaningful scalar domain,
- to maintain communication toward the main data center and respond to the custom control sequences for stations remote dynamic management (remote control),
- to support and serve maintenance service requests and actions (system diagnosis), and
- to control and manage ultra-low consumption power plan (power save and control).

The whole system is designed in a way to be very power conservative, power efficient respectively. Due that very restrictive policy a special attention is given to the part of algorithm that utilizes system power distribution. As it shown in Fig. 4, system wakes up from the almost zero-power state and regularly checks condition of meeting the scheduled fully system functionality. If that condition is fulfilled the rest of algorithm is activated according sequence for further proceeding in proper data acquisition. It is expected that once or twice a day for data acquisition will be enough due the fact that the hydrological processes are very slow. In consent with hydrological experts these intervals are confirmed as valid.

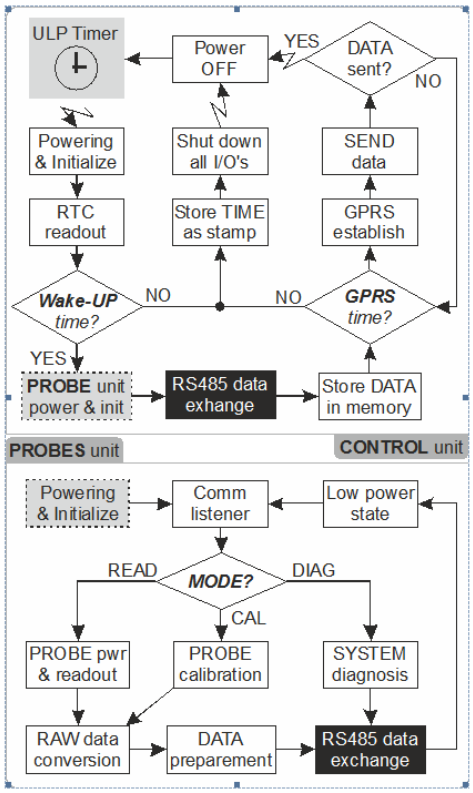

Figure 4. Program structure and flow diagram for probes and CONTROL unit

The period that is chosen for periodical waking-up the whole system is fixedly set to 2 hours. This is way too fast, according known needs for one or two measurements per day. The reason for select such period is tightly related to hardware properties of ultra-low power timing circuitry that is used for waking-up system power controller. The maximum delaying interval for such circuitry is set to maximum 2-hour interval. That fact somewhat makes complication in time and schedule management of this system however, it is solved in a way that system wakes-up every 2 hours, turns on only a main power that is sufficient for powering main controller only (that one in placed in the surface station), Fig 4. The main controller reads RTC state and last wake-up time-stamp, compares it according data obsolescence. If comparison results in wake-up due state, the whole system is powered-on, switched to the acquisition mode, and data was stored in memory and transported over communication interface to the main data center. If result of comparison results in wake-up trigger miss, main controller then shuts down power for all systems thus maintaining ultra-low power consumption.

Also, when data was acquired and stored in memory the system has obligation to transport data to the main data center utilizing some of communication media. This system utilizes GSMs GPRS communication infrastructure. Due the fact that GSM communication circuitry are big power consumers and have high current peaks/surges, one of tasks of this system is to maintain communication as short as is possible or lower frequency of communications establishments per given periods. This system utilizes one communication cycle per day and thus gathers all procured measurements in one day to the one data exchange over GSMs GPRS.

IV. MEASUREMENT RESULTS

System is realized and tested in the laboratory conditions. Measurement results of water samples taken from wetlands are compared to results obtained by analysis attained in accredited physicochemical laboratory.

TABLE I. COMPARISON OF SYSTEM AND LABORATORY MEASUREMENT

Water parameter	System measurement	Laboratory measurement	Relative error (%)
pH	8.16	8.01	1.87
Dissolved oxygen(mg/L)	10.34	10.95	- 6.98
Conductivity (μS/cm)	1003	995	0.8
NO_3- (mg/L)	10	0.09	11000

Comparison of system and laboratory measurement can be seen on Table 1.

It can be noticed that temperature measurement is not included since water temperature obviously changed during transport to laboratory, but since the temperature sensor is well known PT1000, its measurement is known to be below 1 %, which was confirmed with additional measurement. Conductivity measurement error is in range of conductivity probe accuracy, it is below 1 %.

Dissolved oxygen measurement error is around 7 %, which is higher than rated probe accuracy of 2 %. This can be accredited to the fact that dissolved oxygen concentration is a highly unstable parameter of water, and its measurement is best performed in-situ with special method for water sampling [9].

Nitrate NO_3- measurement results done by system probe are 100 time higher than values attained by laboratory. Since measurement range of this probe is in range 0.6 to 31000 mg/L, values of 0.09 mg/L are outside its range. Such high error can be explained by low accuracy of used nitrate probe for low levels of nitrate, where response curve of this probe is in non-linear region. Also, the effect of interference from other ions in solution can have signification effect on measurement.

V. CONLUSION

This paper presents a system for automated multi-node environmental water parameter monitoring and conducts assessment of its measurement quality. Solution is realized as low-cost and robust system, it can be placed almost anywhere since GSM network now days can be reached anywhere. Power consumption is minimal, so system can work on battery for several years without need for replacing, and need for maintenance is minimal.

From measurement results of the probes in system, it can be seen that accuracy of the probes is adequate for environmental monitoring, except nitrate measurement. Nitrate probe error is extremely high for such low levels of nitrate in water, so this probe can be only used as detection of higher levels of nitrate concentration. There is a possibility that by additional laboratory measurement of water sample sources of interfering ions can be found and that measured results can be then corrected by additional calibration.

ACKNOWLEDGMENT

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Development of voltage source converter using HiL simulation system

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Abstract - This paper describes and compares two approaches to the development of the voltage source converter. The first approach is the implementation of only the off-line simulation, while the second one also involves the on-line simulation using the hardware-in-the-loop (HiL) system. Particular importance was given to the role of the HiL simulation system in the testing of the control algorithm and the control electronic. The hardware structure and software support for the implementation of HiL simulation in real time and the necessary adjustments in order to utilize the full functionality of the system are described. An off-line simulation model developed in the software package PLECS and a model adapted for execution in the corresponding to RT Box simulation device are shown on the example of the development of fan drive converter. The simulation results were compared with the results obtained by experimental testing of the developed converter. It is shown that the implementation of HiL simulation can largely predict errors in converter design, especially errors in the control algorithm that can not be detected by off-line simulations.

Key words: Voltage source converter; off-line simulation; hardware-in-the-loop simulation; on-line simulation; RT Box; PLECS; control algorithm

I. INTRODUCTION

The development of the industrial prototype of the electronic power converter begins by proving the feasibility and the basic technical characteristics of the proposed concept [1]. For these purposes, various computer simulation tools are used to simulate the electrical behavior of the converter. Two fundamental approaches to the simulation of the power section and control electronic of the converter are commonly used. The first, (traditional) approach is the implementation of off-line simulation only, while the second one involves on-line simulation using the hardware-in-the-loop (HiL) system [2-7].

With traditional approach, the computer simulation program mainly simulates the electrical behavior of the power section of the converter. This type of simulation is known as the so-called software-in-the-loop simulation (SiL). The off-line simulation experiments are followed by choosing the necessary components and the development of a physical (draft) model of the power section of electronic converter. Thereafter, a series of tests are carried out in laboratory conditions together with a control electronic module. Errors detected during these tests usually require modifications in the power and control section of the converter through several iterations of the design process. The increased number of iterations necessarily leads to increased costs and longer time of the converter design process.

In the HiL simulation approach, a physical converter model is not designed upon termination of the off-line simulations of the power section of the converter, but only after the control electronic has been tested and verified. Model of the power section of the converter tested by off-line simulation is uploaded to the specified device that emulates its work in real time. Using its analog/digital inputs and outputs, this device is connected to a control electronic module with a built-in control algorithm. This approach accelerates the design process of the converter and makes it more efficient and economically more cost-effective than design based on off-line simulations alone.

II. TRADITIONAL METHOD OF DESIGNING AND TESTING OF THE VOLTAGE SOURCE CONVERTER

In the traditional approach to the design of the voltage source converter, Figure 1, after selecting a topology, off-

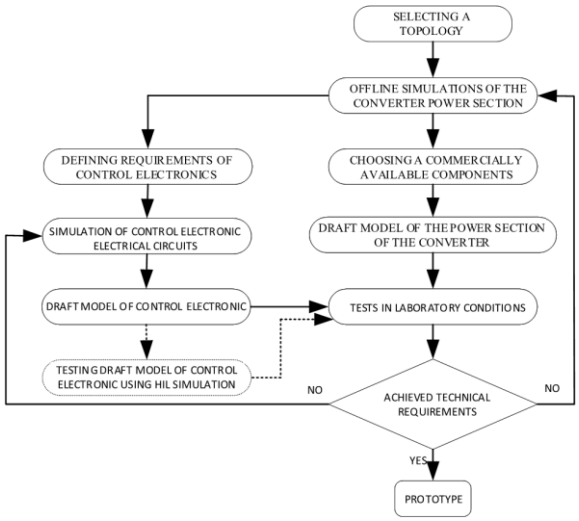

Figure 1 Basic procedures in the traditional approach to the design and testing of the power converter

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line simulations of functional behavior of the converter power section are the following. Simulation programs such as, for example, Matlab/SIMULINK, PLECS or Simplorer with built-in models of a semiconductor and other components are used for this purpose, Figure 2. The level of complexity of the semiconductor component model determines the level of accuracy of the obtained simulation results. Simple static models (ideal and

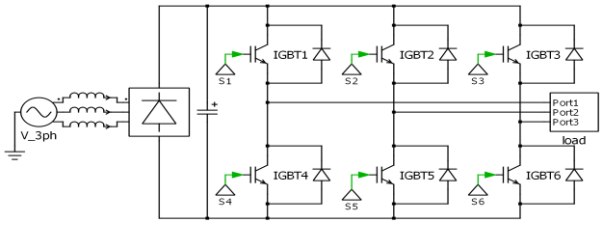

Figure 2 Simulation model in PLECS with built-in models of a semiconductor and other components

idealized), averaged models or highly complex dynamic models are being used. More complex models are more accurate but require more powerful processors and longer simulation time.

After the simulation in time domain, Figure 3, and frequency domain, follows the analysis of the results obtained to verify the functional behavior of the power section of the converter in terms of the required energy conversion and to determine the required control algorithm of the converter. The simulation results of electrical behavior of the converter power section are further used for current and voltage dimensioning of semiconductor power components as well as for passive and filter components. The next step is choosing a

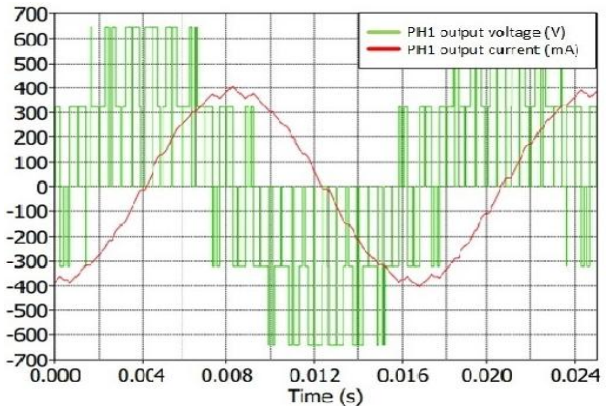

Figure 3 IGBT and phase 1 current and voltage

commercially available components that satisfy the simulation requirements for the required characteristics and parameters. After that, a draft model of the power section of the converter is being developed. Based on the control logic, realized in the off-line simulations, the requirements of control electronic are defined with respect to the regulatory structures, measured feedback signals, and protection and redundant functions. The switching frequency of the converter defines the required processor clock of the control electronic (DSP/FPGA) [8-10]. With further define of working conditions (vibration, temperature, humidity) and assessment of EM disturbance, the control electronic module is designed. The architecture of the module is selected, using specialized software tools (e.g. GRAP) the necessary application programs are made, off-line simulations of the electrical behavior of the auxiliary electric circuits are performed. Lastly, the control electronic module is created and tested using a special test environment and equipment. With the traditional approach to the design of the power electronic converter, for final functional and type testing of the control electronic module with a built-in control algorithm, the physical model of the converter's power section is required. Firstly, the tests of the unloaded converter are carried out, and then with the connected load. Incorrect behavior detected by testing usually requires a new iteration in the design process of the power or control part of the converter, including repetition of off-line simulation.

In order to satisfy the agreed deadlines, because of the above, designers often have to perform functional and type tests of prototype device in substantially shorter time than anticipated. Shorter test time increases the possibility of error and prevents detailed testing of the device in the laboratory or in the real environment.

III. HARDWARE-IN-THE-LOOP METHOD OF DESIGNING AND TESTING OF THE VOLTAGE SOURCE CONVERTER

By using the HIL simulation system for testing functional and typical characteristics of the control electronic, a complex test environment nor a physical model of power section of the converter are required. Instead, a special device is used that simulates the power section of the converter in real time. The HiL simulation system consists of a simulation software package and device connected to a computer with a simulation program installed. Appropriate software support, i.e. interface between a computer and device, is also required. Model of the power section of the converter tested by off-line simulation is uploaded to the specified device that emulates its work in real time. Using its analog/digital inputs and outputs, this device, i.e. the model of the power section of the converter, communicates with the actual control electronic module with a built-in control algorithm. In this way, it is possible to access the values of certain parameters and to carry out the test of the correctness of the module without the need for complex test equipment and the surrounding environment with a substantial acceleration of the process and lower cost, dash line at figure 1.

With the connected model of power section of the inverter in real time and the actual control electronic module, all major type and functional tests of the control electronic are carried out. For this purpose, the PWM signals from the tested control module are supplied to the model switches. HiL simulation enables automated testing of control electronic module and its built-in control algorithm at an early stage of design. Although the HiL simulation can't completely replace the functional tests in the lab, it will certainly shorten the test time and enable earlier detection of errors in the design of the power and control circuit of the converter. This approach accelerates the design process of the converter and makes it more

efficient and economically more cost-effective than design based on off-line simulations alone.

A. *Hardware-in-the-loop simulation system RT Box*

The RT Box is a technical solution of *Plexim GmbH* in which the SiL simulation models realized in the PLECS simulation environment are with minimal changes transformed into real-time models. As shown in Figure 4 [11], the device contains two processors; one for communication with the computer and the other for simulation of power section of the converter and communication with the control electronic module. The tested control electronic module is connected to the RT Box via digital and analog inputs and outputs that provide

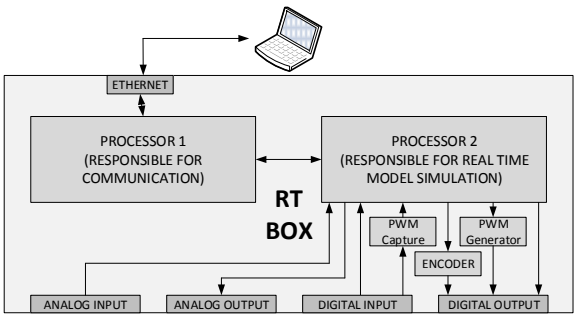

Figure 4 Block scheme of RT Box

sending and receiving the measured signals required for feedback connection as well as PWM signals for the IGBT trigger stages of the converter.

Sequences of control algorithm within the control electronic are performed in discrete time steps that are multiples of time steps defined by the clock of digital processors. The model of power section of the converter simulated in real time on the RT Box is discretized by a fixed step that can theoretically be 1 μs. For more complex models, the discretization step is approximately 6 μs (as switching frequency of the PN35AC is 4000 Hz and HiL step size is 6 μs, only condition about HiL step size is that it is not bigger than step size of DSP on control electronic that is 20 μs). This step is consequently related also to the sampling time of analog and digital inputs and outputs, whereas the digital signals may have a higher resolution when accessed via PWM Capture, PWM Generator or ENCODER blocks. The sampling step of these blocks is 7.5 ns because they use the FPGA core to read from the digital pins. The FPGA samples with this step and saves the digital signal values in memory until the processor reads them.

IV. Design and Testing Example of the Voltage Source Converter Using HiL Simulation System

Končar Electronics and Informatics, Inc has, for the purposes of modernization series of locomotives of the Slovenian railroad, designed the voltage source converter, type number CONTRACT PN35AC, for the fun drive asynchronous motor (35 kW). This drive provides the default airflow through the locomotive diesel engine coolant heat exchange. The converter, besides the control electronic, consists of standard sections; (i) the input diode rectifier, (ii) the DC link, and (iii) the output inverter.

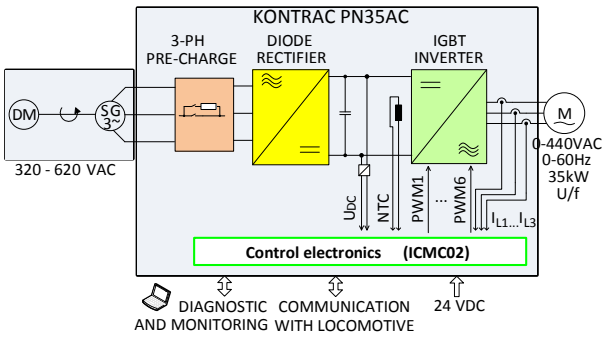

Figure 5 Block scheme of voltage source converter (PN35AC)

Converter is powered by three-phase AC voltage from the main diesel engine-generator set, Figure 5. During the design of the converter, the off-line computer simulations were carried out, using the software platform PLECS, which enabled selection of the converters power electronic components. In the course of a later stage of the converter designing, the algorithm of the converter control

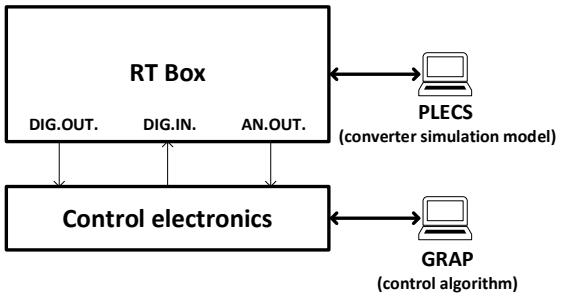

Figure 6 Principles of the HiL simulation system connection with the tested control electronic module

electronic was developed using the RT Box device, i.e. the HiL simulation system. As shown in Figure 6, by connecting the RT Box unit and the control electronic of the inverter (type number ICMC02), the testing of the correctness and implementation of functional and type tests, along with the adjustment of the control module algorithm were enabled.

A. *Simulation model of the converter in PLECS simulation environment*

Simulation model of the converter realized in the PLECS simulation environment is shown in Figure 7. After the off-line simulations, model has been uploaded to the RT Box, to ensure connection to the tested module of the control electronic. The corresponding digital inputs and outputs are used for connection to the module, as shown in Figure 7.

PWM signals, which are brought from the control board to control the model switches, are connected to the digital inputs and are loaded through the PWM Capture blocks (FPGA) because of the higher resolution. However, the converter's power section electrical behavior takes place with a larger step of the simulation. The minimum simulation step is 6 μs, and the minimum sampling time of the FPGA is 7.5 ns. Based on the known mean value of the digital signal between the two simulation steps, it can be concluded how long the digital signal at the input of the PWM Capture block was in logic state 1, and how long it

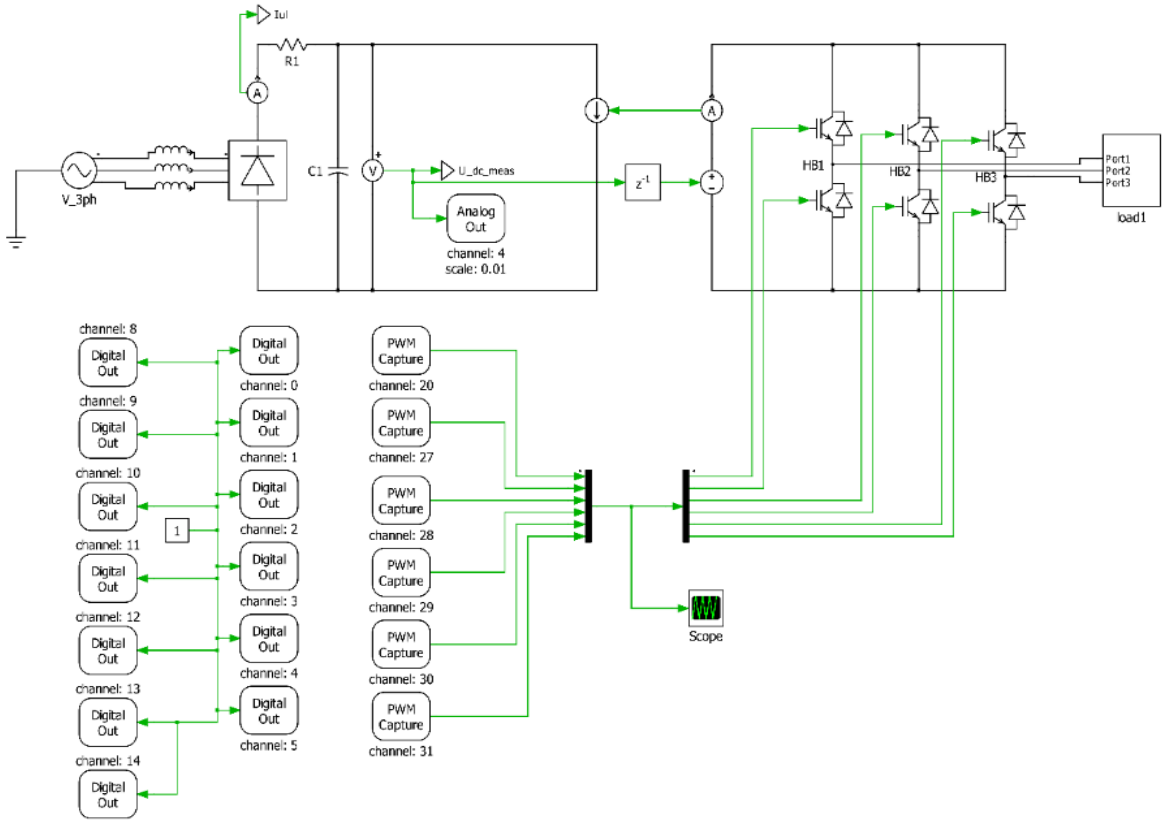

Figure 7 Simulation model of converter in PLECS simulation environment

was in logic state 0. For example, if a selected simulation step is 6 µs and 0.66 is obtained as the output of the PWM Capture block, ergo digital signal was brought to the PWM Capture block input was 4 µs in logic state 1 and 2 µs in logic state 0. In this way it can also be concluded whether the "dead time" is implemented in control algorithm and does it exist on output pins of control electronics (control electronics of converter has DSP that works with time step of 20 µs and FPGA that works with step time of 6.67 ns and generates PWM signal with "dead time" of 2 µs, defined inside control algorithm on DSP).

Digital outputs are signaling the error signals that occur in the event of an IGBT error (the IGBT error signal equivalent generated by the driver and reported in the control electronic). The condition in which all digital outputs from the model are in logical state 1, is IGBT switches error free state. If any of the digital outputs sets the logic state 0, it processes the control algorithm protection and sets all PWM outputs to logic 0. In addition to the digital inputs and outputs of the RT Box, analog output Analog Out in which the DC link voltage of simulation model scaled to the value from 0 V to 10 V, is brought. The scaled voltage of the DC link is further passed through the adapter board to the analog input of the control module ICMC02 to close the voltage feedback.

B. Adjustments of the RT Box in order to achieve full functionality of the hardware-in-the-loop simulation

To ensure connection of the RT Box with the control module, it is necessary to adjust the voltage and current levels of digital and analog signals which are exchanging between the RT Box devices and the tested module. Adjustment of the current level of the analog signals is necessary because of the limits of the integrated blocks per which analog outputs of the TR Box are realized. Maximal current which can be achieved through analog outputs is about 100 times lower than current trough load resistors in analog inputs of ICMC02 control electronic. For adjusting the voltage and current levels of common digital signals as well as more comfortable approach to analog and digital outputs of the RT Box system, four adapter board are made, Figure 8. Special board for adjusting analog signal for performing feedback on the DC link voltage was made too.

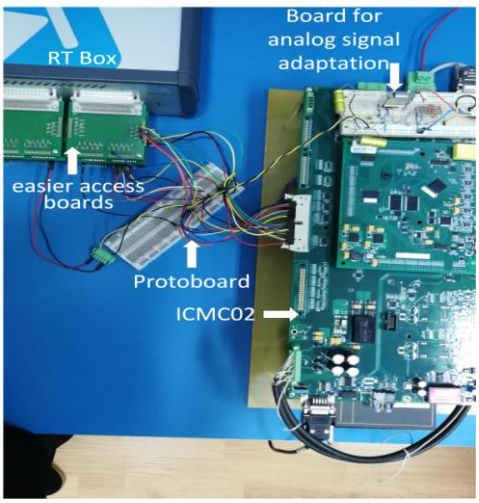

Figure 8 Connecting of RT Box and ICMC02 electronic modul

V. RESULTS OF THE SIMULATIONS AND MEASUREMENTS

Figure 9 shows the waveforms of the voltage and current within the converter obtained by HiL simulation, while Table 1 shows the simulation parameters.

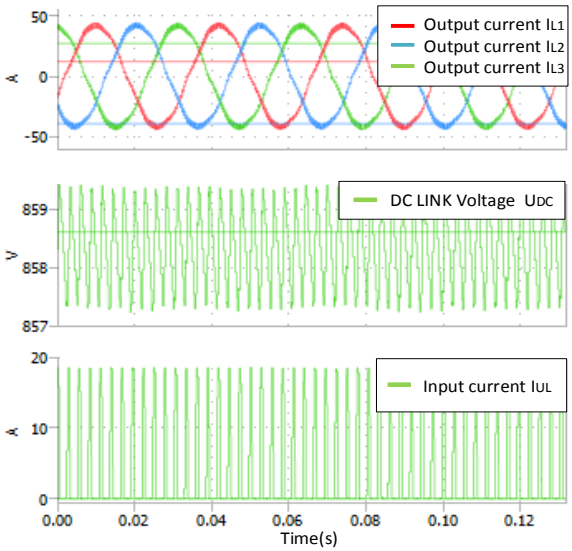

Figure 9 Waveforms obtained by HiL simulation

Table 1 Parameters of the simulation model

PARAMETER	DESCRIPTION	VALUE
U_gen, f_gen	line voltage and generator frequency	620 V, 60 Hz
U_izl_ref, f_izl_ref	reference value of output line voltage and frequency	220 V, 30 Hz
C_dc_link	capacitance of the DC link	4290 µF
p	number of pole pairs	2
R_st	equvivalent stator resistance	0.3015 Ω
R_rot	equivalent rotor resistance	0.6833 Ω
L_sigm	equivalent stator and rotor leakage inductance	2.3733 mH
L_magn	equivalent magneising inductance	105.254 mH
J_rotor	equivalent rotor moment of inertia	0.1894 kgm^2
J_ventilator	equivalent fan moment of inertia	0.332 kgm^2

An engine-fan group used on locomotives was used to test the converter prototype, Figure 10. Figure 11 shows measured voltage and current waveforms within the converter during laboratory testing using the actual engine and fan.

Comparing measured waveforms of the input phase current, DC link voltage and input DC link current with



Figure 10 Fan type 7AZAE 180LA-4T, Končar MES, used for testing of converter PN35AC

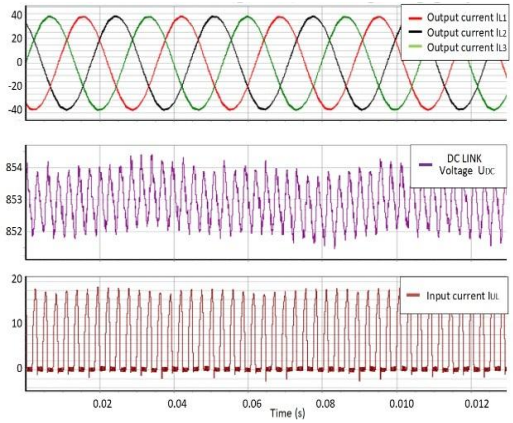

Figure 11 Waveforms obtained by recording during the prototype test of the converter

waveforms conducted by HiL simulation on the prototype of the converter, qualitative similarities of the signals is shown.

Deviation between measured and by simulation obtained current and voltage peak values are result of different parasite elements/influence (parasitic capacitance, measure part fault and discretization, contact and self resistance of cable and power components, parasite inductance of cables and capacitors).

VI. COMPARISON OF TRADITIONAL METHOD OF DESIGN AND METHOD THAT IS USING HARDWARE-IN-THE-LOOP SIMULATION SYSTEM

The previous example shows that the HIL simulation can describe with sufficient accuracy the physical phenomena within the converter, which enables designers to complete a large part of the control electronic and control algorithm tests in advance, before the tests on a real converter are conducted. In the control algorithm test phase, it is necessary to remove the limitations and errors that arise from the fixed step of the algorithm execution (error of discrete control structure, delay and exact

moment of AD conversion, etc.). These limitations and errors can't be predicted by performing a SiL simulation that uses a variable integration step. The HiL simulation system takes into consideration the whole chain from the transducer, the conclusion, the filter to the AD conversion. The software thus tested and configured already takes into consideration the signal propagation through the metering channel, or the phase shift, by which is entered into the control system.

From all of the above, possible savings can clearly be observed in the testing of the converter unit using the HiL simulation system compared to the classical test methods. In addition to the shorter testing time in the lab, it is possible to shorten the overall development cycle of the converter by elaborating the control software and the HiL simulation for the duration of component delivery or assembly of the device itself. Furthermore, the possibility of earlier detection of errors in the design of the device is perhaps the biggest potential of material, time and money saving compared to eliminating them during laboratory or field testing. Resource savings on a small and simple device such as the PN35AC (35 kW) may not be so significant, but potential savings in design and testing of complex converters with the application in electrical traction (main drive converter, auxiliary power supply, battery charger) are several orders larger in size. Testing such large and complex devices in the laboratory requires extensive preparation and use of expensive equipment, while field testing means engaging and securing track segments and carrying out test runs on trains (demanding logistic, additional time and cost).

VII. CONCLUSION

It is well known that the HiL simulation can reduce the duration and cost of the development of power electronics devices. In addition to the shorter testing time in the lab, it is possible to shorten the overall development cycle of the converter by elaborating the control software and the HiL simulation for the duration of component delivery or assembly of the device itself.

Although the HiL simulation was not realized in full scope, with all the analogue signals transmitted to the control electronics from the RT Box, it is shown on a single channel that this connection is possible and that it is a faithful representation of the signal normally supplied from the measuring device that is responsible for measuring the voltage of the DC link. Requirements for the adaptive electronic board that will enable the full range of HiL simulations have been made and it will be possible to automate the testing of control electronic modules with a built-in control algorithm.

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Power converter circuits for recuperation of the regenerative braking energy in rail vehicles

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Abstract **- Electric rail transport offers a sustainable development in the transport sector with regard to an increasing urbanization and adverse climate changes. Due to rising energy costs, there is also a need for adequate energy saving solutions in this type of transport. In order to save energy and increase performance of the vehicle the recuperation of regenerative braking energy solution is used. The stored energy could be used to increase performance and energy efficiency during acceleration and even enable autonomous drive. This paper considers storing of regenerative braking energy of rail electric vehicles in lithium-ion batteries and supercapacitors, installed on the vehicle. Discussed power converters' topologies perform energy conditioning and optimal energy management between vehicle's storage, power train and power line, during traction, braking and driving with constant speed. Simulation models of typical power converters which are used for this purpose have been developed and simulation experiments were conducted. The comparative analysis of simulation results highlights the advantages and disadvantages of the simulated converters and the observed types of energy storage with respect to the set criteria.**

Key words – regenerative braking; topologies; railway vehicles; energy storage elements; DC/DC converters

I. Introduction

Electric railway vehicles are a safe, economic and ecologically viable choice for transporting goods and people. To further reduce greenhouse gas emissions and enhance the energy efficiency, necessary improvements must be undertaken. Storing and reusing the energy obtained during dynamic braking is one of the most effective methods to increase energy efficiency in electric railway vehicles.

Dynamic braking energy is the transformation of the vehicle's kinetic energy into electrical energy during deceleration and it is based on the ability of the electric motors to operate in generating mode. Uncontrolled energy returns to the power supply grid can cause over-voltages and decrease the grid's quality if there are no demands for that energy. Systems that can improve the power supply quality and which also enable the storage and subsequent use of dynamic braking energy are called regenerative braking systems. In these systems, the braking energy is mainly stored in battery and/or supercapacitor modules and can be used for starting and accelerating the vehicle, as well as for limited autonomous driving without a power supply.

There are two approaches in developing and implementing a regenerative braking system for railway vehicles. One approach consists of installing an energy storage system (ESS) outside the vehicle as wayside or stationary ESS, which enables the capture of surplus energy in the power supply grid during braking and returning the stored energy during acceleration. Stationary energy storage units improve the grid's stability. The second approach is based on integrating the ESS in the vehicle itself. This mobile regenerative braking system can provide a limited autonomous drive without catenary.

Energy storage elements are connected to the main drive's DC link through a bidirectional DC/DC converter which has the task of controlling the flow of braking energy according to demands of the vehicle and energy storage element. The goal of this paper is to give a review of typical and most utilized bidirectional DC/DC converter topologies used in mobile regenerative braking systems of railway vehicles.

II. DC/DC Converter Requirements In Regenerative Braking Systems

Energy flow in regenerative braking systems is between the main drive inverter's DC link and the energy storage element. Since the DC link's voltage level is usually different from the voltage of energy storage element, a bidirectional DC/DC converter is necessary to adjust voltage levels and control energy flow according to the requirements set by the vehicle and energy storage element.

Generally, in order to simplify converter controllability, the energy storage element's voltage level is lower than the DC link's voltage level. This means that during braking the DC/DC converter will charge the energy storage element and will function as a buck (step-down) converter; and during the vehicle's acceleration it will discharge the energy storage element and function as a boost (step-up) converter.

It is necessary to consider several parameters when choosing a DC/DC converter topology.

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The converter efficiency is always an important parameter and the goal of development is to achieve highest efficiency possible, especially in systems with larger power. Also, the DC/DC converters in these systems should operate reliably in a wide temperature range and in terms of significant cyclic loads.

The transfer voltage ratio of the DC/DC converter is an important parameter, especially if the converter is connecting an energy storage element with a much lower voltage level than the power supply grid's voltage. If output and input ratio is over 20, it is recommended using topologies with a galvanic isolation i.e. a transformer [1]. A suitable turns ratio achieves the desired voltage increase. Converters using a transformer are also safer to use, since in a case of malfunction the energy storage element and rest of the system are electrically separated.

Another important parameter in selecting the topology of a DC/DC converter is the number of power semiconductor switches used. Increasing the number of semiconductor switches increases the number driving circuits and the complexity of the converter control unit. The converter's mass and dimensions also increase, as well as its price. On the other hand, a higher number of semiconductor devices lowers the voltage and current stresses and possibly losses. Considering the above, a compromise must be made between lowering the complexity and price in contrast to lowering the total power losses.

Energy storage elements used in regenerative braking systems are most commonly lithium-ion batteries and/or supercapacitors. These storage elements require a constant charge or discharge current with minimal ripple. Therefore, converters in these systems must have the lowest possible current ripple on the energy storage element side.

III. DC/DC Converters Topologies In Regenerative Braking Systems

A. Half-bridge buck-boost DC/DC converter

The half-bridge buck-boost DC/DC converter is the simplest and most utilized bidirectional DC/DC converter topology, shown in Fig. 1.

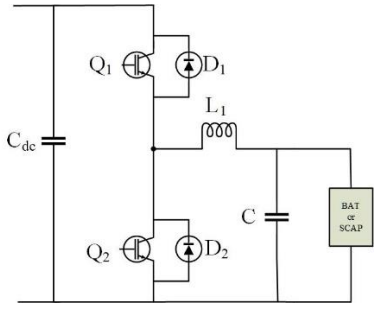

Figure 1. Half-bridge buck-boost DC/DC converter

The capacitor C_{dc} represents the main drive's DC link and the block BAT/SCAP represents the energy storage element. During braking, energy flows from the DC link towards the energy storage element i.e. the converter functions as a buck converter. The duty cycle of transistor Q_1 controls the amount of power conveyed to the battery. During this mode of operation, the inductor L_1 functions as a filter. When the energy flows from the battery towards the DC link, the converter functions as a DC/DC boost converter. The duty cycle of transistor Q_2 controls the amount power sent to the DC link. During either flow direction, the converter operates in continuous-current mode.

This topology advantage is that it only uses two controlled switches in complementary duty cycles which simplifies the excitation circuitry and control. A small number of switches and the fact that this topology does not use a transformer, its efficiency does not fall below 90% [2].

This topology disadvantages are the limited voltage level increase during boost mode operation and that it does not have galvanic isolation of the energy storage element [3].

B. Interleaved buck-boost DC/DC converter

The interleaved buck-boost DC/DC converter is a parallel connection of two or more half-bridge DC/DC converters. The control signals are phase shifted by an angle of 360°/n, where n is the number of parallel phases. Fig. 2 shows an example of the converter with 3 parallel phases.

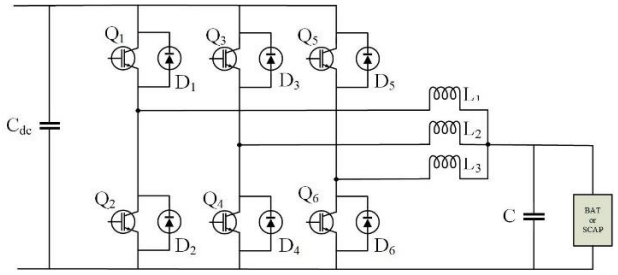

Figure 2. Interleaved buck-boost DC/DC converter

The advantage of this converter is a lower charging current ripple since phase-shifted signals control each phase. For this reason, filters of lower values and dimensions are used. Also, due to current split on multiple phases (I/n), for the same switching frequencies and for the same average output current value, the total losses of the semiconductor switches in this topology are smaller in relation to single phase half-bridge buck-boost DC/DC converter shown in figure 1. For this reason, this converter topology results in higher efficiency and power density [4], [5].

The main disadvantage is the higher cost due to the higher number of semiconductor devices integrated in the converter as well as a more complicated control algorithm [4].

C. Buck-boost DC/DC converter with coupled inductors

Fig. 3 shows a buck-boost DC/DC converter with magnetically coupled inductors with the same number of turns [5].

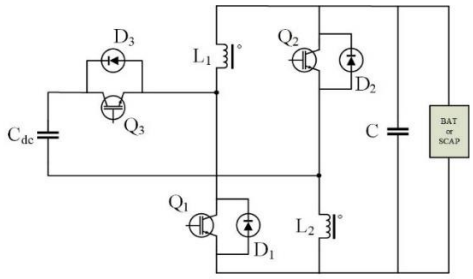

Figure 3. Buck-boost DC/DC converter with coupled inductors

In boost mode, when energy flow is from the BAT/SCAP energy storage element to the DC link C_{dc}, Q_3 switch is not conducting and a control signals are sent to switches Q_1 and Q_2 simultaneously. When Q_1 and Q_2 are conducting, inductors L_1 and L_2 are in parallel and are accumulating energy from the BAT/SCAP energy storage element. When Q_1 and Q_2 are switched off, the inductors are in series with the load and delivering energy through the diode D_3.

In buck mode, when the energy flow is reversed, a control signal is sent to Q_3 while Q_1 and Q_2 are off. When Q_3 is conducting, the inductors are in series and act as a filters along with the capacitor C. When Q_3 is switched off, current flows through forward-biased diodes D_1 and D_2.

Advantages of using this topology instead of the half-bridge buck-boost DC/DC converter are a lower current stress of the switches, a higher efficiency and a higher voltage increase during boost mode [5].

D. Dual active full-bridge DC/DC converter

This DC/DC converter consists of two bridge converters, one on the high voltage side (primary) and one on the low voltage side (secondary) of a high-frequency transformer T_r, Fig. 4. Using transformer, galvanic isolation and a necessary voltage increase or decrease are achieved. Using the leakage inductance L_k and by implementing commutation capacitors C_{c1}–C_{c8}, soft-switching is accomplished to reduce switching losses [7].

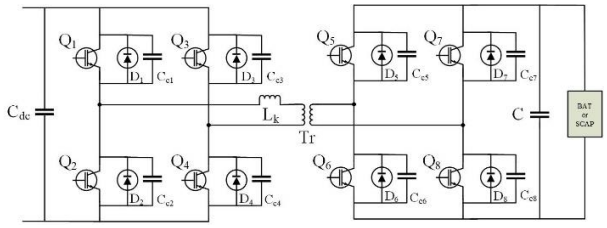

Figure 4. Dual active full-bridge DC/DC converter

Depending on energy flow direction, one converter functions as an inverter and the other as a full-wave rectifier. E.g. if energy flows from the DC link to the battery, the converter connected to the DC link functions as an inverter and the converter connected to the battery functions as a rectifier. The swicthes are switching in diagonal pairs with a duty cycle of 0.5, generating a square-wave voltage waveform on the primary and secondary. Multiple power flow control methods exist for this converter topology. A basic and commonly used one is controlling the phase shift between the transformer's primary and secondary, called the *phase shift control strategy*.

The advantage of this topology is the operation on high frequencies and the consequently usage of a relatively small transformer to achieve galvanic isolation and high power density assuming that the leakage inductance is sufficiently low [3]. Efficiency in this converter is around 95%, both for low and high power applications [8], [9], [10].

The disadvantage of this converter is a high input and output current ripple, which can be reduced by adding an adequate filter [3]. A high number of semiconductor devices and a complex control algorithm can represent a challenge during design and implementation of this topology.

E. Dual active half-bridge DC/DC converter

This converter consists of two half-bridge converters, one on the high voltage side (primary) and one on low voltage side (secondary) of a high frequency transformer T_r.

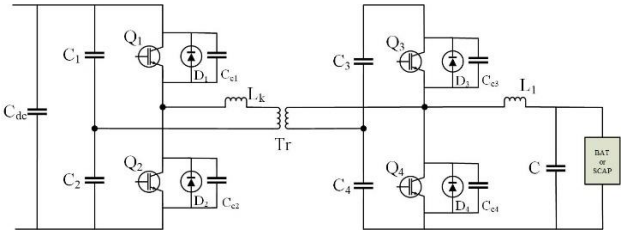

Figure 5. Dual active half-bridge DC/DC converter

Similarly as in the dual active full-bridge DC/DC converter, the amount of power and direction of energy flow is controlled through the primary and secondary voltage phase shift. During power transfer from the high voltage side to the low voltage side, switches Q_3 and Q_4 along with the inductor L_1 achieve a DC/DC buck converter. During power transfer from the low voltage side to the high voltage side, the aforementioned components accomplish the effect of a DC/DC boost converter. The voltage on the primary and secondary is a square-wave waveform. Primary voltage amplitude is equal to half of the DC link voltage. Secondary voltage amplitude is equal to half the voltage on the series capacitors C_3 and C_4.

In comparison with the dual active full-bridge DC/DC converter, the dual active half-bridge DC/DC converter has half the amount of semiconductor devices for the same amount of rated power. Furthermore, the buck/boost converter on the low voltage side achieves lower current ripple on the side of the energy storage element and lower switch current stresses [10]. Soft-switching is achieved equally on every switch for both energy flow directions [10].

One of the main disadvantages of this topology is that peak load current flows through the capacitors in the capacitive voltage divider [3], [10].

IV. Simulation Of Functional Behavior Of Dc/Dc Converter In Regenerative Braking System

In this chapter, a simulation model of the DC/DC converter is developed. This simulation model is used to control the flow of braking energy of the rail vehicle during charging and discharging of the supercapacitor module. The simulated topology is dual active full bridge DC/DC converter. This topology was chosen with the intent to assess the current ripple level of the energy storage element. The simulation model was developed using PLECS simulation software, and after simulations were carried out, results are commented.

The simulation model consists of DC link capacitor connected to a grid modeled as an ideal voltage source of 600V with a serial connected resistor modeling the internal resistance of the grid. The electric motor and inverter are modeled as an controllable current source. The controllable current source models the acceleration and braking of the vehicle. The supercapacitor is modeled as a block from the PLECS model base and its parameters can be modified accordingly. The parameters for supercapacitor model used in this simulation were taken from Maxwell BM0D0063 P125 B08 supercapacitor module datasheet and are listed in Table 1. In simulation four such models connected in series were used.

Table 1. Supercapacitor module Maxwell BM0D0063 P125 B08 parameters

Rated capacitance	Maximum ESR	Rated Voltage	Leakage Current
63 F	18 mΩ	125 V	10 mA

Figure 6 shows the scheme of a simulation model of a dual active full bridge DC/DC converter. The simulation model parameters are presented in Table 2, and the simulation parameters are presented in Table 3.

Table 2. Simulation model parameters

Component	Parameter	Value
Q1 - Q8, Q_brake	Ideal IGBT with ideal diode	
	Switching frequency (Q1-Q8)	20kHz
Cdc	Capacitance	30e-3 F
	Initial Voltage	600V
	ESR	0.009 Ω
Lk	Leakage Inductance	5 µH
	Initial current	0 A
Tr – ideal transformer	N1/N2 (transfer ratio)	1.2
Rprimary	Resistance of primary coil	0.001 Ω
Rsecondary	Resistance of secondary coil	0.001 Ω
C	Supercapacitor capacitance	30 F
	Initial Voltage	480 V
V_dc – grid voltage	Voltage	600 V
Rvdc – grid resistance	Resistance	0.00387 Ω
R_brake	Resistance	1 Ω

Table 3. Simulation parameters

Parameter	Value
Max step size	1e-6 s
Relative tolerance	1e-3
Initial step size	Auto
Absolute tolerance	Auto
Refine factor	1
Solver type	Variable-step
Solver	RADAU (stiff)

In this simulation, the control of the converter is performed by achieving a phase shift between the primary and secondary transformer voltages. In the case of discharging of the supercapacitor, the secondary voltage precedes the primary voltage, and in the case of charging, primary voltage precedes the secondary voltage.

In real applications, it is necessary to implement the control of phase shift in order to control charging and discharging power, but since the goal of this chapter is to describe only the functional behavior of the converter in the regenerative braking system, the converter is controlled in such a way that the phase shifts are constant.

The modeled converter is controlled via the "CONTROL UNIT" block. From figure 6 it can be seen that inputs to the block „CONTROL UNIT“ are: DC link voltage, supercapacitor voltage and current from current source which in this simulation models the current on the input of the inverter of electric drive. Based on these variables, the control signals for the converter switches Q1-Q8 and the brake resistor switch Q_brake are determined. The control system is implemented in such a way that the control block "CONTROL UNIT" based on the direction and the amount of current of current source and of the voltage of the supercapacitor, starts or stops charging and discharging of the supercapacitor module.

The simulation was performed with the profile of the current source shown in the top graph of figure 7 for the case when initial voltage of supercapacitor is 400V which represents 80% charge level. Negative current source profile represents acceleration of the vehicle while positive current profile represents dynamic braking of the vehicle.

The negative direction of the current source current in this simulation means that the direction of the current is from the DC link to the inverter of electromotor drive. When the direction of this current is negative, and when its absolute value is greater of the set threshold value, and if supercapacitor voltage is greater than 250V converter starts discharging supercapacitor by generating phase lead of secondary voltage relative to primary voltage. When direction of current is positive and greater than the set threshold value, and if supercapacitor voltage is less than 500V, the converter starts charging of the supercapacitor by generating phase lead of primary voltage relative to secondary voltage.

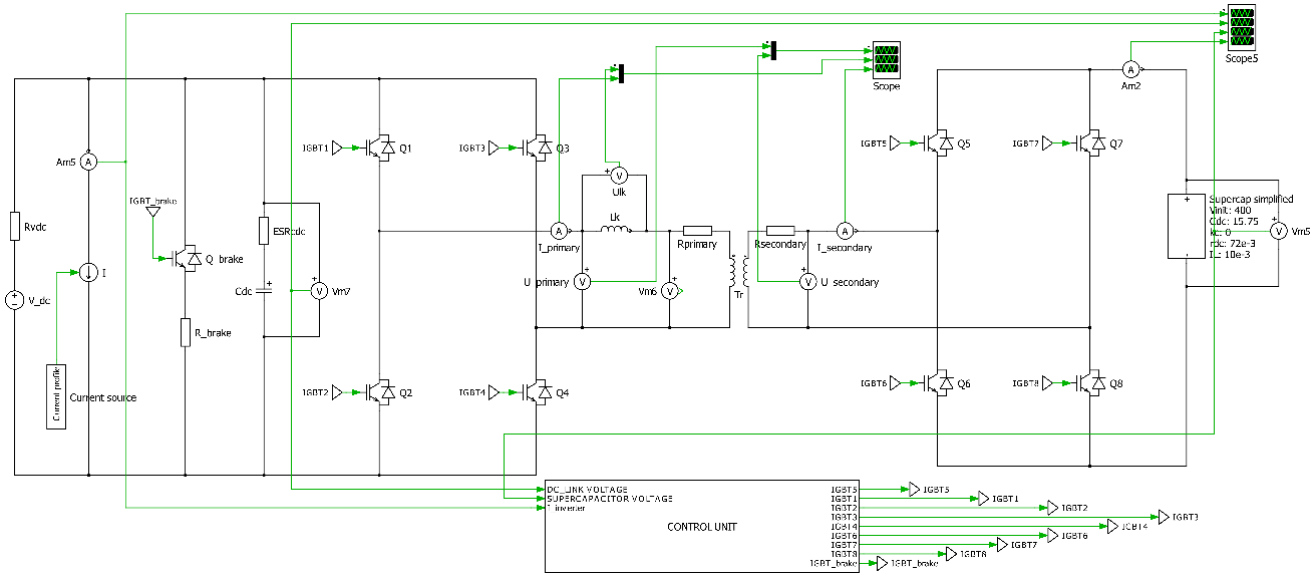

Figure 6. Simulation model of dual active full bridge converter

Braking assembly made of switch Q-brake and resistor R_brake serves to stabilize the DC link voltage during dynamic braking. In case the DC link voltage rises above 610V, the Q_brake switch closes and the excess dynamic braking energy is dissipated through braking resistor as heat while the DC link voltage does not falls below 605V.

The current source profile, DC link voltage, supercapacitor voltage and current during discharge and charge process are shown in Figure 7.

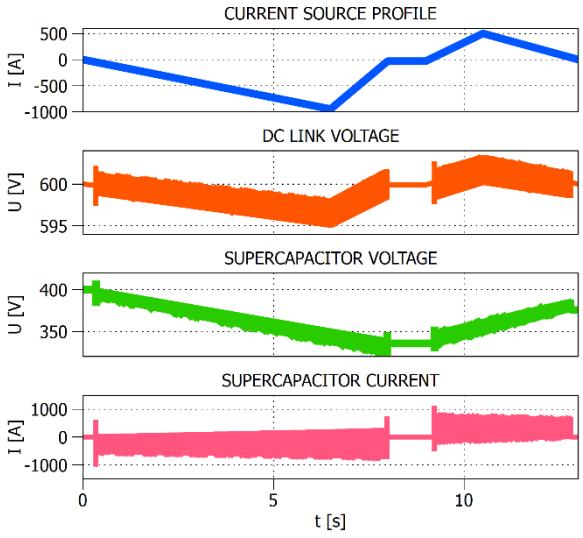

Figure 7. The current source profile, DC link voltage, supercapacitor voltage and current during discharge and charge process

Figure 8 and Figure 9 show two periods of the above mentioned values during discharging and charging. It is possible to notice substantial ripple current of charging and discharging of supercapacitor. It is already mentioned in chapter 3.4 that the biggest drawback of this topology is significant current ripple on the side of energy storage element.

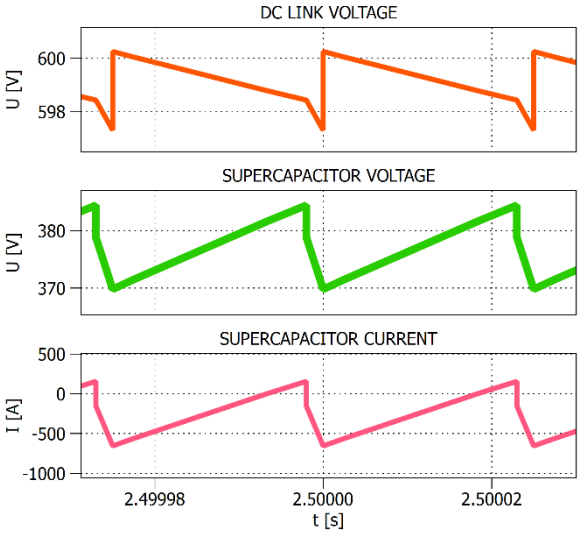

Figure 8. Waveforms of DC link voltage and supercapacitor voltage and current during discharging

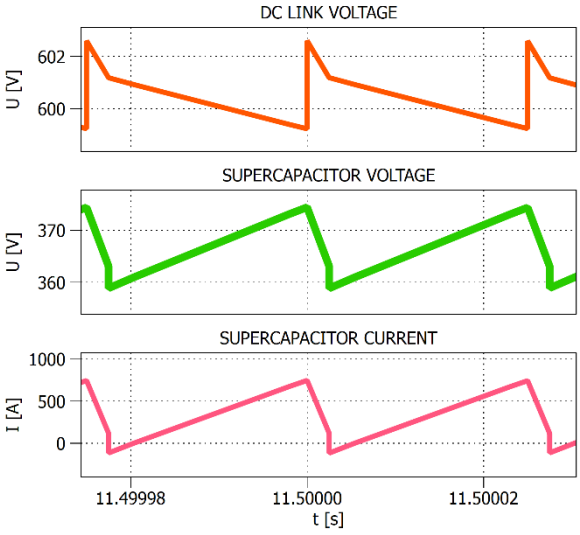

Figure 9. Waveforms of DC link voltage and supercapacitor voltage and current during charging

Figure 10 and Figure 11 show the phase shifts of primary and secondary voltages of transformer and corresponding currents. In addition to primary current, the voltage of leakage inductance is shown (green color).

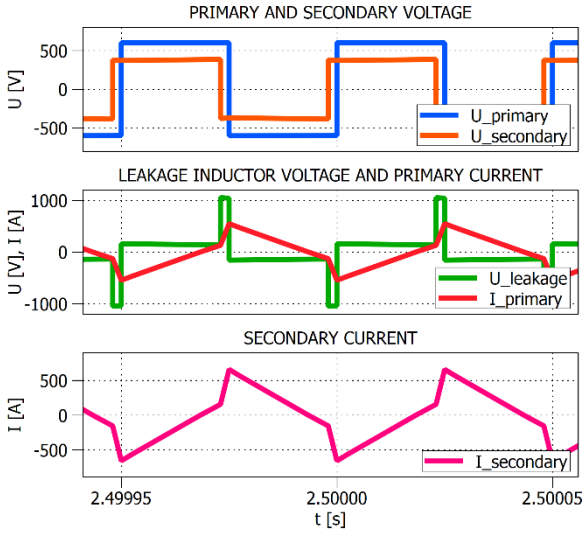

Figure 10. Waveforms of voltages and currents in the transformer during discharging

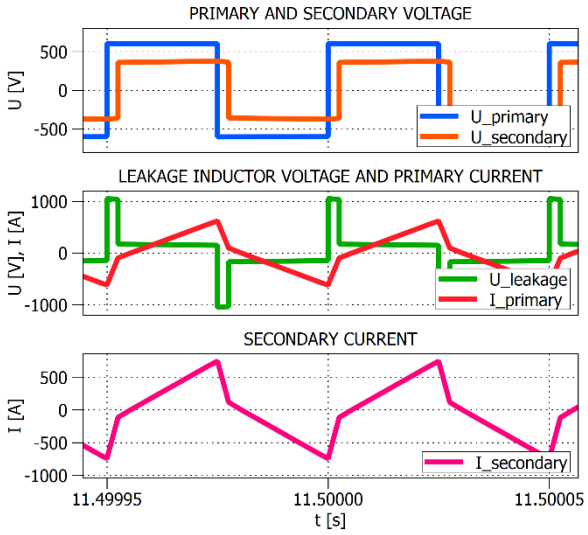

Figure 11. Waveforms of voltages and currents in the transformer during charging

V. Conclusion

The role and significance of regenerative braking systems is described and the main requirements for DC/DC converters in regenerative braking systems are presented. There is a wide variety of topologies that can be used in regenerative braking systems, and the ultimate choice depends on the power, the ratio of output and input voltage, as well as price and complexity. An overview of some of the basic topologies of DC/DC converters used in regenerative braking systems has been presented. The basic work principles and the most significant advantages and disadvantages of each adduced topologies are presented as well. The simulation of the regenerative braking system with dual active full bridge DC/DC converter was performed and the results obtained were matched with the theoretical predictions.

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Analysis of the uninterruptible power supply influences to the power grid

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Abstract - Systems of uninterruptible power supplies (UPS) are indispensable part of many industrial plants, transportation, telecommunications and other systems, enabling their proper functioning and supply with stable DC and AC voltages. The structure of power section of the UPS system typically consists of a DC link and two converters which perform an indirect AC conversion with bidirectional energy flow. This article provides an overview of the various topologies and structures of the advanced UPS system. UPS input rectifier circuits used to achieve power factor correction (PFC) are specifically described in accordance with the requirements to the load powered by the UPS system. In addition to comparative analysis of these circuits, their main advantages and disadvantages are described. The simulation models of the power and control part of the selected solutions are elaborated for program package MATLAB and PLECS as well. In addition, simulation experiments based on developed models are carried out in order to analyze solution functionality, in terms of PFC and UPS influence to power grid.

Key words – Uninterruptible power supplies, power factor correction, power converter

I. INTRODUCTION

The UPS systems provide reliable and uninterrupted power supply to sensitive devices in communication and transportation systems, data centers, medical equipment, etc. Regardless of input voltage or load variation , outputs of UPS systems are regulated DC or AC voltages with a low Total Harmonic Distortion factor (THD). The structure of the power section of UPS system typically consists of a DC link and two conversion stages that perform an indirect AC conversion with bidirectional power flow. The UPS system emphasised importance of the power factor correction (PFC), total efficiency and dependability. According to the method of connection to the AC power grid and load, UPS systems can be divided into off-line UPS, line interactive UPS and on-line UPS [1]. Depending on common network failures, various UPS systems provide protection against specific errors that occur at the point of common coupling (PCC). PCC is the connection point of the power supply system and many different electrical loads. Off-line UPS systems provide protection against long-term interruptions or network failures, voltage drops and dynamic overvoltage. Line interactive UPS systems are used to provide protection against permanent occurrences of undervoltage, overvoltage and rapid jump of voltage. Active UPS systems are used to provide protection against constant and periodic transient perturbation, harmonic distortion, noise, impulses and frequency changes. In this article, active UPS systems with PFC at the input stage are specifically described. The selected example shows one PFC controller solution. A simulation model of the power section of the converter was developed by PLECS/Blockset, while the control algorithm of the selected PFC controller was developed by MATLAB/Simulink.

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II. STRUCTURE AND CLASSIFICATION OF UPS SYSTEMS

Structure of the UPS system consists of three conversion stages: rectifier at the input stage, DC link with the battery, and inverter or DC converter in the output stage, depending on the load (AC or DC), Figure 1. In addition, the UPS system may also have a bypass line that supplies power directly from the grid to the load. Depending on the implementation of bypass lines, the input stage, DC link and the output stage of UPS systems can be divided into: (i) off-line, (ii) line interactive and (iii) on-line.

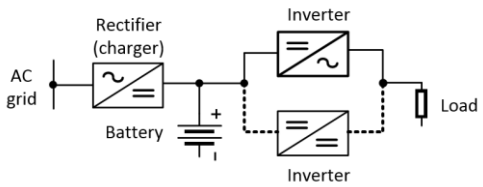

Figure 1. Block structure of the UPS system

A. *Off-line UPS systems*

Off-line UPS systems have three possible operation modes. The first mode is the normal mode where the load is directly supplied from the AC grid, and the battery is charging through the rectifier, Figure 2.

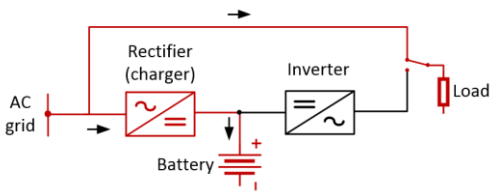

Figure 2. Normal operation mode of off-line UPS

In the second operation mode, which occurs when supply from AC grid cuts off, the static switch is switching off connection to the AC grid and switching on connection to the inverter, i.e. the battery. In this case the load depends only on the energy stored in the battery. The third operation mode occurs if battery or inverter are in failure. In that case, the load depends only on the direct connection to the AC grid and in the case of a power failure the load remains without power supply.

B. Line interactive UPS systems

The specificity of these systems is a two-way rectifier/inverter. There are two possible operation modes for line interactive UPS systems. In the first operation mode, the load is directly connected to the AC grid and the battery is charging through the two-way rectifier/inverter, Figure 3. The two-way rectifier/inverter in this mode acts as a rectifier. It should be noted that this situation is the same as in normal mode of off-line UPS systems.

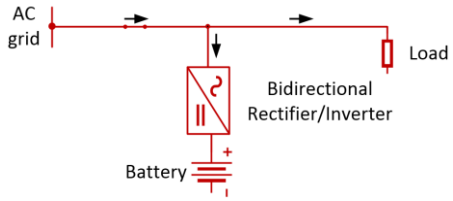

Figure 3. Normal operation mode of line interactive UPS

The diversity of the system is only seen in the second mode when supply from AC grid cuts off. Line interactive UPS systems, unlike off-line UPS systems, have the static switch located at the input side. This ensures that the load doesn't remain without power even when the switch is disconnected because the required energy is obtained from the battery through a two-way rectifier/inverter that operates in the inverter mode.

C. On-line UPS systems

There are three possible operation modes of active UPS systems. In the normal mode, shown in Figure 4, the AC grid is connected to the rectifier, which converts the AC voltage to the DC voltage of the battery. This DC voltage is passed through the inverter to the load.

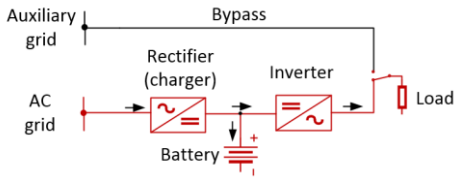

Figure 4. Normal operation mode of on-line UPS

In the second operation mode, in which a main power failure of AC grid appears, the load doesn't remain without power supply. It takes energy from the battery and thus satisfies the continuity of power supply. The third operation mode occurs when inverter or battery are in failure. In this case, the switch is connecting an auxiliary power supply via the bypass line. This ensures that despite the main power failure and the failure of the inverter or battery, load remains supplied.

III. REQUIREMENTS FOR THE UPS SYSTEMS

The power factor of an AC electrical power system is defined as the ratio of the real and the apparent power of the supply network:

$$\lambda = \frac{P}{S} = \frac{UI_1 \cos(\varphi)}{UI} = \frac{I_1}{I}\cos(\varphi),$$

Where I_1/I is distortion power factor, and cos(φ) is displacement power factor. In the case of linear loads the distortion factor is 1. For nonlinear loads, the distortion power factor and displacement power factor differ from one, because of reactive power and higher harmonics influence. Higher harmonics of load current are „soiling" the grid and lowering the quality of the power supply voltage. They can cause various perturbations and errors in the control devices, harmonic losses and vibrations of the mechanical parts. One way to express distortion of the load current waveform is by the Total Harmonic Distortion (THD). The THD shows the total content of the higher harmonics in the load current and is express by the following formula:

$$\mathrm{THD} = \sqrt{\sum_{n=2}^{\infty} \frac{I_n^2}{I_1^2}},$$

where I_n is the effective value of the n-th harmonic of the load current. Besides the THD, distortion of the current waveform can be expressed by the Total Demand Distortion (TDD). The TDD shows the total content of the higher harmonics in the maximum demand load current at the PCC, and is express by the following formula:

$$\mathrm{TDD} = \sqrt{\sum_{n=2}^{\infty} \frac{I_n^2}{I_L^2}},$$

where I_L is the maximum demand load current at the PCC.

Requirements for the loads and devices with regards to the power supply influences, are contained in the valid standards. Some of the most important standards are IEEE 519 and IEC 555 (IEC 61000) [2-3]. The IEC 61000-3 standard limits the amounts of higher harmonics that devices inject into the power supply. The IEC 61000-3-2 standard defines the permitted values from the 2nd to the 40th current harmonic. Table 1. shows the harmonic limits for UPS systems.

Table 1. Harmonic limits for UPS systems

Harmonic order (n)	**Maximum permissible harmonic current (A)**
Odd harmonics	
3	2.30
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
15-39	0.15 x 15/n
Even harmonics	
2	1.08
4	0.43
6	0.30
8-40	0.23 x 8/n

IEEE 519-2014 standard defines the limits of the harmonic voltage distortion based on the measurements and recommended limitations of voltage and current harmonics on PCC. Table 2. shows limits of the harmonic voltage distortion in this standard.

Table 2. Limits of voltage distortion

Bus voltage at PCC	**Individual harmonic (%)**	**Total harmonic distortion THD (%)**
≤ 1.0 kV	5.0	8.0
1 kV – 69 kV	3.0	5.0
69 kV – 161 kV	1.5	2.5
> 161 kV	1.0	1.5

Limits of current distortion and TDD for systems rated 120 V through 69 kV are shown in table 3. All values in table 3. are in percent of the maximum demand current (I_L) connected to the PCC. This current value is determined as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12. I_{SC} is the maximum short - circuit current at the PCC.

Table 3. Limits of current distortion for systems with a voltage of 120 V to 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)						
I_{SC}/ I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 – 50	7.0	3.5	2.5	1.0	0.5	8.0
50 - 10^2	10.0	4.5	4.0	1.5	0.7	12.0
10^2- 10^3	12.0	5.5	5.0	2.0	1.0	15.0
> 10^3	15.0	7.0	6.0	2.5	1.4	20.0

IV. UPS SYSTEMS WITH PFC

Elements of energy electronics, due to their non-linear characteristics, distort the sine waveform of the voltage and current. The input part of the UPS system consist of a rectifier that loads the network with a current with rich harmonic content. Higher harmonics have a negative impact on the elements in the power system, which is expressed by the appearance of resonance in the network, additional losses in the conductors because of heating, the negative influences on capacitor batteries, elements of protection and the accuracy in the measurements and the reduction of the power factor. Due to adverse effects, the PFC is necessary. There are two common approaches to the PFC; passive and active [4]. Passive filters are used for passive PFC techniques. In case of active PFC, converter with semiconductor switches designed for operation at high frequencies are used. Most used passive filters for PFC are: (i) inductor on the side of the network (ii) inductor on the side of the rectifier (iii) band-pass filter (iv) band-stop filter (v) trap filter (vi) LCD filter. The main disadvantages of passive filters are large mass and volume, significant dissipation of power and high price. High-frequency inverters are used in the active PFC method to reduce the demands on the passive components in the view of mass, volume and price. This section will briefly describe the structure of the UPS systems connected to a single-phase supply network that use the Boost converter, Flyback converter and Boost Integrated Flyback Rectifier/Energy storage DC/DC (BIFRED) converter for the PFC at the input stage.

A. UPS system with boost converter for PFC

Figure 5. shows UPS system with boost converter for PFC. In the input stage of the UPS system is a single-phase diode rectifier and a DC boost converter that is used for PFC. In the input stage there is also a forward symmetrical converter with a transformer that is used for galvanic isolation and to achieve DC-link voltage. In the output stage of the UPS system is an inverter that is used to achieve the AC output to the load. This topology has the advantages of small size and weight because of the high frequency transformer and can also provide galvanic isolation. But high number of active switches decrease the efficiency of the system and add complexity to the circuit.

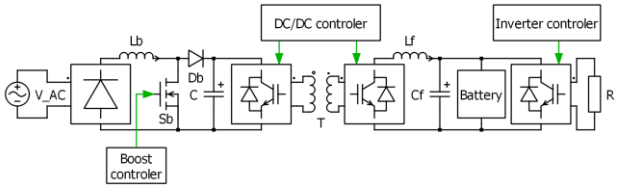

Figure 5. UPS system with boost converter for PFC

B. UPS system with flyback converter for PFC

Figure 6. shows UPS system that uses flyback converter for PFC [5]. This UPS system serves to supply DC loads through the boost converter in the output stage.

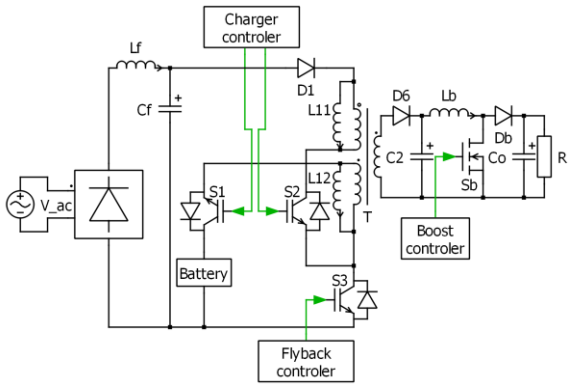

Figure 6. UPS system with flyback converter for PFC

As in the previous UPS system, the input stage is a single-phase diode bridge circuit. Full-wave rectified voltage is transmitted via diode D_1 to the first primary of the transformer, while the battery is connected to the second primary of the transformer via switch S_1. In normal mode, the energy is taken from the network and stored in the battery (S_2 leads, and S_1 does not). In case the power supply from the network fails, the required energy is provided by the battery (S_1 leads, and S_2 does not). Flyback converter control in terms of PFC takes place using the high-frequency switch S_3 (frequencies up to 100 kHz). The main advantages of this UPS system are galvanic isolation with a high frequency transformer and the usage of the same magnetic component for PFC and battery charging. In this way a lower price is achieved, increasing the simplicity and reliability of the system.

This type of UPS system is suitable for relatively low powers.

C. UPS System with BIFRED converter for PFC

Figure 7. shows UPS system with BIFRED converter for PFC [6].

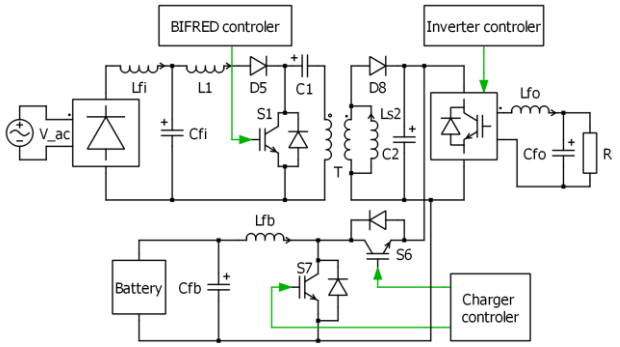

Figure 7. UPS with BIFRED converter for PFC

BIFRED is a combination of boost and flyback converter, and has only one switch and a characteristic bulk capacitor. PFC is achieved with the boost converter, and the galvanic isolation and the output voltage control by the flyback converter. The problem of excessive voltage on the bulk capacitor is solved by the boost and flyback converter operating in the discontinuous conduction mode (DCM). At the input of the boost converter is a full-wave rectified voltage. Characteristic of a boost converter is that in the DCM for a given value of inductance of the boost inductor, and a certain duty cycle, through the single-phase diode rectifier, pulls the sinusoidal current waveform from the network. While the switch is on, energy is accumulated in the boost inductor, the bulk capacitor is connected parallel to the primary of the transformer and the magnetization current flows through the primary of the transformer. During this time the current of the secondary of the transformer is zero and the load is powered form the output capacitor. When the switch is off the boost inductor releases the accumulated energy to the bulk capacitor, the magnetic flux in the core is supported by the current of the secondary of the transformer that supplies the load.

V. PFC CONTROL IN UPS SYSTEMS

This section will discuss the control of the input level of the UPS systems that uses boost converter for PFC. Specifically, the current mode control (CMC) of the boost converter will be described.

A. CMC of the boost converter

Boost converter can be controlled by voltage or current mode control. The primary difference between the voltage and current mode control is in the modulation of the PWM control signal of the converter switch. In voltage mode control only one feedback loop is used. Duty cycle is determined by comparing the fixed internal ramp with the error signal between the reference and the measured output voltage. CMC uses the internal and external feedback loop, figure 8. The external loop is by the voltage and the internal by the current. The external loop provides an error signal between the reference and measured output voltage that is used to determine the reference current in the current loop. The internal current loop compares the obtained current reference value with the measured current of the switch or the inductor, and then based on the error signal between these two currents defines the control signal for the converter switch. The CMC can be divided into average or peak current control. With average current control the momentary mean current value through the inductor or switch (averaged within the switching period) is adjusted. This mode of control ensures very low current distortion, constant switching frequency and there is no need for compensation ramp. In peak current control, the peak current through the inductor or switch (peak value within the switching period) is adjusted. In this mode of control, the system loses stability in DCM when the duty cycle is greater than 50% which results in subharmonic oscillations. For this reason it is necessary to add a compensation ramp in order to stabilize the converter response [7-10], Figure 8.

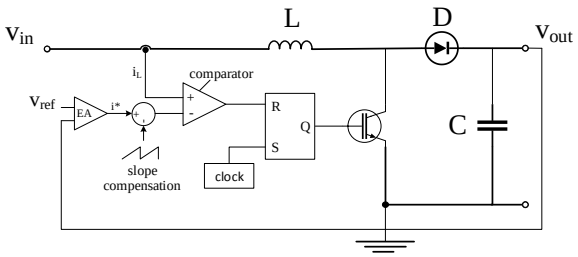

Figure 8. Example of using the compensation ramp in peak CMC

The input current ripple in the converter can be reduced by using multiple phases of the boost converter. By interleaved switching of the individual phases of the boost converter, the total input voltage ripple and the output current ripple are reduced. The phase shift between the control signals of the inverter switches is determined by the number of phases.

B. PFC controllers

Dedicated integrated circuits – PFC controllers, are used to control the input level of UPS systems that have the PFC capability. Some of the typical commercial PFC controllers are UCC28070 (TEXAS Instruments), TDA4819 (Siemens), ML4812 (Micro Linear) and TK84812 (Toko). Figure 9. shows the basic structure of the *ML4812 Power Factor Controller* by the *Fairchild Semiconductor* manufacturer [11]. The basic functional parts of this integrated circuit are; error amplifier, current amplifier modulator, compensation ramp and PWM comparator.

Figure 10. shows the basic control structure of the PFC controller coupled to the power part of the current controlled boost PFC converter. Measured output voltage is supplied to the PFC regulator in order to compare it with the voltage reference value to get the error signal. This error signal in the Gain Modulator determines the amplification of the reference current signal.

The waveform of the reference current signal is a fully corrected sinus to which the signal from the compensation ramp is added. The output from the Gain Modulator is supplied to a comparator where it is compared with the signal of the measured current through

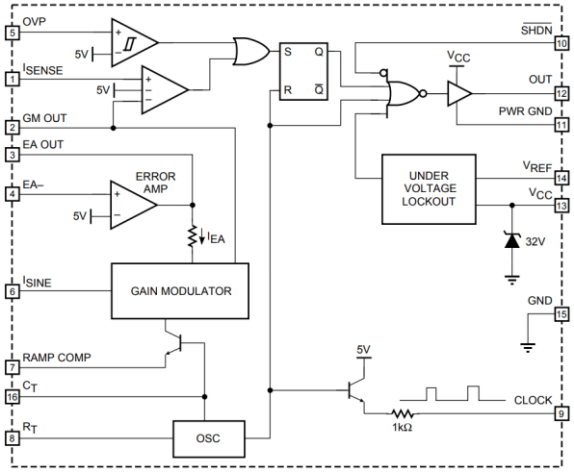

Figure 9. Block diagram of the ML4812 controller

the switch. Logic output of the comparator is further brought to the S (set) input of a flip-flop, while an oscillator signal is brought to the R (reset) input of the flip-flop which represents a reset pulse for the flip-flop. Negative output of a flip-flop is the control signal for the inverter switch.

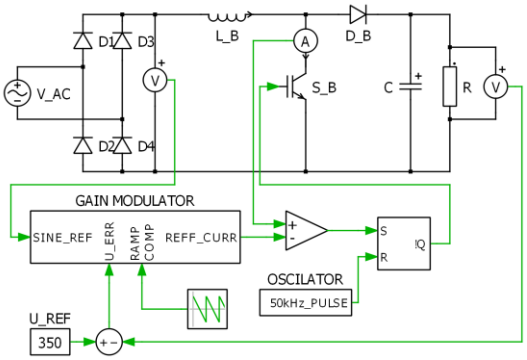

Figure 10. Principal control scheme of a boost PFC converter with the ML4812 controller

VI. SIMULATION EXPERIMENT

In this section, a simulation experiment of the UPS system input section, with a boost converter that has the ability of PFC by using the ML4812 PFC controller, will be displayed. Simulation of the control and power section of the converter is performed by connecting the two programming tools. The controller model is created using MATLAB/Simulink, and the power section model using PLECS/Blockset. Both models (power section and controller) can be connected to one MATLAB/Simulink model.

A. Simulation model

The block diagram of the model in which the connection between UPS system control section and power section is achieved, is shown in Figure 11. The power section is realized within the PLECS Circuit block while the control part is realized within the PFC controller block. The topology of the simulated converter within the PLECS Circuit block is shown in Figure 12, and model parameters are given in Table 4. A detailed view of the PFC controller block is shown in Figure 13., and block parameters are given in Table 5.

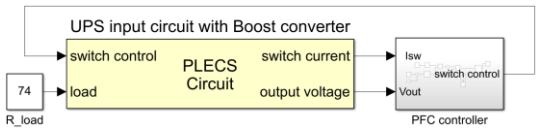

Figure 11. The block diagram of the connection between UPS system control section and power section

The power section of the converter within the PLECS Circuit block consists of an AC source, a single phase diode rectifier, and a boost converter with a resistive load.

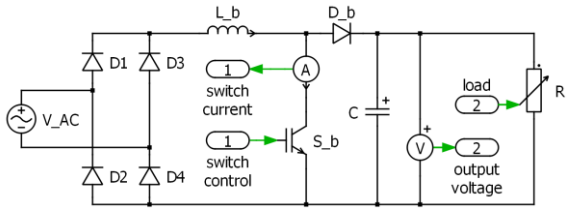

Figure 12. The topology of the converter within the PLECS Circuit block

Table 4. Parameters of PLECS Circuit block model

Elements	Parameters	Value
V_AC	-	325 VAC, 50 Hz
D1, D2, D3, D4	Forward voltage = 0, On-resistance = 0	-
L_b	Initial current = 0	7 mH
S_b	Forward voltage = 0, On-resistance = 0, Initial conductivity = 0	-
D_b	Forward voltage = 0, On-resistance = 0	-
C	Initial voltage = 0	1500 μF
R	-	74 Ω

Boost CMC simulation is realized by two loops: first, for achieving the desired output voltage (external, slow loop) and second, for achieving the sinusoidal input current that is in-phase with the sinusoidal input voltage (internal, fast loop). The reference current is computed by adding the signal generated by Compensation Ramp block to the product of the output of the PI regulator and the full-wave of the sine signal, generated by Sine Ref block. The PI regulator achieves the output voltage error as small as possible.

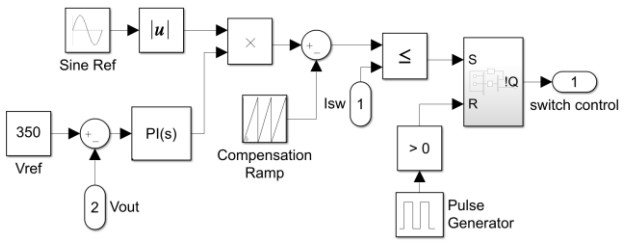

Figure 13. PFC controller block in MATLAB

Table 4. Parameters of the PFC controller block model

Elements	Parameters	Value
Sine Ref	Frequency = 100*pi (rad/sec)	1
Vref	-	350
PI(s)	P = 0.0011, I = 0.478778	-
Compensation ramp	Carrier frequency = 50 kHz, Signal range = [0 0.2]	-
Pulse generator	Period (secs) = 0.00002, Pulse Width (%) of period = 2	-

B. *Parameterization of PI regulator*

The parameters of the PI controller are obtained by numerical optimization of the system step response. The control structure is defined for optimization purpose as simple loop of the PI controller, and process in direct path and measured output voltage as the feedback signal. The process consists of boost converter with current control circuits. Error signal, i.e. difference between reference signal (Step from 150V to 350V) and feedback signal is used as controller input. For optimization purpose the constant input DC voltage of 150V is used. The objective function is defined as ISE (integral square error criterion). The characteristic of the system with controller optimized according to ISE criterion is overshoot of the output variable over 20%. As the goal of system response in our case is 1.5% overshoot, constraint function is applied beside ISE criterion. The constraint function forces the optimization procedure to choose controller parameters in the area where the overshoot does not exceed 1.5%. These conditions determine that system response should be as close as possible to critically damped system response. The optimization procedure was performed by fmincon function from MATLAB optimization toolbox. The method is based on Newton optimization with constraints. Controller parameters obtained by optimization are as follows: P = 0.0011, I = 0.478778.

C. *Simulation results*

Figure 14. shows the comparison of the input current response with the fixed duty cycle (D = 0.2) and the input current response with the built-in PFC regulator. The result of the use of the PFC regulator is the input current of approximately sinusoidal waveform without phase shift in relation to the voltage, i.e., the approximate unit power factor is obtained.

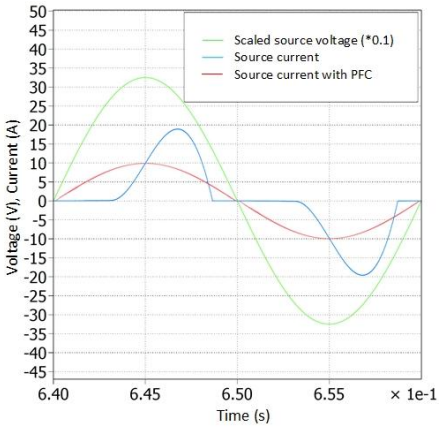

Figure 14. Waveforms of input voltage and input current with or without PFC

Figure 15. shows a comparison of the inductor current response when a compensation ramp is used and when is not used. It has been shown that using a compensation ramp, even in a critical area where the duty cycle is greater than 0.5, the system stabilizes and achieves a controlled response of the sinusoidal input current.

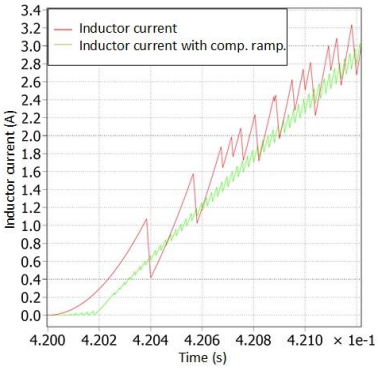

Figure 15. The influence of compensation ramp on input current

VII. CONCLUSION

A review of various PFC solution is shown in this article. One of the above structures based on single phase diode rectifier and PFC controlled boost converter is selected for demonstration by simulation. The peak current control of the boost converter has been designed, and simulated using two program tools. Simulation results show that an approximately unit power factor was successfully achieved. In the conclusion, the development of new control algorithms and electric components will further enhance the control of PFC and integrated circuits that are used as PFC.

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PAPERS

DATA SCIENCE

Calculating average shortest path length using Compute Unified Design Architecture (CUDA)

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***Abstract*—Large graphs with millions and even billions of vertices are found in many real-life network analysis, the processing of which is challenging. One of the toughest tasks is computing the average shortest path length in a large network, which requires a lot of memory and processing time while calculating many independent paths. Hence, this task becomes a good candidate for parallelizing. The idea of using graphics processing units (GPUs) for general purpose computing is not new, and with recent increases in performances and memory capacity, they make a perfect candidate for working with graphs. We will explore how the Dijkstra's algorithm can be used to calculate the average shortest-path length, and how it can be used in a massively parallelized system and compare the performance gains and drawbacks.**

***Index Terms*—graph; path length; CUDA**

I. Introduction

Graphs are data structures commonly used to describe sets of nodes and their connections as edges. There is a large number of graph operations such as traversals (Breadth First and Depth First), topological sorting, minimum spanning trees, connectivity, shortest paths etc., finding applications in many domains such as biology [1], social sciences [2], computer chip design and many others.

Average shortest-path length (ASPL) is a concept in network topology that is defined as the average number of steps along the shortest paths for all possible pairs of network nodes. It is a measure of the efficiency of information or mass transport in a network. Examples include the average number of clicks you would need to navigate from one to other website, or the number of roads you need to take to get from one city to another, or one of the most familiar examples the average number of people you would have to involve in order to send a message between two complete strangers, the small-world property [3] of many networks.

The ASPL finds applications in designing and researching many real-world networks. The power grid is more stable if the average path is minimized, the Internet will be able to transfer information faster given shorter ASPL etc.

The ASPL is defined as the sum of all the distances between every pair of nodes in a network divided by the number of nodes in the network. For weighted graphs the time complexity of calculating the ASPL is $O(N^3)$ using the Floyd algorithm [4]. For networks that have millions of nodes and edges the time needed to compute the ASPL becomes impracticable which makes massive parallelization a must.

There is more than one available method of parallelization for this problem. One of the methods is computing the single-source shortest-path length (SSSPL) for each node in parallel to reduce the computation time for each node, which reduces the time needed to compute the shortest path for a single node. Another method of parallelization is where each core computes the SSSPL for a single node, or if we have more nodes than cores available, namely N nodes and C cores, every core would be responsible for computing the SSSL for N/C nodes, which wouldn't decrease the time taken to compute the SSSL for a single node, it will actually increase the time when using the GPU, but, hopefully, given a large enough graph it would drastically reduce the time needed for computing the all-pairs shortest-path length.

The second approach is much easier to implement on a massively parallel processor as it only requires a single reduce operation after all the cores have completed their work, while the first approach requires lots of scheduling and communication which doesn't make it a good fit for CUDA computation.

The paper is organized as follows. Section II gives an overview of related work. Background about CUDA programming model and graph presentation are elaborated in Section III. Section IV presnets the algorithm and its parallel version. Performance analysis of the implementation of this parallel algorithm is given in Section V. Conclusions and directions for future work are given in Section VI.

II. Related work

The field of network science was unpopular until the beginning of the twenty-first century, mainly because of the hardware limitations [5] required to compute most of the network properties, especially the ASPL, so not a whole lot of research has gone into parallelizing the algorithms for computing the ASPL, especially on many-core processors.

Pankhari Agarwal and Maitreyee Dutta have worked [6] on parallelization of the SSSPL on the Nvidia CUDA framework, namely the Bellman-Ford Algorithm with big

speed-ups over the corresponding serial implementations. The device memory was the only limit on how large the graphs could get.

Guoyong Mao and Ning Zhang have worked [7] on parallelizing the ASPL on multi-core processors using the dynamic programming model using the average out-degree of neighboring nodes.

Nvidia's Graph Analytics library nvGRAPH has a SSSPL parallel algorithms built-in that works on graphs with up to 2 billion edges. This can also be used to calculate the ASPL if the nvGRAPH's SSSPL algorithm is used for every node [8].

Pawan Harish and P.J. Narayanan have implemented several graph algorithms on the GPU, one of which uses CUDA to calculate the all pairs shortest path length using Floyd-Warshall's parallel implementation, however, the parallel execution of Floyd-Warshall was slower than sequentially invoking a parallel SSSPL algorithm for every node [9].

Singla, Tiwari and Singh [10], as well as Martín, Torres, and Gavilanes [11], have worked on parallelizing Dijkstra's SSSPL algorithm on Nvidia's CUDA architecture which could be used to calculate the ASPL if the SSSPL was calculated for every node in the graph and stored in the CPU memory.

III. Background

A. CUDA Programming model

The CUDA programming model uses tens of thousands independent threads running in parallel grouped by warps that are later grouped by blocks (Fig. 1) that run over a multiprocessor in a given time, allowing multiple blocks to run on a single multiprocessor in a timeshared manner. Such blocks are collected to form a grid.

Each thread block can be considered independent to the other, and it is at this level at which internal communication (among threads) is cheap using explicit barriers to synchronize, and external communication (among blocks) becomes expensive, since global synchronization only can be achieved by the barrier implicit between successive kernel calls. Each thread in a block, and each block in a grid has its own unique ID and the threads use these IDs to decide what data to work on. Each thread can read/write per-thread registers, per-thread local memory, per-block shared memory, per-grid global memory and read only per-grid constant memory and per-grid texture memory (Fig. 2). Threads from different blocks cannot cooperate [12].

B. Graph representation

A complete description of a network requires us to keep track of its links. The simplest way to achieve this is to provide a complete list of the links. For mathematical purposes we often represent a network through its adjacency matrix [13] as in Fig. 3.

Although simple, since most real networks are sparse, this representation is not ideal since lots of space is being wasted on nonexistent edges. For such networks, a more compact way for representation would be using an adjacency list. However, because of the varying lengths of the arrays per vertex, this representation is not suitable for use with the CUDA model. Although this is possible with using two arrays, one for the nodes with each node pointing to its edge list in the second, larger, adjacency list array. Due to the simplicity of the adjacency matrix representation and since this paper focuses on the speed gain of computing the ASPL using a GPU compared to CPU, we will be using the adjacency matrix representation.

IV. Calculating the average shortest-path length

A. Mathematical formula

The average shortest-path length is defined as follows. Consider a graph G with the set of vertices V. Let $d(v_1, v_2)$ where $v_1, v_2 \in V$ denote the shortest distance between v_1 and v_2. Assume that $d(v_1, v_2) = 0$ if v_2 cannot be reached from v_1 or if $v_1 = v_2$, then the average shortest path length $ASPL_G$ is as given in (1) where n is the number of nodes in G.

$$ASPL_G = \frac{\sum_{i,j}^{n} d(v_i, v_j)}{n \cdot (n-1)} \tag{1}$$

B. Algorithm

Calculating the ASPL is basically just calculating the distances between every node combination in the graph, so we can use Dijkstra's algorithm for this. We will use Dijkstra's algorithm for every node and add up all the shortest path lengths. This results in n^2 independent calculations in a graph with n nodes if the graph is directed.

1) Dijkstra's algorithm: Dijkstra's algorithm is one of the most commonly used algorithms for finding the shortest path between two nodes in a graph. It was conceived by Edsger W. Dijkstra in 1956. [15]

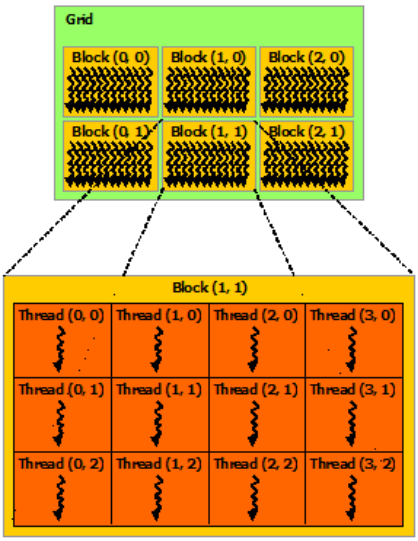

Fig. 1. CUDA programming model [12]

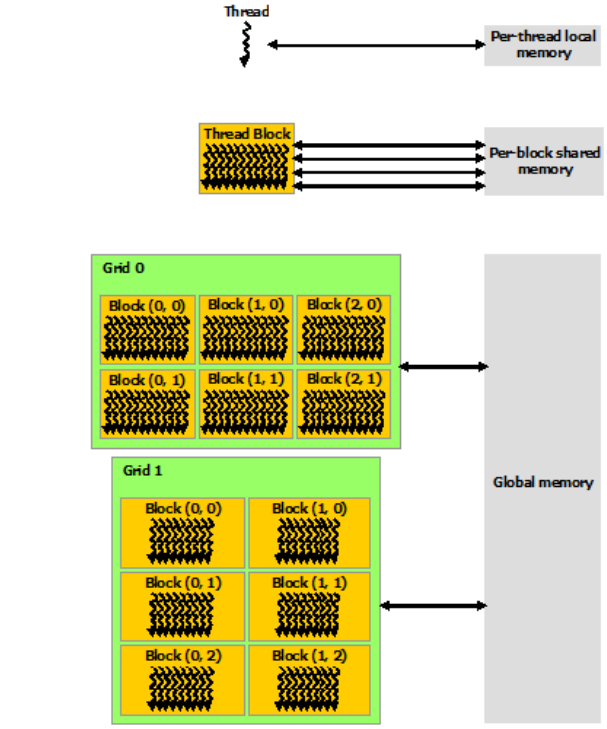

Fig. 2. CUDA GPU memory hierarchy [12]

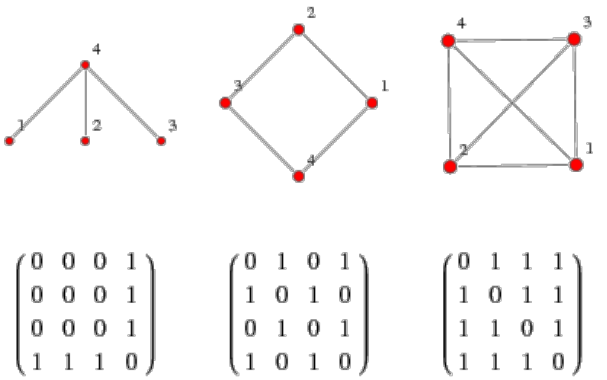

Fig. 3. Adjacency matrix representation of graphs [14]

C. Parallelizing the calculation of the ASPL

The idea of the parallel approach in calculating the ASPL is to have as many threads as possible each calculating the SSSPL for a single node, or if there are more nodes than we can launch threads, striding forward, so that each thread would calculate the SSSPL for N/T nodes, given N nodes and T threads.

For calculating the SSSPL we will be using Dijkstra's algorithm for adjacency matrix which has time complexity of $O(|V|^2)$ where $|V|$ is the number of vertices. For this we will need two more arrays with length $|V|$, one for the distances from the node i to every other node, and one for the shortest path tree set that keeps track of vertices included in shortest path tree, i.e., whose minimum distance from source is calculated and finalized. Due to the large sizes of the arrays we will be keeping them as two large arrays, each of size $|V| \cdot blockDim \cdot gridDim$ in the GPU's global memory, since for larger graphs they wouldn't fit in the thread's local memory. Once each thread has finished finding the SSSPL we will calculate the sum of the path lengths and then do one atomic addition per thread to sum up the total shortest path length in the graph.

Because we don't use the shared memory, the kernel dimensions can be as large as possible, such that they do not largely exceed the graph's size, and the size of $(V \cdot blockDim \cdot gridDim) \cdot 2 + V \cdot V$ does not exceed the device memory available. Where $(V \cdot blockDim \cdot gridDim) \cdot 2$ is used for the two auxiliary arrays and $V \cdot V$ is used for the distance matrix. The pseudo-code for the kernel is given in Algorithm 1.

Algorithm 1 Single source shortest path length

```
1:  procedure KERNEL(Graph, NumVertices)
2:      id ← blockIdx.x * blockDim.x + threadIdx.x
3:      stride ← blockDim.x * gridDim.x
4:      for i ← id; i < V; i+ = stride do
5:          sum[i] ← SSSPL(Graph, i)
6:      end for
7:      for all sum do
8:          atomicAdd(total, sum)
9:      end for
10: end procedure
```

D. Restrictions and drawbacks

The biggest restriction when parallelizing the ASPL calculation, as stated before, is the huge amount of memory required to store all the path lengths. Another problem when calculating the paths in parallel is that we basically do double the calculations in undirected graphs, i.e. calculating the shortest path both from v_i to v_j and from v_j to v_1. This can be solved by using a map to store the distances and checking if the distance is already calculated or is currently being calculated before starting to calculate.

V. Performance analysis

The evaluation of the performance of the parallelization for computing the ASPL was done on a real network with 12 thousand vertices, containing up to 18 million edges, as well as smaller subsets of the same network. The performance gain was significantly noticeable with as little as 100 vertices compared to the serial implementation, and without any further optimizations. For huge networks, the biggest bottleneck is the memory required to store the adjacency matrix, as well as the auxiliary arrays in the GPU global memory, as they were quickly getting over 4GB when tested on our network of 12 thousand nodes, since the auxiliary arrays take up $O(|V| \cdot blockDim \cdot gridDim)$ space. However, if the Dijkstra algorithm is adapted to be used with adjacency list, this problem would be reduced, while at the same time improving the time complexity.
The time taken to calculate the ASPL for the entire network on the GPU was 276 seconds when running on an Nvidia Tesla V100 GPU, including the time taken to

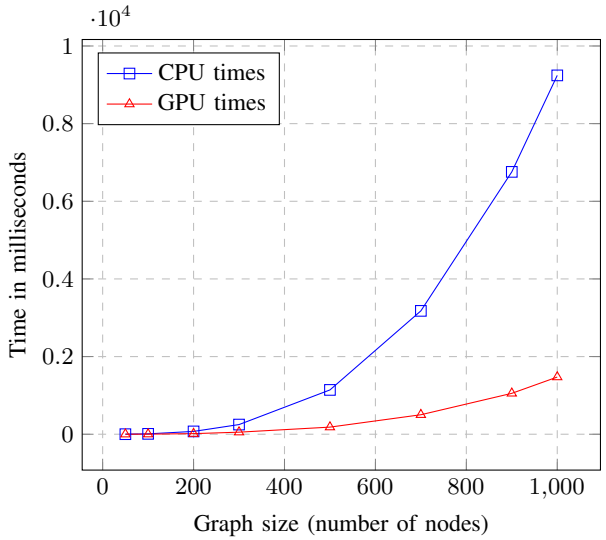

Fig. 4. Time taken to calculate the average shortest path length using serial execution on CPU compared to parallel execution on GPU

transfer the memory from and to the device, although this was only 0.01% of the GPU activities.

When comparing the times it took to compute the sum of all the paths on CPU and GPU, we saw the first improvements at 20 vertices, although less than 1 millisecond. With graphs with over 500 vertices the time difference becomes drastically noticeable between the serial and parallel implementation. As long as the entire adjacency matrix can fit in the GPU's memory we can have nearly exponential increase in speed, as seen in Fig. 4.

VI. Conclusion and Future Work

The implementation of the problem, although fairly simple, and using only the global memory and not utilizing the much faster shared and local memory, gave huge improvements compared to the serial execution. This calculation can further be optimized by not using an adjacency matrix and using an edge list instead, which would reduce the memory usage, as well as the time complexity of the Dijkstra algorithm.

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Exploiting GPUs on distributed infrastructures for medical imaging applications with VIP and DIRAC

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***Abstract* - GPU usage has become mandatory for the processing of (3D) medical data, as well as for efficient machine learning approaches such as deep learning. In this contribution, we present how VIP and DIRAC can be leveraged to run medical image processing applications on distributed computing resources equipped with GPUs.**

VIP (Virtual Imaging Platform) is a web portal for the simulation and processing of massive data in medical imaging. VIP users can access applications as a service and significant amounts of computing resources and storage with no required technical skills beyond the use of a web browser. VIP relies on the DIRAC (Distributed Infrastructure with Remote Agent Control) interware for scheduling tasks for execution on distributed infrastructures such as grid, clouds, and local clusters. New applications are regularly integrated into VIP/DIRAC. They all have their own requirements, among which GPU usage is more and more frequent.

This contribution will give an overview of the targeted medical applications and their requirements, as well as technical insights on how VIP and DIRAC allow end users to efficiently exploit GPU resources with no specific knowledge about the underlying distributed infrastructure.

Keywords - medical imaging, distributed computing, GPU

I. INTRODUCTION

Medical imaging applications have always been compute intensive and, in the last few years, GPU usage has become mandatory for the processing of (3D) medical data, as well as for efficient machine learning approaches such as deep learning.

Researchers in the biomedical and life-science communities have had access to distributed infrastructures such as EGI for many years, but they were usually "limited" to CPU-based resources. The scientific gateways available, as well as other tools allowing researchers to deploy their scientific applications, were therefore tailored to the available computing resources.

With the growing interest in GPUs, we try to answer the question of what it takes to have a medical imaging application available as a web service and executed on distributed computing resources equipped with GPUs.

The paper is organized as follows: Section II introduces the EGI infrastructure, as well as DIRAC and VIP. Section III gives an overview of two medical imaging applications, their implementation and specific needs. Section IV provides technical insight on how these applications can exploit GPU resources through VIP and DIRAC. Finally, Section V is dedicated to conclusions and perspectives.

II. DISTRIBUTED INFRASTRUCTURES AND THEIR TOOLS

A. EGI

Distributed computing has been available for various research fields since the early 2000s through the European DataGrid Project, which became the European Grid Infrastructure (EGI). During the last 20 years, this infrastructure has continuously evolved, proposing a large spectrum of services alongside computing and data resources. Today, EGI provides access to over 850,000 logical CPUs and 650 PB of disk and tape storage. These resources are shared among different research fields, named Virtual Organizations (VOs).

The Biomed VO, gathering researchers from the biomedical and life-science communities, has access to about 65 computing sites world-wide, including more than 130 computing clusters and 5PB of storage distributed across 50 different storage elements (SEs).

Although most computing resources are composed of "classical" CPUs, some sites are also providing GP-GPU resources through the EGI Federated Cloud. The number and heterogeneity of available resources make it difficult for researchers (end users) with no specific knowledge of the underlying infrastructure to use these resources easily and efficiently.

B. DIRAC

The DIRAC Project provides software for building large scale distributed computing systems [4], [7]. Services created using this software allow to integrate computing and storage resources of different types located anywhere in the world in a coherent federation with a single access point from the user perspective. The Project was initially started to exploit available grid computing resources for LHCb, one of the experiments on the Large Hadron Collider (LHC) at CERN, Geneva, as a response to a challenge of processing unprecedented data volumes collected at LHC. The solution developed for LHCb was later adopted by other experiments in the High Energy Physics, Astrophysics and other scientific domains. Services based on the DIRAC software are also offered to the users of large national grid infrastructures, e.g. France-Grilles National Grid Infrastructure (NGI) in France. Since 2014, the DIRAC services are also provided for the users of the European grid infrastructure (EGI). As a result, even small user communities can benefit from an easy access to vast amounts of resources available in these infrastructures.

DIRAC services include both Workload and Data Management tools. The Workload Management Service (WMS) integrates resources provisioned by grid and cloud infrastructures but also by supercomputers, standalone computing farms or even volunteer computing systems. User tasks are submitted to the central Task Queue and then sent for execution to the resources matching the task requirements, taking into account the task priorities and resource usage policies. Special attention is paid to automation of the management of large numbers of tasks that can be organized in complex workflows driven by the availability of the data to be processed. Users access the service using several interfaces – command line tools, Web Portal, RESTful interface or programming API. The work pattern is similar to the one of using a large-scale batch system distributed worldwide. For example the DIRAC WMS of the LHCb experiment is capable of executing of up to 150K user tasks simultaneously, effectively operating a virtual computing center distributed over more than 120 sites over the world with a total capacity of 150K computing cores. The Data Management System (DMS) of DIRAC provides access to different kinds of data storage systems with virtually any access protocol existing in infrastructures supporting scientific research. The File Catalog service keeps track of all the physical copies of existing files and provides means for user defined metadata which allows efficient selection of datasets for a specific user analysis task. Support for massive data operations is also provided. In the whole, users perceive various computing and storage resources operated by the DIRAC services as a single large computer with a large distributed file system.

The DIRAC software architecture is conceived to be used by various applications in different scientific domains. The modular structure of the software allows for easy extensions by developing additional components specific to workflows of particular user communities using the same software framework.

C. VIP

The Virtual Imaging Platform [1], [8] (VIP[1]) is a web portal for medical simulation and image data analysis. It leverages resources available in the Biomed VO of the EGI e-infrastructure to offer an open service to academic researchers worldwide. In January 2019, VIP counts more than 1000 registered users, some 20 applications and 44 publications made by VIP users with results obtained through VIP.

Until recently, applications were manually integrated in VIP as workflows written in the Gwendia language. Workflow languages provide a number of valuable advantages such as the concatenation of multiple applications, as well as different iteration strategies on input list. Nevertheless, they require a certain level of expertise which made porting applications to VIP a costly human effort. In order to ease the integration of new applications, we now rely on a formal application description as proposed by Boutiques[2]. To do so, we developed an importer allowing to automatically generate the application workflow and associated script files based on the Boutiques descriptor.

VIP uses the French national instance of the DIRAC service[3] for job submission. Based on the application description, VIP generates a form to be filled-in with inputs from the end user. VIP then prepares the jobs to be submitted and handled by DIRAC. The complexity of the infrastructure is thus hidden to the end user, who only has to provide the inputs for the application.

III. MEDICAL IMAGING APPLICATIONS AND THEIR REQUIREMENTS

A. Multimodality neuroimaging and machine learning

The analysis of multimodality neuroimaging data (MRI, PET) is increasingly used in diagnostic and pre-surgical work-up of patients suffering neuropathologies.

[1] https://vip.creatis.insa-lyon.fr/
[2] https://github.com/boutiques
[3] https://dirac.in2p3.fr/DIRAC

Computer-aided diagnosis (CAD) systems have been introduced to assist clinicians in various tasks such as brain structure or lesion detection and segmentation. The vast majority of the existing CAD systems are built upon machine learning methods developed in supervised settings. Such systems benefit from the available data sets (usually) annotated at voxel-level, and output maps where each voxel is characterized by a score discriminating healthy versus pathological voxels. Supervised learning, however, cannot be effectively applied when the number of pathological cases in the training set is not sufficient to account for the complexity of the task. This is often the case when it comes to detecting some brain pathologies such as epilepsy, when the lesions are subtle and vary largely in terms of shape and texture. It is not trivial to obtain a well-annotated data set to represent such variability. To bypass the problem of insufficient labelled data, we cast epilepsy lesion detection task as an outlier detection problem. Such an approach solely needs a training set of non-pathological images, hence no labelled data is required. The novel CAD architecture that was proposed in [6] consists in learning an oc-SVM model for each voxel in the brain volume using automatically learnt representations based on unsupervised deep neural networks, as shown on Fig. 1. This system was trained on 75 healthy subjects and tested on 21 epilepsy patients whose MRI exams are considered negative, meaning that the radiologist could not detect the lesion. The scientific details and results of this study are reported in [5] [6].

Fig. 1 depicts the processing pipeline, which includes (i) an image pre-processing step using Matlab (SPM) tools and (ii) the main processing tools, corresponding to feature extraction and classification, developed in Python. The feature extraction, which is compute intensive, uses the Theano library and runs on GPUs.

One of the aims of the project presented here is to build a demonstrator of this CAD system on the VIP platform. This web application should allow users with no specific knowledge on distributed computing to perform different CAD-related tasks, such as:

- Test a given CAD model based on provided reference sample images.
- Process their own data with the entire CAD pipeline, including the preprocessing, feature extraction and classification steps.

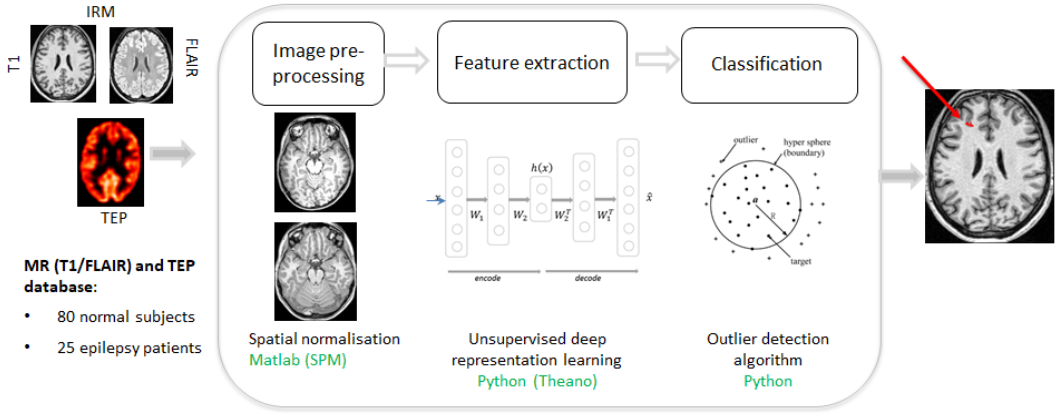

Figure 1. CAD-Epilepsy pipeline

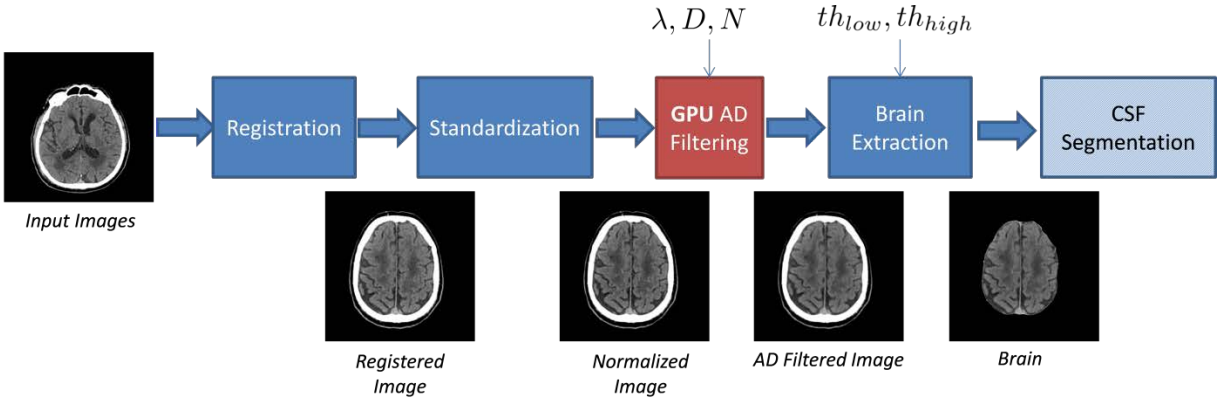

Figure 2. Pipeline, data and important parameters for the CSF segmentation

B. GPU-based filtering for 3D CT Scan

In the context of the study of cerebrospinal fluid (CSF) volume changes across time, we have designed a pipeline able to process robustly 3D CT brain volumes of a given patient. These longitudinal studies consist of 4 or 5 time points each with a 3D CT scan. The pipeline applied on data of a patient is described in Fig. 2. After a registration on a template patient (with a given orientation and resolution), we apply a grey-scale standardization using the first acquisition as baseline, and then we filter the data using an Anisotropic Diffusion approach. Finally, we perform a brain extraction and start the CSF segmentation (these two steps are not described here as they are parts of active research now).

For the preliminary study, the data set consists of 5 patients. The aim is to optimize the parameters' value involved in each step of the pipeline in order to obtain the most suitable parameters for this data set, expecting that they will also provide good results for the hundreds of coming patients.

Basic exhaustive search has been done for the registration step. The standardization step does not require any parameters. Our brain extraction step only needs two thresholds (thlow and thhigh) and we have observed that the most crucial step for the final CSF segmentation is the filtering step.

According to state of the art of filtering approaches and considering the CT scans' noise specificity and our computational time cost constraints, we adopt anisotropic diffusion [3]. This approach aims at smoothing drastically areas without any edges and doesn't process too much edges thus preserves them. It is based on the anisotropic equation:

$$\frac{\partial I(x,t)}{\partial t} = C(x)\nabla_x I(x,t) + \nabla_x C(x)\nabla_x I(x,t)$$

Where I(x,0) is the input image, I(x,t) is the image at time t, and C(x) is a function that weights the diffusion such that it tends to 0 when x is close to an edge (which implies no smoothing) and around 1 when the neighbourhood of x is on a piecewise constant region. The function used for C(x) is:

$$C(x) = \exp\left(-\frac{\|\nabla I(x,t)\|^2}{D^2}\right)$$

with D the parameter selecting the amount of variation that can be considered as edges.

This equation is solved iteratively. Three parameters must be adjusted carefully to obtain interesting results: D, the time step □ and the number of iterations N. The iterative process is stable if the time step is chosen below a value calculated from the pixel spacing of the data and the number of dimensions of the data (3 in our case). Thus, we have to search D and N providing the best results.

This search is performed in an exhaustive way and we opt for the ITK implementation on GPU that is at least 100 times faster (with a Nvidia GeForce GTX 1070Ti) than the CPU implementation (run concurrently on 8 Intel(R) Xeon(R) CPU E5-2403 0 @ 1.80GHz cores).

The proposed work, coupling VIP and DIRAC would allow such parameters optimization. Even if preliminary, Fig. 3 shows results of the whole pipeline using optimal parameters for the given segmentation approach and Fig. 4 shows a segmentation result of a 3D CT Scan.

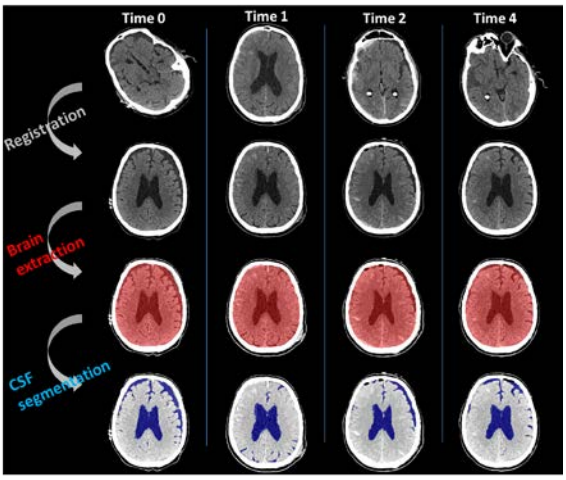

Figure 3. Results summary of the parameters optimized pipeline on a 4 time points study

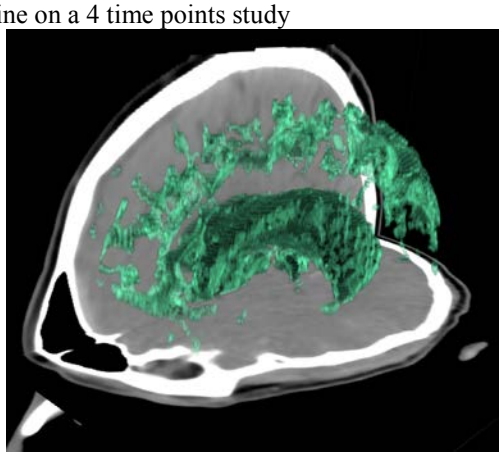

Figure 4. Example of a 3D CSF segmentation

IV. Application Integration and Deployment with VIP and DIRAC

A. Containers

Containers have lately become one of the most popular ways of packaging, deploying and executing scientific applications in distributed environments. They have a number of advantages, such as reproducibility,

isolating application processes and ease of use. With containers, end users can easily pack their own applications with the precise versions of the libraries they depend on. Moreover, they can build their applications on their desktops and run hundreds or even thousands of instances on remote CPUs or GPUs.

Docker has become synonymous with container technology because it has been the most successful at popularizing it, but other container technologies exist, such as Singularity and CharlieCloud. As a matter of fact, Singularity has gained enormous popularity in the scientific and HPC world. Singularity containers differ from Docker containers in several important ways, including the handling of namespaces, user privileges, and the images themselves. The excellent news is that "Singularity is good friends with Docker."[4], which allows us to build Docker images and then easily convert them to Singularity if needed.

For the deployment of the CAD Epilepsy applications, we deployed Docker images created using an existing Nvidia image with cuda and cuDNN already installed.

B. Boutiques

Boutiques [2] is a cross-platform descriptive command-line framework for applications. It relies on Linux containers to facilitate the application installation and sharing, and it uses a versatile JSON format to describe the command-line template, inputs and outputs.

```
{
    "name": "epilepsy-test",
    "tool-version": "1.0",
    "description": "Run Epilepsy test, using launcher script",
    "command-line": "launch-train.sh [INPUT] [OUTPUT]",
    "schema-version": "0.5",
    "container-image": {
        "type": "docker",
        "image": "feature-extraction"
    },
    "inputs": [
        {
            "id": "image",
            "name": "Input image",
            "type": "String",
            "description": "Image file to test",
            "value-key": "[INPUT]",
            "list": false,
            "optional": false,
            "default-value": ""
        }
    ],
    "output-files": [
        {
            "id": "result",
            "name": "Result image file",
            "description": "Result image file",
            "value-key": "[OUTPUT]",
            "path-template": "[INPUT].tar.gz"
        }
    ]
}
```

Figure 5. Boutiques JSON descriptor to define the command-line, inputs and outputs of the application

Fig. 5 shows a simple JSON descriptor we created for the "Epilepsy test" application. It allows to (i) point to the Docker image "feature-extraction" we created previously, (ii) define the command-line to be executed and (iii) define its input and output.

C. DIRAC SSH Computing Element

Access to different types of computing resources (standalone batch systems, grids, clouds) is provided by the DIRAC services. In the DIRAC framework an abstract "Computing Element" class encapsulates all the necessary functionality to submit tasks to a computing resource, monitors their progress and gets back the results. Various implementations of this abstract interface are provided, for example: ARCComputingElement for the ARC middleware [5], CREAMComputingElement for CREAM [6], etc. SSHComputingElement is the implementation allowing access to a standalone computing farms through an SSH tunnel. It can be specialized to use various types of batch systems, e.g. SLURM, OAR, Torque or GE. For each computing resource specified in DIRAC configuration, the type of Computing Element must be defined together with its general properties - operating system, memory, number of processors, system limits and so on.

In our particular case, the Biomed VO has access to GPU resources at the site savba.sk through an SSH connection. In the DIRAC configuration, a dedicated computing element of the type SSH must be defined. A specific tag can be associated to this computing element in order to restrict its usage to jobs that request GPUs. This prevents GPU resources from being wasted with regular CPU jobs.

This resource was added to the France-Grilles' DIRAC service configuration, with special care taken to provide confidential configuration parameters that are stored in local protected files in the machine where the SiteDirector, the DIRAC job submission agent, is running.

From the users' point of view, they only need to add the tag: "RequiredTag = nvidiaGPU" to the job description and the jobs will be executed at the sites where the corresponding resources are available. Since in this case jobs are created and submitted to DIRAC through VIP, the job description, including this specific tag, is entirely handled by VIP service.

Fig. 6 shows the cumulative number of CAD-Epilepsy jobs executed by DIRAC on GPU resources.

[4] https://singularity.lbl.gov/docs-docker

[5] http://www.nordugrid.org/arc/

[6] https://cream-guide.readthedocs.io

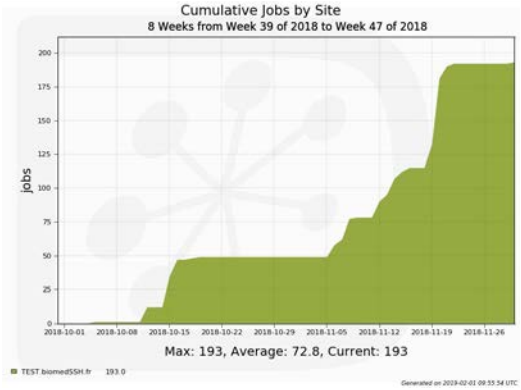

Figure 6. Cumulative CAD-Epilepsy jobs executed by DIRAC on GPU resources

V. CONCLUSIONS AND PERSPECTIVES

Scientific applications have specific needs to which infrastructures and technologies bring multiple solutions, contributing to a very rich and heterogeneous environment. In this paper, we described an end-to-end system enabling medical imaging researchers to use distributed computing resources with GPUs for their specific applications.

VIP, as a web portal and scientific gateway, makes applications available as a service. Boutiques greatly facilitates application integration into VIP, while containers make it possible to easily deploy complex applications on distributed infrastructures. The DIRAC interware allows for an efficient exploitation of distributed computing resources (CPUs or GPUs), despite their heterogeneity.

A first version of the CAD-Epilepsy demonstrator is available for testing, but further work will allow to optimize certain aspects, such as the handling of large data files. The feature extraction tools, which need to execute on GPUs, produce large volumes of data (tens of GB per training model), which are further needed for testing/prediction jobs. The latter are less compute intensive and could be executed on simple CPUs provided that the previously produced data are available. The data needs thus to be transferred as efficiently as possible.

GPU resources are still scarce compared to “classical” CPUs. In order to optimize the use of GPU resources, we plan to further split the current Epilepsy applications into smaller tools that can efficiently run on CPUs from those that need a GPU. By using application workflows at the VIP level, this kind of splitting is transparent for the end user and allows DIRAC to submit the jobs to the correct type of resources.

Last but not least, we would also like to go further into testing the limits of the compatibility and reproducibility provided by container technology with respect to the ever evolving GPUs cards, drivers and libraries.

ACKNOWLEDGMENTS

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GPU implementation of the FastICA algorithm

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***Abstract* – Independent Component Analysis is a widely used method in EEG data processing for removing unwanted artefacts from the measured data. The drawback of this method is its high computational cost, resulting in long execution times. A massively parallel GPU implementation of the popular FastICA algorithm is presented in this paper. The implementation uses standard CUDA library functions where possible and custom parallel kernels for the remaining steps. The results show that for typical EEG processing setups our version can be executed within real-time limits, allowing sophisticated automatic artefact removal algorithms to be executed during measurement.**

Keywords – Independent Component Analysis; EEG; artifacts; hidden sources; GPU, FastICA, Infomax ICA

I. INTRODUCTION

EEG measured from scalp electrodes is a mixture of signals originated from sources located in the brain. Finding the original sources of activation has long been the ultimate goal of EEG source localization [1]–[3]. This requires the solution of the so-called inverse problem [4], [5]. This problem is ill-posed and can provide accurate and unique solutions only in specific, well-constraint cases.

Independent Component Analysis (ICA) is a relatively new procedure to separate source signals from a measured linear mixture. The goal here is not to find the geometric location of sources, but to separate them from each other based on their statistical independence. ICA has become an effective tool in artifact removal, since eye, muscle and cardiac activities are independent from the underlying EEG activity.

Unfortunately, ICA algorithms are time-consuming; their long execution on sequential or multi-core CPU systems often forces researchers to reduce the number of channels and/or the sampling frequency used during the experiments. The goal of our project is to examine the most popular ICA algorithms for potential parallelization and create high-performance GPU implementation that can significantly reduce ICA execution time. In this paper, we present the first results of this effort, namely the parallelization and performance analysis of the FastICA algorithm [6] on an NVIDIA GPU architecture.

The structure of the paper is as follows. In Section II, a general introduction to the theory of Independent Component Analysis is given. Section III concentrates on one of the best known ICA algorithm variants, the FastICA algorithm. Section IV discusses strategies for the parallel GPU version of the algorithm and describes the implementation details. Section V presents the results of the current implementation. The paper ends with conclusions.

II. INDEPENDENT COMPONENT ANALYSIS

Independent Component Analysis (ICA) was originally developed to solve the Blind Source Separation (BSS) problem [7] [8] and normally refers to a class of algorithms that can recover statistically independent signals (components) from a linear mixture, based on higher-order statistics as a measure of independence. ICA is considered a robust method for identifying and removing artefacts normally found in EEG signals.

A brief formal introduction is as follows [9]. Let us assume that we have N statistically independent sources, $s_i(t)$, $i = 1, \ldots, N$. Suppose that the sources cannot be observed directly, only via N sensors that obtain N observation signals, $x(t)$. The observed signals are mixtures of the original sources. Sensors must be spatially separated (e.g. as the electrodes on the scalp), as each sensor must measure a mixture different from the others. The mixing process than can be described as:

$$\mathbf{x}_t = \mathbf{A}\mathbf{s}_t , \tag{1}$$

where $\mathbf{A}$ is the unknown square mixing matrix. An unmixing matrix $\mathbf{W} = \mathbf{A}^{-1}$ must be obtained in order to obtain an estimate $\hat{\mathbf{s}}_t$ of the original sources as

$$\hat{\mathbf{s}}_t = \mathbf{W}\mathbf{x}_t , \tag{2}$$

The difficulty of the problem is that in (1) neither the sources nor the mixing matrix are known. This seemingly insolvable problem has a solution under certain conditions and assumptions. In order for the ICA problem to produce a solution: (*i*) the sources must be statistically independent; (*ii*) the sources cannot have Gaussian distribution; and (*iii*) the mixing matrix must be invertible.

The estimation of $\hat{\mathbf{s}}_t$ requires a number of pre-processing steps that help in solving the problem in a step-wise manner. We use Singular Value Decomposition to decompose the mixing matrix $\mathbf{A}$ as

$$\mathbf{A} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^T , \tag{3}$$

where $\mathbf{U}$ is a rotation, $\mathbf{\Sigma}$ is a scaling and $\mathbf{V}$ is also a rotation matrix, each being simpler than the original matrix $\mathbf{A}$. Using this decomposition, $\mathbf{W} = \mathbf{A}^{-1}$ can be expressed as

$$\mathbf{W} = \mathbf{V}\boldsymbol{\Sigma}^{-1}\mathbf{U}^T . \quad (4)$$

The next step is to determine $\boldsymbol{\Sigma}$ and $\mathbf{U}$ by examining the covariance of the data, then to find a way to calculate $\mathbf{V}$ using assumptions on the independence of $\mathbf{s}$.

The covariance is the expected value of the outer product of the observation samples $\langle \mathbf{x}\mathbf{x}^T \rangle$. Using our mixture model (1), this can be expressed as

$$\begin{aligned} \langle \mathbf{x}\mathbf{x}^T \rangle &= \langle (\mathbf{A}\mathbf{s})(\mathbf{A}\mathbf{s})^T \rangle \\ &= \langle (\mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^T\mathbf{s})(\mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^T\mathbf{s})^T \rangle \\ &= \mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^T \langle \mathbf{s}\mathbf{s}^T \rangle \mathbf{V}\boldsymbol{\Sigma}\mathbf{U}^T . \end{aligned} \quad (5)$$

Assuming that our sources $\mathbf{s}$ are whitened, $\langle \mathbf{s}\mathbf{s}^T \rangle = \mathbf{I}$, where $\mathbf{I}$ is the identity matrix, and $\mathbf{V}^T = \mathbf{V}^{-1}$, equation (5) reduces to

$$\langle \mathbf{x}\mathbf{x}^T \rangle = \mathbf{U}\boldsymbol{\Sigma}^2\mathbf{U}^T . \quad (6)$$

Noticing that this forms is similar to the eigenvalue decomposition of a matrix

$$\langle \mathbf{x}\mathbf{x}^T \rangle = \mathbf{E}\mathbf{D}\mathbf{E}^T , \quad (7)$$

where $\mathbf{D}$ and $\mathbf{E}$ are the eigenvalues and eigenvectors of the covariance of $\mathbf{x}$, $\mathbf{W}$ can be expressed in terms of a sole unknown $\mathbf{V}$, as

$$\mathbf{W} = \mathbf{V}\mathbf{D}^{-1/2}\mathbf{E}^T . \quad (8)$$

Returning to (2) and substituting (7) we arrive at

$$\hat{\mathbf{s}} = \mathbf{W}\mathbf{x} = \mathbf{V}\left(\mathbf{D}^{-1/2}\mathbf{E}^T\mathbf{x}\right), \quad (9)$$

where the bracketed term is the whitened version of the observed data that we can refer to as $\mathbf{x}_w$, simplifying (9) to

$$\hat{\mathbf{s}} = \mathbf{V}\mathbf{x}_w . \quad (10)$$

From (3) we know that $\mathbf{V}$ is a rotation matrix, hence the problem can be solved by finding the "correct" rotation. This requires examining the independence of the data. If the sources are independent, for the joint distribution of sources $P(\mathbf{s})$ the following holds:

$$P(\mathbf{s}) = \prod_i P(s_i) \quad (11)$$

The mutual information can be used to describe independence by using the multi-information measure defined as

$$I(\mathbf{s}) = \int P(\mathbf{s}) \log_s \frac{P(\mathbf{s})}{\prod_i P(s_i)} d\mathbf{s} , \quad (12)$$

which gives the minimum zero value if and only if the sources are independent; based on the independence assumption, the *log* term in (12) is $log(1) = 0$ and consequently $I(\mathbf{s}) = 0$. The goal is thus to find a rotation of $\mathbf{V}$ that results in independence, i.e. $I(\hat{\mathbf{s}}) = 0$.

Since (12) is difficult to compute, alternative independence minimization contrast (or objective) functions are used in practice, such as entropy, negentropy, etc. during the optimization process.

We end this overview with the outline of the simplified skeleton of the generic ICA algorithm.

Generic ICA algorithm

1. *Preprocessing*
   a. *subtract mean from input*
   b. *whiten data using singular value decomposition*
2. **while** *not converged*
   a. *rotate V*
   b. *compute convergence based on contrast function*

end

Several ICA algorithms (e.g. InfoMax ICA, FastICA, JADE, SOBI, FOBI, ORICA) exist that differ in the contrast function, i.e., the way independence is computed, in their convergence properties, the quality of source separation and their runtime complexity [10]. For a more detailed description of the theoretical foundations of ICA and the various ICA algorithm variants, the interested reader is referred to the literature [5-6][15-19].

III. FastICA algorithm

FastICA proposed by Hyvärinen [11][12] is one of the first and most popular ICA variants. Its main advantages are its computational simplicity, fast convergence rate and reliability. FastICA maximizes independence using the *negentropy* with a choice of contrast functions. The goal is to maximize the following function:

$$J_G(\mathbf{w}) = \left[E\{G(\mathbf{w}^T\mathbf{x})\} - E\{G(v)\}\right]^2 , \quad (13)$$

where $G(u)$ is a non-quadratic function, e.g. *log cosh*(u), $\exp(u)$ or u^4. The iteration loop solves the simplified form of (13)

$$\begin{aligned} \mathbf{w}^+ &= E\{\mathbf{x}g(\mathbf{w}^T\mathbf{x})\} - E\{g'(\mathbf{w}^T\mathbf{x})\mathbf{w}\} \\ \mathbf{w}^* &= \mathbf{w}^+ / \|\mathbf{w}^+\| \end{aligned} , \quad (14)$$

where $g(\cdot)$ is the contrast function and $g'(\cdot)$ is its derivative; then – in order to avoid different components to converge to the same solution – decorrelates the outputs $\mathbf{w}_1^T\mathbf{x},\ldots,\mathbf{w}_n^T\mathbf{x}$ after every iteration. This can be performed either sequentially (*deflation* method), one component after the other, or in parallel (*symmetric decorrelation* method), using all components at the same

time. The latter one can be performed using matrix square roots, as

$$\mathbf{W} = \left(\mathbf{W}\mathbf{W}^T\right)^{-1/2}\mathbf{W}, \qquad (15)$$

where $\left(\mathbf{W}\mathbf{W}^T\right)^{-1/2} = \mathbf{E}\mathbf{D}^{-1/2}\mathbf{E}^{\mathrm{T}}$ obtained from eigenvalue decomposition.

IV. GPU IMPLEMENTATION

Many sequential and CPU-oriented parallel FastICA implementations are in use these days. Interestingly, very few implementations have been created for GPUs. Among the first implementers of GPU FastICA versions are Ramalho *et al*. [13], who developed a cuBLAS and custom kernel based version for early versions of CUDA. Results are reported for a GTX 8800 first-generation CUDA card. Source code is not available publicly. Dan Brandt in his MSc Thesis [14] developed a similar implementation. A more advanced card, GTX 295, was used for testing. Lacking library support for eigenvalue decomposition, the iterative deflation decorrelation approach was implemented in his solution. Source code is available for this project. Kumara *et al*. [15] created a Kepler architecture version, tested on the Tesla K40 GPU, that uses a hybrid CPU-GPU implementation, changing the execution location depending on problem size and execution time estimates. EVD is performed using the commercial CULA library [16] whose availability is now restricted. Source code is available but cannot be executed without CULA. The reported best speedup in these works varied with problem size in the range of 6.36 to 78. This indicates the potential advantages of using GPUs for ICA execution.

Our goal was to implement a software framework for the execution and performance analysis of several ICA algorithms, using the latest architectural and software features the CUDA platform can offer (Pascal and later architecture GPUs, minimum CUDA 9.0 support, up-to-date, standard CUDA libraries). The advanced hardware features in these chips and the more sophisticated programming interface, as well as library support (e.g. cuSOLVER for EVD execution) all suggest that even better performance is achievable.

Since the deflation approach in FastICA executes the computation for components sequentially, the symmetric approach was chosen as the basis of our implementation, as this allows us to perform component calculations simultaneously. The main iteration loop contains the following two calculations:

$$\mathbf{W}_1 = g\left(\mathbf{W}\mathbf{Z}\right)\mathbf{Z}^T - diag\left[g'\left(\mathbf{W}\mathbf{Z}\right)1_p\right]\mathbf{W}, \qquad (15)$$

$$\mathbf{W} = \left(\mathbf{W}_1\mathbf{W}_1^T\right)^{-1/2}\mathbf{W}_1, \qquad (15)$$

where $g(u) = tanh(u)$ and $g'(u) = 1\text{-}tanh^2(u)$ or $g(u) = u^3$ and $g'(u) = 3u^2$. The dominant operation is the dense matrix-matrix multiplication, and Eigenvalue decomposition for (15). These operations are supported on NVIDIA GPUs by the cuBLAS and cuSOLVER libraries. Computing the g and g′ values required the development of custom kernels. The same is true for the matrix subtraction. The convergence calculation was carried out on the CPU after copying matrix **W** back to the host. All operations are performed in double precision.

The use of libraries helped minimizing the programming effort. One of the goal of our work was to evaluate the performance and effectiveness of the library routines in the FastICA execution process.

The simplified outline of the GPU implementation showing the custom kernels and library functions used is the following:

```
1. // centering
2. // whitening
W = random_init                    // host function
d, D = svd(W)                      // using cusolverDnDgesvd()
TU = D · Wd                        // cublasDgemm
d = 1 / d                          // custom CUDA kernel
D = diag(d)                        // custom CUDA kernel
TMP = W · D                        // cublasDgemm
D = TMP · W^T                      // cublasDgemm
Wd = D · W                         // cublasDgemm
3. // Main ICA computation loop
   while (delta > epsilon)
      GWX = Wd · X                 // cublasDgemm
      GWX = tanh(GWX)              // custom CUDA kernel
      TMP = GWX · TXp              // cublasDgemm
      GWX = 1 – tanh^2(GWX)        // custom CUDA kernel
      d = row_mean(GWX)            // custom CUDA kernel
      D = diag(d)                  // custom CUDA kernel
      TU = D · Wd                  // cublasDgemm
      W1 = TMP – TU                // custom CUDA kernel
      W = W1 · W1^T                // using cusolverDnDsyevd()
      d = 1 / sqrt(d)              // custom CUDA kernel
      D = diag(d)                  // custom CUDA kernel
      TMP = W · D                  // cublasDgemm
      D = TMP · W^T                // cublasDgemm
      W = D · W1                   // cublasDgemm
      TMP = W · W^T                // cublasDgemm

      delta = | max_diag(TMP) |    // host function
   end
```

V. RESULTS

The results of this implementation were validated by comparing the output components to those obtained with the original Matlab FastICA implementation. The GPU execution times on two target systems (an entry level and a top-of-the range card) compared to CPU results is listed in Table 1. Two contrast functions have been used in the test, and two problem sizes were selected; one and 20 second windows for 128 channels at f_s = 2048 Hz. The iteration count of the Matlab version as well as the

TABLE I. FASTICA EXECUTION TIME AND SPEEDUP

Problem size Function [iterations]	**Execution time (s) [speedup]**			
	FastICA 2.5 Matlab 8-core (est. 1-core) time		***Quadro K2000M***	***Titan Xp***
128 × 2048				
g=u^3 [129]	1.672	(8.424)	12.738 [0.6]	0.556 [15]
g=tanh [208]	1.412	(11.286)	20.568 [0.5]	0.856 [13]
128 × 40961				
g=u^3 [115]	10.845	(86.76)	28.168 [3]	1.287 [67]
g=tanh [620]	43.389	(347.112)	160.48 [2.1]	6.907 [50]

estimated single-core Matlab execution time are included in the table. The GPU versions used the same iteration count to make comparisons easier.

Kumara et al [15] provide execution time values for a varying size of problems with channel count varying from 2 to 128, the sample size running from 1024 to 524288. Since the focus of our work is EEG not audio processing, we were only interested in channel count larger than 32. With their implementation and the used GPU card, for more than 64 channels they could not achieve performance sufficient for real-time ICA execution. Fig. 1 list the execution time of our implementation using an NVIDIA Titan Xp GPU for 32, 64 and 128 channels for the same range of sample sizes found in [15]. We have also included reference lines for the sample size expressed in seconds at different sampling frequencies. For instance, 8192 samples is a 32 second segment at f_s = 256 Hz, 16 seconds at f_s = 512 Hz, 8 seconds at f_s = 1024 Hz and 4 seconds at f_s = 2048 Hz. These measurements reflect actual convergence and show that real time performance is guaranteed for longer than 4 second segments at any sampling frequency practically used in routine EEG measurements. The four-second threshold is easily satisfied in practice as normally 10 or 20-second segments are input to the ICA routines for artefact removal.

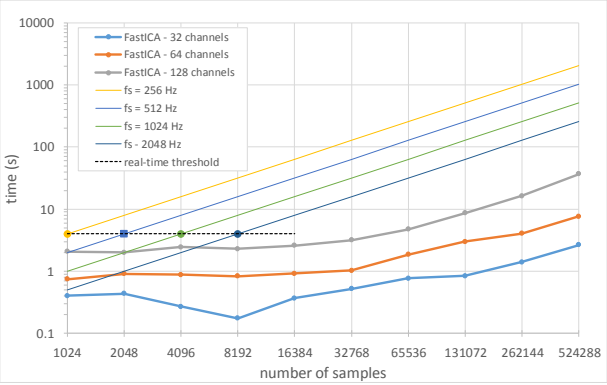

Figure 1. Execution time of the GPU FastICA algorithm for different number of channels on a Titan Xp card. Straight lines represent the number of samples in seconds at varying sampling frequencies. Over four second input segments, real-time execution is achieved.

VI. Conclusion

A parallel implementation of the FastICA algorithm was developed for NVIDIA GPU architecture. The implementation used CUDA 9.0 and targeted Pascal and later GPU architectures. Our results illustrate that using the latest cuBLAS and cuSOLVER libraries, a high-performance implementation can be developed that provides real-time performance in typical EEG measurement settings. This opens up the possibility of performing automatic artefact removal during measurement that can significantly simplify and speed up the EEG signal analysis. Work is underway to optimize this implementation by merging custom kernels and executing the convergence test on the GPU. Execution profiling also revealed that the key performance limiting operations in FastICA are matrix multiplication and Eigenvalue decomposition, consequently more work is needed to develop more efficient versions of these routines. Moreover, there are parallel execution paths in the current algorithm, which could be executed more effectively using concurrent CUDA streams. These are options we will be investigating in the next stage of our project.

Acknowledgment

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Computational efficiency of linear system construction for MLPG method on a multicore computer

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Abstract – A contact problem is simulated and surface stresses are analyzed in order to determine the conditions for crack initiation due to fretting fatigue. A weak-form Meshless Local Petrov-Galerkin (MLPG) method is used for simulating the displacements in the material, due to the applied external forces. The solution accuracy increases with higher nodal densities under the contact but so does the calculation time. To manage the computation time, parallel programming is used. Experimental setup is built around a 16-core processor with simultaneous multi-threading (SMT) capabilities to test how well the parallelism in modern hardware can be exploited for solving a single task. We analyze computation times of the linear system construction to evaluate the maximum expected efficiency of parallelization.

I. Introduction

The fretting fatigue is present in most practical cases where two or more vibrating surfaces in contact experience a slip-stick zone. That is, a portion of the contact region sticks together due to applied forces, while a portion of a contact slips. An undesired consequence of such an interaction are mechanical failures, usually in form of cracks, after a very large number of vibration cycles. Examples of applications where these are common are drive splines, bolted joints, bearings and many other industrial applications. The material failures and fretting fatigue cracks have been studied both experimentally and numerically [1]. Computation time of fretting fatigue simulations grows rapidly with a denser spatial discretization, which is used to achieve higher accuracy [2].

In this paper, an MLPG methodology is described with a contact problem definition and settings for fretting fatigue application. The analytical solution of Hertzian model is employed to obtain suitable boundary conditions for surface tractions. The simulated surface stresses are analyzed in order to estimate the solution accuracy. Adequate accuracy of the method is achieved, by applying much higher nodal density under the contact than in the rest of the simulated domain. Consequently, to keep computation time in check, nodal density in the domain can be adapted to the given problem case, to the required method accuracy, to the limitations in execution time and available amount of memory, and to the available number of processing units.

A crucial phase of the fretting fatigue simulation is thus assuring optimal execution and exploitation of all available resources. That means an efficient implementation of the simulation procedure on parallel computer architectures, which are nowadays ubiquitous on the whole range of computer-based devices, from high performance workstations, desktop computers, smart devices, down to micro-controllers. Among the most common parallelization approaches, are application programming interfaces (APIs) for parallel programming, e.g. OpenMP for shared-memory computers [3], Message Passing Interface (MPI) for distributed-memory computers [4], or OpenCL for compute accelerators such as Graphic Processing Units (GPU) [5].

In this paper, MPI parallelization is used and assessed by a set of experiments, performed on a domain with varying nodal density. The results are analyzed primarily from the view of execution time, providing some findings that could prove useful in future implementations of the meshless methodology. A real-case scenario is used for the experiments, that is, the problem solving task is executed on a modern PC with hierarchically interconnected processor cores, complex cache hierarchy, and dynamically varying clock frequencies.

In the rest of the paper, first the meshless methodology is briefly introduced, followed by the description of experimental setup. Then the results are presented, both from the aspect of solution correctness, and from the aspect of computation times; the latter are given greater emphasis. Finally, the paper is concluded and the findings are summarized.

II. Methodology

A. Meshless methodology

Meshless numerical methods avoid the use of predefined spatial relations between discretization nodes [6] and shift their definition into the solving procedure. The end goal of this approach is to provide higher flexibility in geometrically complex domains and dynamic domains that change during the simulation. A weak-form Meshless Local Petrov-Galerkin (MLPG) method [7] is used for solving the experimental fretting fatigue case.

A weighted Moving Least Square (MLS) is used for the approximation of a trial function for the MLPG method. Shape functions are constructed above a circular support domain with either n_s nearest discretization nodes or predefined radius r_s, and with a monomial basis of order m. MLS weight functions are also used as the test functions of

the weak-form for the governing PDE, i.e. Cauchy momentum equation $\nabla \cdot \boldsymbol{\sigma} = \boldsymbol{f}$, where $\boldsymbol{\sigma}$ is stress tensor and $\boldsymbol{f}$ is body force vector. The MLS weight functions determine local square quadrature domains with a side d_Q and with n_q integration points, similar as in [8]. For our experimental case, the parameters mentioned above are set to $n_s = 13$, $m = 2$, $d_Q = 0.5 r_s$, and $n_q = 9$. r_s is calculated for each node as the mean of the distances between the node and its n_s and $n_s + 1$ nearest neighbours.

It has been estimated that the accuracy of MLPG method is similar to the accuracy of FEM, but has a slightly higher calculation complexity [9]. On the other hand, potential advantages of MLPG compared to FEM are that the domain polygonalization (meshing) and the post-processing of stresses are not required.

An estimated computational complexity of the MLPG system matrix construction is $O(N n_q [\log N + n_s m^2])$ [6]. The memory requirements of the MLPG method are related to the number of non-zero elements in the system matrix, which is approximately $2 n_i N$, where 2 comes from the two-dimensional displacement of nodes and n_i is the number of quadrature points in the influence domain, which we found was typically about 38 on our domains with the above presented MLPG parameters.

The construction procedure for MLPG matrix is implemented with an in-house C++ code that was designed with MPI parallelization in mind. It uses Eigen C++ library for some of the linear algebra [10] calculations and Medusa [11] as a wrapper over HDF5 library [12].

The system construction results in a sparse linear system that has to be solved for displacements. While this can be done though use of Eigen library, which is already a part of the project, the provided linear sparse system solvers were found to be very slow. Therefore, as a temporary solution we are using the solver provided by Octave [13] by its built-in function `x=A\b`, which is an order of magnitude faster than the solvers provided by Eigen. In future, solving the sparse linear system will be performed within the main program code, possibly with an available library for solving sparse systems that would be at least at the same performance level as Octave.

B. Simulated experimental setup

The simulated experimental setup is the same as described in [2] and used previously in [14]. A rectangular aluminium 2420-T3 specimen of width $W = 5\ mm$, length $L = 40\ mm$ and thickness $t = 4\ mm$ is stretched in x axis with axial traction $\sigma_{ax} = 100$ *MPa*, and normally compressed by two cylindrical pads with a force $F = 543\ N$. A tangential force $Q = 155\ N$ is also applied on the pads, to cause fretting. The pads were not simulated directly; their normal traction $p(x)$ and tangential traction $q(x)$ are rather computed as per the Hertzian contact theory for an elastic cylinder on an elastic half-space flat surface [15]. Due to the tangential traction, the effect of friction is modeled by splitting the surface under the contact into a stick and two slip zones. A schematic presentation of the fretting fatigue experimental setup is shown in Fig. 1. The boundary conditions are presented in Fig. 2.

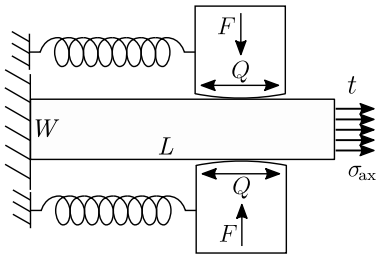

Figure 1: Experimental fretting fatigue setup.

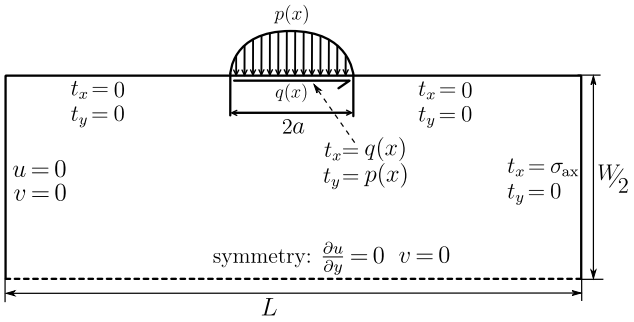

Figure 2: Boundary condition.

Due to high stresses present, the plane-stress formulation is used to reduce the problem to two dimensions. The symmetry along the horizontal specimen axis is used to reduce the problem domain size by half. Therefore, the symmetry boundary conditions are used on the bottom boundary. All the remaining parameters are set similar to [2]: pad radius $R = 50\ mm$, coefficient of friction $\mu = 0.3$, modulus of elasticity $E = 72.1$ *GPa* and Poisson's ratio $\nu = 0.33$.

C. Computer setup

A custom-built parallel program that implements the MLPG algorithms, described in previous section, based on MPI and a 1-D domain decomposition, was run on an experimental parallel computer. The processor used in experiments is AMD Ryzen Threadripper 2950X with 16 cores and simultaneous multithreading (SMT) capabilities, which enable the processor to execute 2 threads concurrently on a single core. The computer was running Ubuntu 18.10, the simulation executable was compiled using GCC 8.2.0 C++ compiler setup for maximum optimizations (-O3) and architecture target to native (-march=native). The version of Octave was 4.4.1.

The processor used in our tests is interesting for several reasons.

- It comprises relatively large number of cores for a desktop processor, but the increasing number of cores seems to be the trend for future, as seen by recent developments on the PC processor market governed by AMD and Intel.
- Its SMT capabilities increase the number of processes that can be executed simultaneously, allowing for a broader scalability scan, and a test of the SMT benefits.

- It exhibits a complex non-symmetric core architecture. On the topmost layer it is split into 2 physically separate dies (chiplets), each containing two separate CPU complexes. Each CPU complex is a cluster of 4 cores with shared L3 cache, and an interconnection crossbar.

- It utilizes turbo boost and other technologies that dynamically adjust the clock frequencies of individual active cores. The general rule for dynamic frequencies is that more activating more cores lowers the active core frequencies. We observed the core frequencies to range between 3.8 GHz and 4.3 GHz during the performed experiments.

- The processors's four L3 caches (one per CPU complex) are 8 MB each, which is just large enough to hold the smallest of linear systems in whole, thus speeding up memory access, but could prove too small when it has to be shared by multiple processes.

III. Results

The obtained results are presented from two aspects. First, the simulation results are used to validate the solution procedure correctness. Next, the execution time statistics is performed on various number of cores using MPI, to test the efficiency of the processor and the corresponding program implementation.

A. Solution of surface stress

The problem domain is first discretized, as proposed in [16], which is shown to work well with meshless mehods in [17]. The parameters of discretization procedure are varied, to create a set of discrete domains that differ in the number of discretization nodes and thus computational complexity. Discrete domains with the following number of nodes are created: N= [149806, 396359, 469018, 589403, 852011, 1096603, 1326296]. The general rule is, that for the lower number of nodes in the domain, the results will be less precise. On the other hand, the computation load will be lower and thus the execution time of the simulation will be lower. Therefore, the set of above defined discrete domains can be used to show simulation efficiency on a range of different computation loads.

Since the contact problem cannot be solved analytically, a validation based on comparison of the simulation results with the analytical results is not possible. Hence, the simulations are performed on increasingly detailed discrete domains to confirm a convergence of solution results and thus partially validate the simulation procedure.

An example of a discrete domain, the one with the lowest number of nodes $N = 149806$, is shown in Fig. 3. Discretization nodes are clearly much denser around the coordinate $(0, 0)$, which is at the contact center, to allow for more precision in the area that is more demanding to simulate numerically. The discrete domains with higher number of nodes have more nodes distributed across the whole domain so that the relative densities of nodes are similar across all domains.

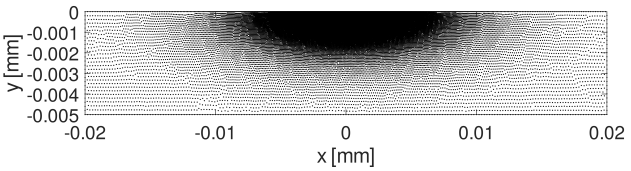

Figure 3: Discretized simulated domain.

The solution of the surface tangential stress, using parameters defined in the previous section, is shown, for the area near the contact, in Fig. 4. Normalized normal and tangential tractions, $p(x)$ and $q(x)$ respectively, both applied as boundary conditions under the contact region, and the corresponding stick and slip zones are also shown for illustration. Besides checking for the convergence of solutions, the correctness of meshless solutions was also successfully validated by comparing them to the reference FEM solutions from previous publications [2].

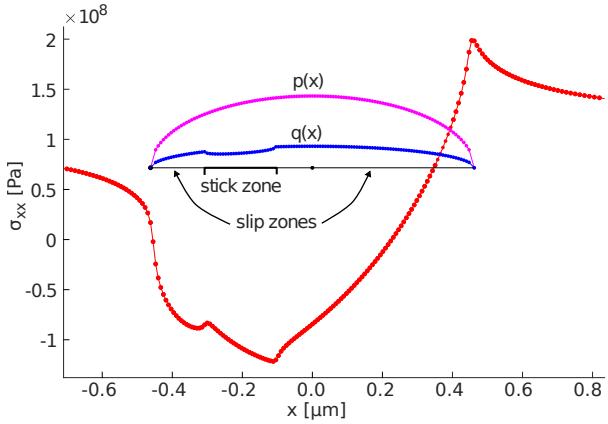

Figure 4: Zoomed-in tangential surface stress (σ_{xx}) under the contact with normalized $p(x)$ and $q(x)$.

B. Computation time

An implicit MLPG solver for a PDE is composed of two most time demanding tasks: the construction of the global system of linear equations and its solution. Each of them is analysed separately, but with an emphasis added on the system construction.

1) Construction task

In an MPI version of the MLPG linear system construction, two communication tasks are introduced that are not present in a sequential algorithm, i.e. the domain distribution and the gathering of separately constructed parts of the final liner system. The latter is optional though, depending on the linear solver that would be used in the next step. The communication time, i.e. time required to complete domain distribution and time to gather constructed subsystems, can be significant in the MPI implementation but could be nearly insignificant in OpenMP implementation, which seems more feasible for the problem at hand. In the rest of the paper, since we are trying to compare computation time only, we exclude the communication times when we mention the time required for construction.

Note that domain distribution usually requires some sequential processing to determine which nodes should be transferred to which process, and thus causes some idle time

on those processes that have to wait for the data to be transferred over to them. In the presented case, however, the program is executed on a single computer, and the distribution translates to copying memory, which is much faster then passing messages over any interconnection network. Gathering of constructed matrix is computationally less demanding than its construction and to some degree overlaps with the construction, because the processes do not all finish constructing their part of the system at the same time.

Since copying memory is relatively cheap, a simplified approach to the domain distribution is used: the whole domain, positions of all nodes, is transferred to all the cooperating MPI processes, which is in our case faster than determining which nodes to send to which process and then copying only the required nodes.

After copying the whole domain, a 1-D domain decomposition is implemented in parallel by dividing the problem domain into *chunks* with approximately equal number of discretization nodes. After each process defines its working chunk, it constructs the rows of system matrix, two rows (for two dimensional displacement) per each node from its chunk, which results in a distributed system matrix. Note that no communication between processes is required in this step. Computation time required to construct the distributed system matrix, for varying number of discretization nodes N, is shown in Fig. 5 for p = [1, 2, 4, 8, 16, 32] MPI processes on a single computer.

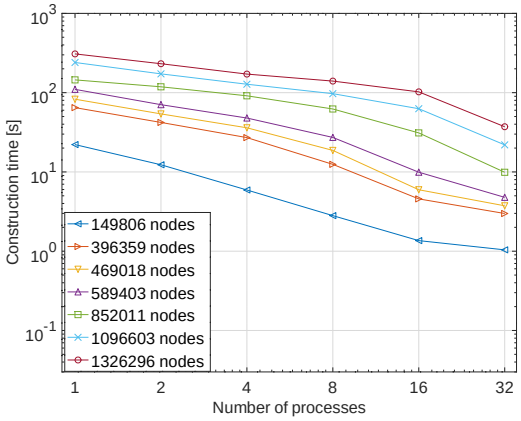

Figure 5: Computation time for construction of system matrix as a function of numbers of discretization nodes and MPI processes.

At a glance, it seems the computing time of MLPG linear system construction scales well with the number of MPI processes. Every increase of the number of processes is rewarded by a decrease in construction time but these decreases are clearly not linear. To measure the scalability better, execution times on p processors t_p can be converted to parallel efficiencies e_p using the following formula: $e_p = \frac{t_1}{t_p * p}$. The parallel efficiency is a measure of how efficiently a parallel program manages to exploit the available processing resources; at efficiency of 1, the parallel program is as efficient as the sequential program. Efficiencies are usually lower than 1 (parallel programs are less efficient than sequential), since parallel programs usually suffer at least some communication overhead. Efficiencies above 1 can also be observed in rare cases, since modern computers use complex memory hierarchies, and execution on more cores usually translates into execution with more of the fast caches available [18]. Efficiencies for the construction of system are plotted in Fig. 6 and they seem quite low at their lowest points. Note again that we are considering construction of system without the communication overhead and are therefore not expecting to see such low efficiencies.

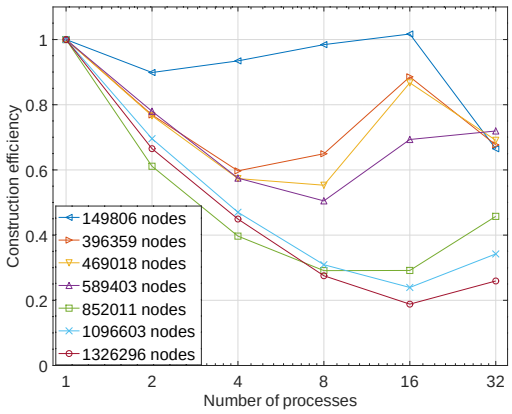

Figure 6: Efficiency of system matrix construction task as a funciton of numbers of discretization nodes and MPI processes.

Before taking a deeper look into the matters, the most obvious reason for decreased parallel efficiencies on a modern hardware has to be looked at. Clock frequencies of the processor cores get lower when the number of active cores increases, due to the processors limited thermal budget. Active cores draw far more power than inactive ones and higher frequencies are known to draw considerably more power than low frequencies. As all the power used by the processor is dissipated as heat, either a low number of cores can be clocked high or large number of cores can be clocked low to achieve the same level of heat dissipation. Therefore, to prevent from overheating while achieving maximum performance, the processor has to actively throttle clock frequencies of individual cores. Clock frequencies range roughly between 3.8 and 4.3 GHz on our experimental setup, which could cause a proportional efficiency drop of up to 12 % on large number of MPI processes. More detailed analysis of this factor is left for future work because the clock frequencies are controlled per core and are highly dynamic. Measuring it accurately will require capturing the detailed statistics in the MLPG program itself.

For the lowest number of nodes, N = 149806, efficiency is very close to 1 and nearly constant up to 16 processes. If we factor in the expected clock frequency reduction for high number of MPI processes, the efficiency would actually grow above 1. The foremost reason for such a high efficiency is rooted in the increased availability of L1 and L2 caches, contributed from each additional core. As expected, at 32 processes, the efficiency decreases, since there are only 16 physical cores on the processor, and the additional processes have to share the cache memories and floating point units of the already active cores.

Efficiencies, and consequently program speedups, for other p follow different patterns, but these are also most

likely the result of the memory hierarchy. For the next three larger numbers of nodes, N = [396359, 469018, 589403], efficiencies are lower on the medium number of processes p = [2, 4, 8], and rise again for p = 16, and do not experience a very dramatic fall for p = 32. The initial drop could signal that the problem is memory bound. Also, the L3 caches shared among the 4 processes of a single CPU complex could become too small to hold several copies of the node coordinates and the constructed system. The following rise at p = 16 could again be related to the availability of larger number of caches that are contributed from all 16 cores. The less significant drop for p = 32 is more enigmatic and we currently cannot speculate on its causes.

For the largest three numbers of nodes, N = [852011, 1096603, 1326296], efficiencies fall quickly with the increasing number of processes p = [2, 4, 8, 16], but then rise when SMT kicks in at p = 32. The former is, as before, an indication that the problem is memory bound, while the latter, rise at p =32, is even more enigmatic than before. We have never before observed the efficiency to rise when more processes are used than there is physical cores available. This is an interesting phenomenon that will have to be further examined.

2) Solution task

In general, after the linear system is constructed in a distributed way, it is either gathered again on a single node to be solved, or the system is solved in a distributed manner, exploiting the existing system distribution. Currently, our code offloads the solving task to external program via files and is far from optimal. We do not consider the times required for this offload as they will be reduced in the future, when a proper solver is integrated into the main code.

A comparison of computation times for constructing the system and solving it is shown in Fig. 7. The comparison confirms that, while constructing the system in parallel is beneficial, solving the system is the more demanding task that requires further attention. Note that the solution of the system task is plotted only for p =32. This is because the sparse linear system solver in Octave could not be configured to run in any other mode than fully parallel, that is on 32 cores. It is not clear whether this is actually the optimal number for the Octave solver, therefore, its performance should only be viewed as an approximate number.

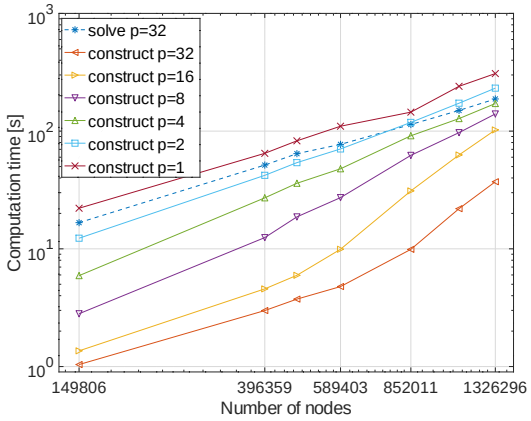

Figure 7: Computation time for the construction of system matrix on varying number of MPI processes, compared to computation time for the system solution on 32 processes.

To enlighten the execution times even more, all the relevant times were gathered for the case of largest domain with N = 1326296 discretization nodes in Fig. 8. Summing the individual task times for distribution of nodes, system construction and system solution, results in a total MLPG execution time, which is shown on the same figure. Execution times of all other tasks, such as program initialization and reading the nodes from storage are not shown, since they were found to be insignificant and constant with the number of processes as these tasks are too simple to be parallelized. The time for system construction scales well with the number of nodes. On the other hand, the time for distribution of nodes increases and becomes relevant at p =32. However, it is still two orders of magnitude lower than the time required for system solution, which seems to be a bottleneck of the proposed approach. Note that the system was solved outside our current parallel code.

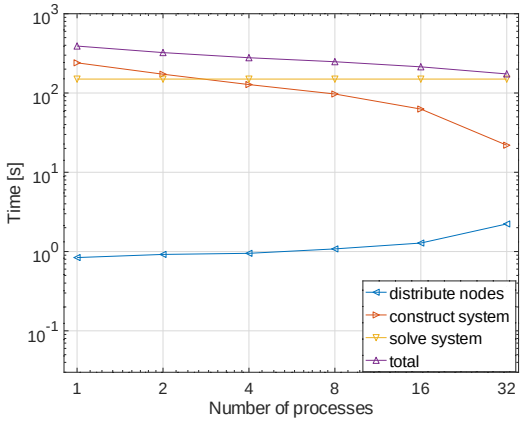

Figure 8: Computation time of the three most time consuming tasks and their total for the largest domain with N = 1326296.

IV. Conclusion

The obtained results indicate that the fretting fatigue case can be solved efficiently in parallel by the MPLG method. There is plenty of room for improvement on almost every step of the simulation process.

Solving the system efficiently and within the main program is the very first task on our list as it seems to be the most important step of the MLPG methodology. We will, however, start with an engineering approach to this task and use an established well tested and reliable library for implementing it, since developing an own solution is a research area on its own.

A more efficient distribution of nodal positions by sending only relevant domain parts to particular MPI processes is required if the MPI MLPG implementation were to be executed on distributed systems. The distribution of nodes would not even be required for shared memory systems and replacing MPI with OpenMP should be of high priority for the optimization of the MLPG program, however with a potential limitation of limited scope of use to the shared memory computer systems. On a multi-core computer, the efficiency of system construction should under OpenMP parallelization should be similar as under MPI parallelization, since no communication is involved, but the memory re-

quirements would be decreased, since the multiple threads would operate on the same memory, instead of on dedicated copies.

This paper also presented the view on computational efficiency of running a single task on a modern personal computer, which probably also relates well with the increasingly many-core modern workstations. Some unexpected inefficiencies were found when processing large systems in parallel with large number of cores, where minimum efficiency reached the very low value of 0.2. On the other hand, SMT proved to be remarkably efficient for very large problems, which is a pleasant surprise. Overall, we discovered that modern multi-core computers are capable of solving tasks that used to be reserved for clusters. The price to pay, though, is a complex internal hierarchy of cores, caches, and even memory connections within these machines, which makes execution times of parallel programs highly unpredictable. Furthermore, tuning parallel programs will in future increasingly rely on the target hardware architecture.

V. ACKNOWLEDGMENTS

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RBF-FD Solution of Electromagnetic Scattering Problem

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Abstract – In recent years, mesh-free approaches have become a widely used alternative to conventional methods, such as the Finite Element Method, in solving numerical scattering problems. In this work a local Radial Basis Generated-Finite Differences method is used to investigate the electromagnetic scattering problem of an infinitely long anisotropic circular cylinder, described by two coupled complex partial differential equations. The method proves useful for treating the complex valued solutions of the problem with material discontinuity at the junction between the anisotropic cylinder and free space. The numerical solution is compared to a known analytical solution in terms of accuracy and the values of Radar Cross Section.

I. Introduction

Electromagnetic scattering by different objects has been of interest to physicists for a long time. Mie [1] provided a solution of plane wave scattering by homogeneous dielectric sphere that was later extended to spheroids, ellipsoids [2] and infinite cylinders [3]. In recent decades, motivated by various applications [4, 5, 6], substantial research on electromagnetic scattering by different anisotropic scatterers has been conducted. While closed form solutions for circular [7] and elliptical [8] cylinders exist, it is difficult to find solutions for arbitrary shapes, possibly made of anisotropic materials. This has led to to a wide variety of numerical methods being used to study the problem. Finite-Difference Time-Domain (FD-TD) method, developed by Yee [9], was applied to this problem by Taflove [10] and Umashankar [11], followed by Finite-Difference with Measured Equation of Invariance (FD-MEI) to simulate scattering by a transversely anisotropic cylinder [12, 13]. Also weak form Finite Element Method (FEM) and its variants, namely edge-based FEM, have been widely used to study the problem [14]. Mesh-based methods can however run into problems when solving severely anisotropic problems. Such problems require mesh refinement along the anisotropy direction, which makes them computationally expensive [15].

In the past decades, meshfree or meshless methods based on radial basis functions (RBFs) have emerged as an attractive alternative to the above mentioned mesh-based methods, for solving partial differential equations (PDEs) [16, 17]. The main strength of meshless methods is that there is no need for mesh generation. Furthermore, meshless methods have been applied to a variety of electromagnetic problems [18, 19]. The electromagnetic scattering problem by anisotropic cylinders has been solved using the method of approximate particular solution (MAPS), a global strong form approach [15] and using meshfree local Petrov-Galerkin method (MLPG), a local weak form approach [20].

In this paper Radial Basis Function-generated Finite Differences (RBF-FD), a local strong form approach, is applied to the scattering problem by an anisotropic circular cylinder, the scattering is formulated as a complex valued problem and is solved using in-house Medusa library [21]. The error of the numerical solution is evaluated with respect to the known analytical solution.

The rest of the paper is structured as follows: in section II one can find the formulation of the direct scattering problem from an anisotropic cylinder along with the definition of RCS, RBF-FD method description and details are presented in section III and finally, the numerical solution and its analysis can be found in section IV.

II. Electromagnetic scattering problem

A. Scattering

Let $D \subset \mathbb{R}^2$ be the cross section of an infinitely long anisotropic dielectric cylindrical scatterer surrounded by a free space, with an outward normal n on boundary ∂D. The anisotropy of the scatterer is described by A, a 2×2 symmetric positive definite matrix, whose entries are relative magnetic permeabilities.

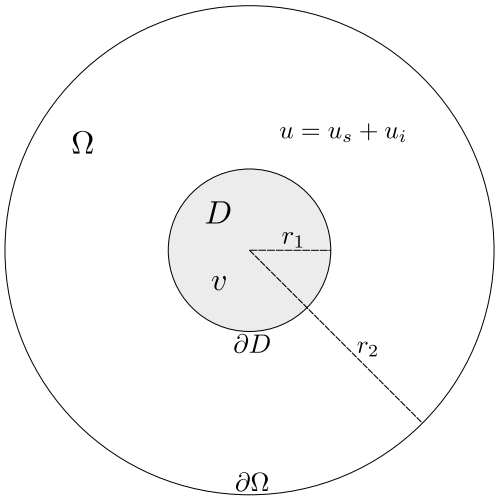

Figure 1. Anisotropic scatterer with cross section D, inside the computational domain Ω.

The scatterer is excited by an $e^{i\omega t}$ time-harmonic plane wave with $\boldsymbol{TM}^z$ polarization, with ω standing for its angular frequency. Let $v \in C^2(\mathbb{C})$ denote the complex

valued field inside the scatterer and $u \in C^2(\mathbb{C})$ the field outside of the scatterer. Field u can be further decomposed into the incident u^i and the scattered field u^s. The scattering of u^i by an inhomogeneity with cross section D in $\mathbb{R}^2$ can be formulated as a system of complex PDEs for v and u:

$$\nabla \cdot A\nabla v + \epsilon_r k^2 v = 0 \qquad \text{in} \quad D \tag{1}$$

$$\nabla^2 u^s + k^2 u^s = 0 \qquad \text{in} \quad \mathbb{R}^2 \setminus D \tag{2}$$

with boundary conditions

$$v - u^s = u^i \qquad \text{on} \quad \partial D \tag{3}$$

$$\frac{\partial v}{\partial n_A} - \frac{\partial u^s}{\partial n} = \frac{\partial u^i}{\partial n} \qquad \text{on} \quad \partial D \tag{4}$$

$$\lim_{r\to\infty} \sqrt{r}\left(\frac{\partial u^s}{\partial r} - iku^s\right) = 0, \qquad r = |\boldsymbol{r}|, \tag{5}$$

where $k = \omega\sqrt{\mu_0\epsilon_0} = \frac{2\pi}{\lambda}$ is the wave number of free space, μ_0 and ϵ_0 are magnetic permeability and electric permittivity of free space, while ϵ_r is the relative electric permittivity of the scatterer. Relative magnetic permeability matrix A is of the following form

$$A = \frac{1}{\mu_{xx}\mu_{yy} - \mu_{xy}^2}\begin{pmatrix} \mu_{xx} & \mu_{xy} \\ \mu_{xy} & \mu_{yy} \end{pmatrix} \tag{6}$$

and the anisotropic normal derivative is calculated as

$$\frac{\partial v}{\partial n_A} = n \cdot A\nabla v. \tag{7}$$

To numerically solve the described problem we construct a finite computational domain Ω around our scatterer, as seen on Figure 1. This slightly changes the problem formulation, (2) is now only solved in $\Omega \setminus D$ and (5) changes to:

$$\frac{\partial u^s}{\partial n} + \left(ik + \frac{1}{2r_2}\right)u^s = 0 \quad \text{on} \quad \partial\Omega. \tag{8}$$

The condition described in (5), and numerically calculated as (8) is the so called Sommerfeld boundary condition and it ensures that the scattered field u^s is outgoing.

B. Radar Cross Section

Radar cross section $\chi(\theta)$, sometimes called the scattering cross section, is often of primary interest rather than the fields u and v themselves, as it can be effectively measured [22]. In 2D it is defined as the following limit:

$$\chi(\theta) = \lim_{r\to\infty} 2\pi r \frac{|\boldsymbol{E}_s(\theta, r)|^2}{|\boldsymbol{E}_i(\theta, r)|^2} = \lim_{r\to\infty} 2\pi r \frac{|\boldsymbol{H}_s(\theta, r)|^2}{|\boldsymbol{H}_i(\theta, r)|^2}, \tag{9}$$

where $\boldsymbol{E}_s$, $\boldsymbol{H}_s$ and $\boldsymbol{E}_i$, $\boldsymbol{H}_i$ are the far field scattered and incident electric and magnetic field intensities, respectively. For $\boldsymbol{TE}^z$ and $\boldsymbol{TM}^z$, where $|u^i| = 1$, the expression can be further simplified to

$$\chi(\theta) = \lim_{r\to\infty} 2\pi r |u^s(\theta, r)|^2. \tag{10}$$

Finally given $|u^s|$ along the outer contour we can calculate RCS by expanding the solution in terms of Green's functions for the Helmholtz equation [23].

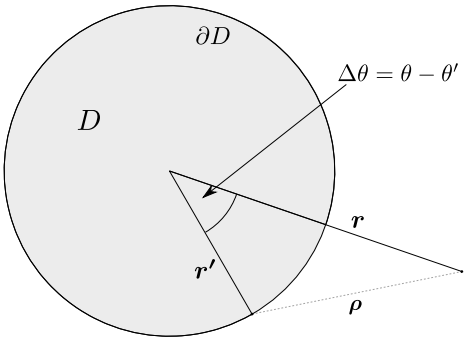

Figure 2. Given $|u^s|$ inside a finite domain, one can calculate the scattered field for any point $\boldsymbol{r}$ outside the domain via Green's function for the Helmholtz equation.

In the case of a circular outer contour the expression simplifies into:

$$\chi(\theta) = \frac{R^2}{4k}\left|\int_0^{2\pi} F[u_s(\boldsymbol{r'})]e^{ikR\cos\Delta\theta}d\theta'\right|, \tag{11}$$

where R is the radius of the outer contour and

$$F[u_s(\boldsymbol{r'})] = \frac{\partial u_s(\boldsymbol{r'})}{\partial n} - (ik\cos\Delta\theta)u_s(\boldsymbol{r'}), \tag{12}$$

where $\Delta\theta$ is defined as the angle between vectors $\boldsymbol{r'}$ and $\boldsymbol{r}$ as depicted in Figure 2. We will use the $|u^s|$ calculated in the points on the boundary ∂D, as they are most densely spaced in angle θ. Hence R in the above equations is really r_1.

III. Numerical method

A. Radal basis functions

The foundation of the RBF-FD method are radial basis functions. They are defined over a set of nodes $X = \{x_1, \dots x_n\}$ generated by a radial function $\phi\colon [0, \infty) \to \mathbb{R}$ as

$$\{\phi_i := \phi(\|\cdot - x_i\|), \text{ for } x_i \in X\}. \tag{13}$$

Commonly used RBFs are Gaussians, which we will also be using in this paper. They are defined as

$$\phi_i(x) = \exp(-(\varepsilon r)^2), \tag{14}$$

where $r = \|x - x_i\|$ and ε is the shape parameter which controls the flatness of radial basis functions.

B. Solution procedure

A discrete formulation of a PDE is obtained by using the RBF-FD method. Consider an elliptic boundary value problem with Dirichlet boundary conditions

$$\mathcal{L}u = f \qquad \text{in} \quad \Omega \tag{15}$$

$$u = u_0 \qquad \text{on} \quad \partial\Omega, \tag{16}$$

where f and u_0 are known functions. In order to obtain a discrete representation of the PDE, the domain is populated with N nodes. N_i nodes are placed in the interior of the domain and N_b on its boundary. Each node x_i is

assigned n neighbors, denoted $N(x_i)$, that constitute its *support domain* or *neighborhood*.

RBD-FD is a natural generalization of the FD method. When using the FD method, stencil weights for operator $\mathcal{L}$ are known in advance. For example, if $\mathcal{L}$ is the second derivative on a one dimensional equispaced grid with spacing h, the weights are $[1/h^2, -2/h^2, 1/h^2]$. Assembling the weights gives a global sparse system, whose solution is an approximation of u in points x_i. RBF-FD works the same way, except the stencil weights cannot be known in advance, as different neighborhoods have different arrangements, hence computing the weights becomes a part of the solution procedure. Moreover the operator $\mathcal{L}$ is approximated as a linear combination of function values at support points

$$(\mathcal{L}u)(x_i) \approx \sum_{x_j \in N(x_i)} w_j^i u(x_j). \tag{17}$$

Weights w_j^i are computed by imposing exactness of (17) for a set of radial basis functions, as it is done with monomials in the FD method. This gives a set of equations

$$(\mathcal{L}\phi_k)(x_i) = \sum_{x_j \in N(x_i)} w_j^i \phi_k(x_j), \tag{18}$$

for all $x_k \in N(x_i)$. Rewriting (18) in matrix form, one obtains

$$\begin{bmatrix} \phi(r_{j_1}^{j_1}) & \cdots & \phi(r_{j_1}^{j_n}) \\ \vdots & \ddots & \vdots \\ \phi(r_{j_n}^{j_1}) & \cdots & \phi(r_{j_n}^{j_n}) \end{bmatrix} \begin{bmatrix} w_{j_1}^i \\ \vdots \\ w_{j_n}^i \end{bmatrix} = \begin{bmatrix} (\mathcal{L}\phi_{j_1})(x_i) \\ \vdots \\ (\mathcal{L}\phi_{j_n})(x_i) \end{bmatrix}, \tag{19}$$

where $r_{j_m}^{j_k} = \|x_{j_k} - x_{j_m}\|$ and j_k are indices of nodes in the neighborhood $N(x_i)$ of node x_i. This is a system of n linear equations and can be compactly written as $A_i w_i = b_i$. Matrix A_i is symmetric and in the case of Gaussian basis functions with distinct support nodes [24], positive definite, hence nonsingular.

After the weight vectors w_i for all nodes n are computed, they are assembled in a sparse matrix, and f and x_0 are used to obtain the right hand side of the system. The system is then solved to give an approximation of u. Boundary conditions that include differential operators, such as Neumann (4) or Sommerfeld (8) boundary conditions, are discretized using RBF-FD analogously to operator $\mathcal{L}$.

C. Remarks on weight computation

It should be noted that the value of the shape parameter ε is important as it influences the performance of the algorithm. It is known for example, that as ε decreases, the accuracy of the solution increases, but the matrices A_i become more and more ill conditioned [25]. This is combated by scaling the shape parameter ε inversely proportional to the internodal distance, as this keeps the condition number of A_i constant with increasing node density. For large values of ε and variable nodal densities, issues may arise due to the Runge phenomenon [26]. The authors used the scaling shape parameter technique and no such issues were detected.

IV. Solution

A. Case description

The scattering of interest is such, that the wavelength of the incident wave is of the same order of magnitude as the scatterer radius. Hence the product of the wave vector k and the radius of the scatterer r_1 characterizes the problem. We will be studying incident plane wave that is $\boldsymbol{TM}^z$ polarized, with linear frequency of 300 MHz and of the form

$$u^i = \exp(ik(x\cos\theta^i + y\sin\theta^i)), \tag{20}$$

where θ^i is the angle of the incident wave. To get the radius of the scatterer we set $kr_1 = \frac{\pi}{2}$, to obtain $r_1 = 0.25$. As it is customary [15, 20], we chose the radius of the outer computational domain to be three times that of the inner boundary. The authors also solved the problem with different ratios in the range $\frac{r_2}{r_1} \in [2, 15]$ and larger ratios provided no additional accuracy when computing RCS and were much more computationally expensive, while $\frac{r_2}{r_1} = 2$ was unstable. Finally, the relative permeability matrix of our problem is

$$A = \frac{1}{16}\begin{pmatrix} 5 & 3 \\ 3 & 5 \end{pmatrix} \tag{21}$$

the incident angle $\theta^i = \frac{\pi}{4}$ and the electric permittivity of the scatterer is $\epsilon_r = 0.5$.

B. Numerical solution

The problem was solved using the RBF-FD method described in section III. Gaussian basis functions $\phi_i(x) = \exp(-(\varepsilon r)^2)$ were used, with a support size of $n = 9$. The value of the shape parameter ε was set to $\varepsilon \approx 0.0011$. Both the field inside the scatterer and the scattered field are calculated simultaneously as they are coupled via the nodes they share on the boundary of the cylinder. A common way to solve complex valued problems is to decompose the system of equations into real and imaginary parts and obtain a new system of coupled equations. The medusa library [21], can however solve complex valued problems natively, simplifying the process. While both the real and the complex part of the scattered field are needed to calculate the radar cross section the magnitude of the field inside the scatterer and the magnitude of the scattered field are shown in Figures 3 and 4

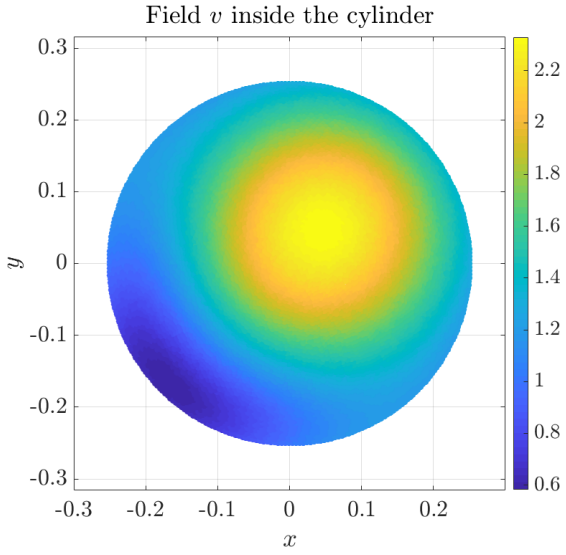

Figure 3. Magnitude of the field inside the cylinder. Number of computational nodes $N_i = 6986$.

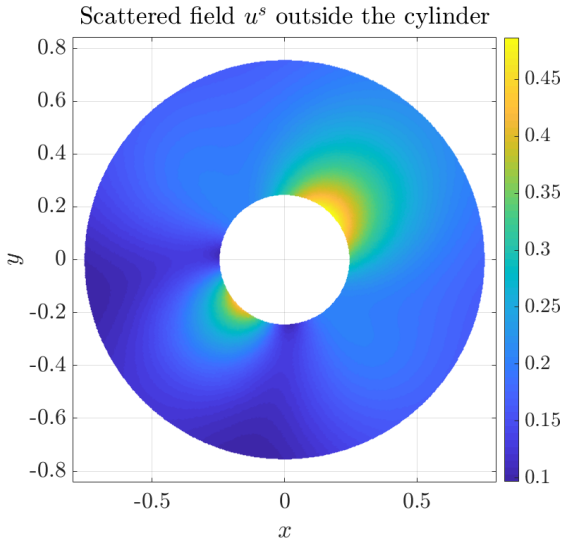

Figure 4. Magnitude of the scattered field outside the cylinder. Number of computational nodes $N_i = 55262$.

Note, the discontinuity at the boundary between the cylinder and free space, which is a result of plotting only the scattered field outside the cylinder. The sum of the incident and the scattered produces a continuous field. The numerical solution is compared to the analytical solution derived by Monzon [27].

To compare the analytical and numerical solution we computed the average error, defined as

$$\varepsilon_{\mathrm{a}} = \frac{1}{N} \sum_{i=1}^{N} |\hat{u}_i - u_i| \tag{22}$$

where, $\hat{u}_i$ and u_i are the analytical and numerical solution in i-th node respectively. Since the numerical solution is sensitive to node distributions, the error was computed for 120 slightly different nodal arrangements and then averaged out. This was repeated for different number of nodes N inside the domain. The results are presented in Figure 5 and Figure 6.

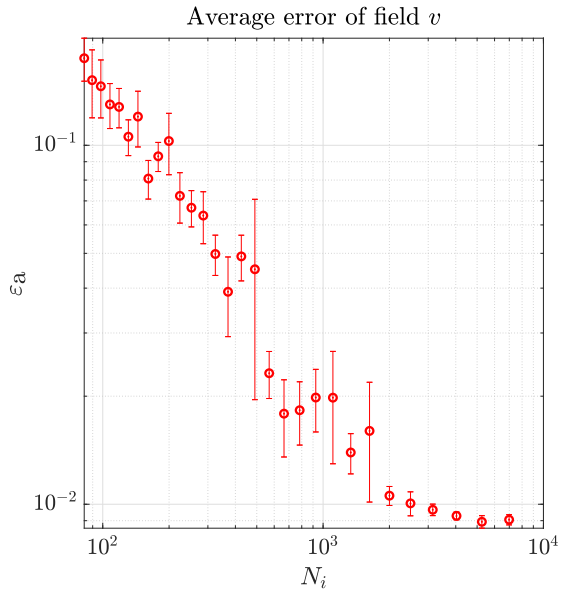

Figure 5. Average error of the numerically calculated field v inside the scatterer, with regards to the number of nodes inside the scatterer N_i.

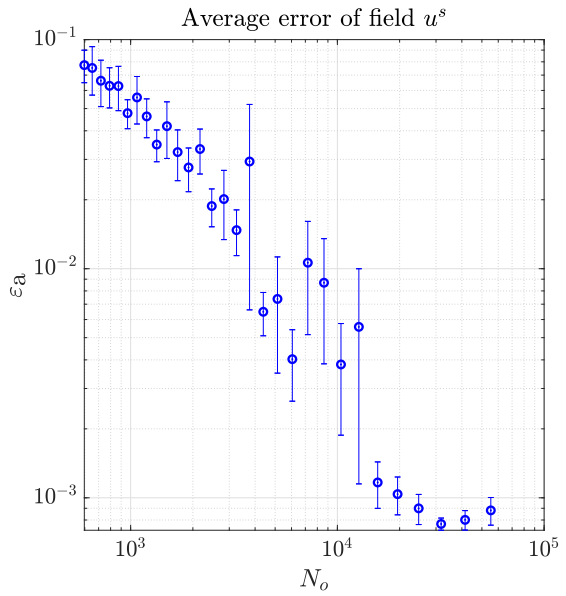

Figure 6. Average error of the numerically calculated field u^s outside the scatterer, with regards to the number of nodes outside the scatterer N_o.

The errorbars in figures 5 and 6 represent the standard error of the mean

$$\sigma_x = \frac{\sigma}{\sqrt{N}} \tag{23}$$

σ being the standard deviation.

C. Radar Cross Section

The radar cross section is obtained from the numerically scattered field by using (11). Normal derivatives of the scattered field are needed for the computation of RCS and they are obtained by explicitly taking the gradient of the computed scattered field u^s using the RBF-FD method. With that, calculating the radar cross section becomes a matter of correctly applying numerical integration techniques; interpolants of both the values and the

normal derivatives of the scattered field are constructed, and then used to numerically integrate (11). The results for the considered case are shown in Figure 7.

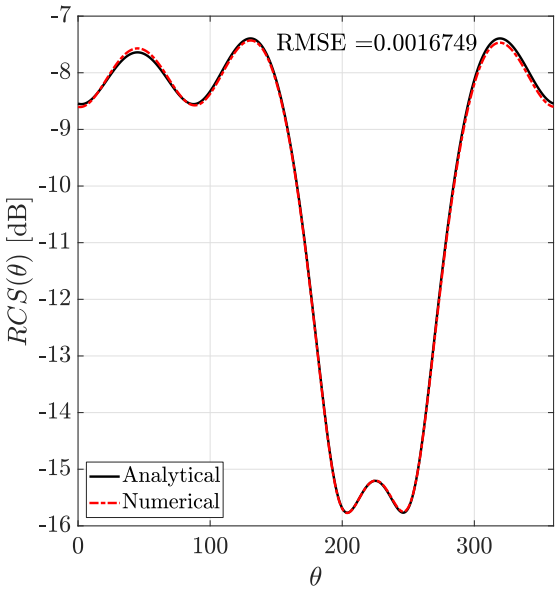

Figure 7. Radar cross section for $\epsilon_r = 0.5$, $\mu_{xx} = \mu_{yy} = 5$, $\mu_{xy} = \mu_{yx} = 3$, $\theta^i = \frac{\pi}{4}$ and $kr_1 = \pi/2$.

The analytical solution shown in Figure 7 was calculated using the method described in [27]. The root mean square error (RMSE), defined as

$$\text{RMSE} = \sqrt{\frac{1}{N_{\text{rcs}}} \sum_{i=1}^{N_{\text{rcs}}} [\hat{\chi}(\theta) - \chi(\theta)]^2} \qquad (24)$$

where $\hat{\chi}$ and χ are the analytical and numerical RCS respectively and N_{rcs} is the number of points in which RCS was calculated. For this case we obtain that RMSE $= 1.6749 \cdot 10^{-3}$.

V. Conclusion

In this paper we present a solution to the direct scattering problem by an infinitely long anisotropic cylinder using the RBF-FD method. It was shown that the method gives satisfactory results when compared to the analytical solution of the problem, both in terms of field strength and RCS. Thus showing that RBF-FD method is a good alternative to other meshless methods (MAPS, MLPG) when applied to the scattering problem.

In future work the solution will be extended to irregularly shaped domains in three dimensions with application of refinement of nodes distribution.

Acknowledgments

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Parallel simulation of time-domain acoustic wave propagation

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Abstract – Simulations of acoustic wave propagation are an important tool for reconstructing structure of Earth's subsurface. The core of such simulations is an efficient and accurate method of time-domain acoustic wave simulation in an inhomogeneous domain. Radial Basis Function-generated Finite Differences (RBF-FD) method is a popular variant of local strong form meshless methods that does not require predefined connections between nodes, making it easier to adapt node distribution to the problem under consideration. This paper explores RBF-FD as an alternative to traditionally FDM based methods for time-domain wave propagation. It is demonstrated that RBF-FD provides accurate results even in challenging cases, where conventional methods struggle to even obtain a stable solution.

I. Introduction

A reconstruction of Earth's properties from measurements at the surface can be done by analyzing the acoustic waves that propagate through the Earth. The essential parts of such an approach are a propagation model and its numerical solution. From a numerical point of view an obvious problem arises from the fact that the computational domain cannot cover the whole physical domain and therefore artificial boundaries have to be enforced, which causes nonphysical reflections.

Finite Difference Method (FDM) is often used for such simulations, as it provides an excellent compromise between computational efficiency and accuracy. FDM is also compatible with Absorbing Boundary Conditions [1], one of the simplest methods for suppressing unwanted reflections from the boundaries. Nevertheless, FDM has its shortcomings, namely it suffers from relative inflexibility regarding the considered domain, which arises from its definition on a static uniform grid, while the medium properties can drastically change on relatively small scales. Such cases force a sacrifice to be made either in terms of accuracy or computational efficiency. Limitations of other mesh based method were discussed also in [2] and [3].

In this paper we address the shortcomings of FDM using a solution procedure based on Radial Basis Function-generated Finite Differences (RBF-FD) method [4], a popular form of local strong form meshless methods, which has shown promise with several successful use cases and is still actively researched [5, 6, 7]. RBF-FD offers high flexibility regarding approximation order [6], treating complex domains [8], potential for effective parallel implementation [9] and high control over the complexity vs. accuracy/stability, which makes it an impressive tool for treating problems such as acoustic wave propagation.

The rest of the paper is organized as follows: in section II RBF-FD method and Absorbing boundary conditions in context of RBF-FD are defined, in section III the application of the described method is presented on a concrete problem, in section IV the numerical results are presented to demonstrate the advantages of RBF-FD, and in section V we present the conclusions.

II. Method description

A. Radial Basis Function-generated Finite Difference Method

The RBF-FD method is used for spatial discretization of a partial differential equation (PDE). In this paper an initial value problem will be solved, which requires discretization of derivatives in time, as well. The spatial discretization procedure will be presented first.

Radial Basis Functions are real valued functions $\Phi(r)$ only dependent on the distance from some center point $\boldsymbol{x_i}$

$$\Phi_i(\boldsymbol{x}) = \Phi(r) \text{ where } r = |\boldsymbol{x} - \boldsymbol{x}_i|. \tag{1}$$

In this paper Gaussian Radial Basis Functions are used

$$\Phi(r) = \exp(-r^2/\sigma_B^2), \tag{2}$$

where σ_B stands for the shape parameter.

Consider a differential operator $\mathcal{L}$ acting on a function u in the domain Ω. The domain Ω and its boundary $\partial\Omega$ are populated with N nodes. For each node $\boldsymbol{x}_i$ its n closest neighbors are found, forming the so-called support domain of $\boldsymbol{x}_i$. This is analogous the 5 or 9 neighboring nodes used to construct FDM approximations. Function values at support nodes are used to approximate the operator $\mathcal{L}$ as a weighted linear combination of said values

$$(\mathcal{L}u)(\boldsymbol{x}_i) \approx \sum_{\boldsymbol{x}_j \in \text{ support of } \boldsymbol{x}_i} w_j^i u(\boldsymbol{x}_j) = \boldsymbol{w}_i^\mathsf{T} \cdot \boldsymbol{u}_i, \tag{3}$$

where $u(\boldsymbol{x}_j)$ represents the value of the approximated field at position $\boldsymbol{x}_j$. The expression on the right shortens the notation by representing the sum as a dot product by packaging values inside vectors $\boldsymbol{w}_i^\mathsf{T}$ and $\boldsymbol{u}_i$. As an example, in one dimensional FDM we have the following known approximation for u'':

$$u''(x_i) \approx \begin{bmatrix} \frac{1}{h^2} & -\frac{2}{h^2} & \frac{1}{h^2} \end{bmatrix} \begin{bmatrix} u(x_{i-1}) \\ u(x_i) \\ u(x_{i+1}) \end{bmatrix}. \tag{4}$$

In contrast to FDM, RBF-FD uses weights that are not known beforehand as they are dependent on the positions of the nodes in the support domain. To determine the values of the weights w_j^i, equality is enforced in (3) for a set of Radial Basis Functions. In case of this paper the selected functions are Gaussians centered on all the nodes of the support domain. For the k-th function centered in support node p_k of node $\boldsymbol{x}_i$ we write

$$(\mathcal{L}\Phi_k)(\boldsymbol{x}_i) = \sum_{\boldsymbol{x}_j \in \text{ support of } \boldsymbol{x}_i} w_j^i \Phi_k(\boldsymbol{x}_j) = \boldsymbol{w}_i^{\mathsf{T}} \cdot \boldsymbol{\Phi}_k = \boldsymbol{\Phi}_k^{\mathsf{T}} \cdot \boldsymbol{w}_i. \quad (5)$$

As the number of functions Φ_k and in turn equations is equal to the number of unknown weights w_j, we have a linear system, which can be presented in matrix form by assembling rows $\boldsymbol{\Phi}_k^{\mathsf{T}}$ to a matrix:

$$\begin{bmatrix} \boldsymbol{\Phi}_1^{\mathsf{T}} \\ \vdots \\ \boldsymbol{\Phi}_k^{\mathsf{T}} \\ \vdots \\ \boldsymbol{\Phi}_n^{\mathsf{T}} \end{bmatrix} \begin{bmatrix} w_1^i \\ \vdots \\ w_j^i \\ \vdots \\ w_n^i \end{bmatrix} = \begin{bmatrix} (\mathcal{L}\Phi_1)(\boldsymbol{x}_i) \\ \vdots \\ (\mathcal{L}\Phi_k)(\boldsymbol{x}_i) \\ \vdots \\ (\mathcal{L}\Phi_n)(\boldsymbol{x}_i) \end{bmatrix} \quad (6)$$

where both j and k indices run over the nodes in the support domain of node $\boldsymbol{x}_i$. The matrix is symmetric and when Gaussian basis functions are used, it is also positive definite [5]. This guaranties non-singularity as long as all support domain nodes are distinct.

If the positions of the nodes do not change during the simulation, the weights have to be calculated only once at the beginning of the simulation and can be stored for further use. If the boundary conditions include differential operators as well (normal derivative for example), they can be discretized in a similar fashion to operator $\mathcal{L}$.

With weights computed, the operator $\mathcal{L}$ can be approximated with the discretized version, obtained from (3) as

$$(\mathcal{L}u)(\boldsymbol{x}_i) \approx \boldsymbol{w}_i^{\mathsf{T}} \cdot \boldsymbol{u}_i \quad (7)$$

for each node $\boldsymbol{x}_i$ inside the domain, where $\boldsymbol{u}_i$ still refers to values of nodes in support domain of node $\boldsymbol{x}_i$.

B. Time discretization

In addition to RBF-FD discretization of spatial derivatives, time derivatives must be discretized as well. As solving the wave equation is the goal of this paper only second time derivative must be discretized. The equation

$$\frac{\partial^2 u}{\partial t^2} = \mathcal{L}u \quad (8)$$

is discretized using an explicit scheme

$$\frac{u^t - 2u^{t-1} + u^{t-2}}{\Delta t^2} = \mathcal{L}u^{t-1}, \quad (9)$$

where the superscript index refers to the time step. When $\mathcal{L}u^{t-1}$ is evaluated, the values u^{t-1} and u^{t-2} are already known, either from the initial conditions or from the previous time step. Calculating the value of $(\mathcal{L}u_i^{t-1})(\boldsymbol{x}_i)$ is only a mater of a single dot product, as derived in (7). This formulation also gives rise to parallelization opportunities, since the result for each node $\boldsymbol{x}_i$ can be computed independently within a given time step.

C. Absorbing boundary conditions

In cases where reflections from the boundary are undesirable, some method for suppressing such reflections must be employed in conjunction with the RBF-FD method. Absorbing boundary conditions or ABC [1] is one of the simplest approaches available. The general idea is to introduce a damping factor for nodes inside area close to the boundary of the domain, which will be referred to as absorbing layer. Originally it was formulated in discrete form for FDM on a grid as

$$G(i) = \exp\left(-\left[0.015(i_{max} - i)\right]^2\right), \quad (10)$$

where i_{max} is the integer number of grid points which define the thickens of the absorbing layer; the index i is an integer value and runs from 0 to i_{max}. Usually i_{max} is set to 20. When RBF-DF is used, the nodes are generally not placed on an uniform grid. This necessitates a continuous form of (10),

$$G(x) = \exp\left(-\left[\frac{0.015}{a}(ai_{max} - x)\right]^2\right), \quad (11)$$

where x is the shortest distance from the boundary to the considered node and a is the expected inter nodal distance (which in general is dependent on x).

After this modification, RBF-FD implementation of ABCs continues in same way as in original formulation, i.e. every node inside the absorbing layer has its field value multiplied by $G(x)$ at every time-step.

However, despite the name, ABCs are not true boundary conditions in a sense of Dirichlet or Neumann, as they do not dictate the value or its derivative at the boundary. For this reason Dirichlet's boundary condition $u = 0$ for u on $\partial\Omega$ is used for the actual boundary nodes.

III. Problem formulation

The goal of this paper is to simulate time-domain acoustic wave propagation, where the waves are generated by a point-like source located under the surface of the Earth as depicted in Figure 1.

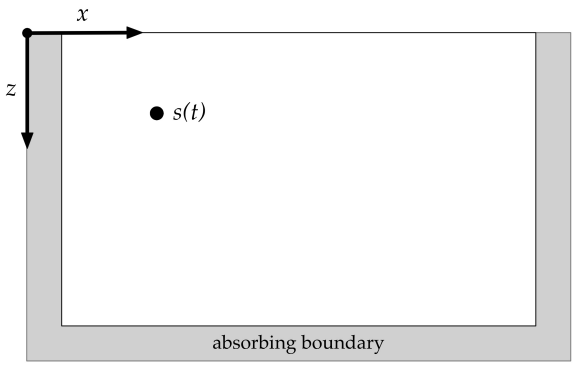

Figure 1. Shematic of the problem.

The problem of acoustic wave propagation is described by the wave equation

$$\frac{1}{v(\boldsymbol{r})}\frac{\partial^2 u(\boldsymbol{r},t)}{\partial t^2} = \nabla^2 u(\boldsymbol{r},t) + s(t)\delta(\boldsymbol{r}-\boldsymbol{r}_s) \qquad (12)$$

$$u(\boldsymbol{r},t=0) = 0 \quad \text{and} \quad \frac{\partial u(\boldsymbol{r},t=0)}{\partial t} = 0 \qquad (13)$$

where $\boldsymbol{r} = (x, z)$ stands for 2D position vector (z stands for the depth and is measured from the top downwards); $v(\boldsymbol{r})$ stands for position dependent wave velocity, which introduces the properties of the medium in the equation; $s(t)\delta(\boldsymbol{r} - \boldsymbol{r}_s)$ is the Dirac delta function, representing the point-like, time dependent source located at $\boldsymbol{r}_s = (x_s, z_s)$. It is assumed that the system is in equilibrium at the beginning of the simulation.

The problem is solved inside a $500\,\mathrm{m} \times 500\,\mathrm{m}$ square domain. The top boundary ($z = 0$) represents the Earth's surface. Reflections from this boundary are physical and for this reason Dirichlet's boundary conditions are used. All other edges of the domain do not represent any real physical barrier and therefore absorbing boundary conditions are employed. However as explained in Section II.C technically Dirichlet's boundary conditions are used in this case as well, allowing for the same boundary condition on the boundary

$$u = 0, \text{ on } \partial\Omega. \qquad (14)$$

The source $s(t)$ is implemented as Ricker's Wavelet

$$s(t) = \frac{2}{\sqrt{3\sigma_R}\pi^{1/4}}\left(1 - \left(\frac{t}{\sigma_R}\right)^2\right)e^{-\frac{t^2}{2\sigma_R^2}}, \qquad (15)$$

where σ_R is parameter related to flatness of the wavelet. Ricker's wavelet is depicted in Figure 2.

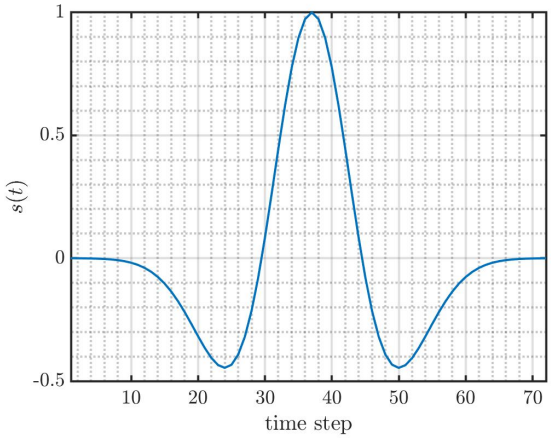

Figure 2. Ricker's wavelet; $\sigma_R = 7.5$.

The $\delta(\boldsymbol{r})$ function is implemented as its approximation

$$\delta(\boldsymbol{r}) = \frac{1}{\pi}\frac{\epsilon}{r^2 + \epsilon^2}. \qquad (16)$$

where ϵ is a small positive number in units of distance. Selection of ϵ has to be larger than the characteristic distance between nodes, as in this case the results were the most consistent between different discretization methods.

This set-up allow for a variety of different cases to be considered, depending on the choose of $v(\boldsymbol{r}, t)$. Case of constant velocity and case of a step in velocity field are presented in next section.

IV. Numerical examples

A. Homogeneous medium

A simple example of the wave propagation problem in homogeneous medium is presented first to validate the RBF-FD solution against the one obtained by FDM. The effect of absorbing boundary conditions will also be compared. The wave velocity is constant throughout the domain and is set to $v = 3000\,\mathrm{m/s}$. A Ricker's wavelet source is located at coordinate $(150\,\mathrm{m}, 150\,\mathrm{m})$, with $\sigma_R = 0.00147\,\mathrm{s}^{-1}$. For δ function approximation parameter $\epsilon = 4\,\mathrm{m}$.

Since the velocity is constant within the domain, RBF-FD was used on uniformly distributed nodes. Poisson Disk Sampling algorithm [7] with constant distance between nodes a is used for node placement. Additionally, regularization algorithm based on simulated annealing and free charged particle simulation is used to move the nodes which might not be placed optimally. This results in randomly placed nodes, the pattern however does resemble a hexagonal grid. The expected distance between nodes is equal to $a = 1.2\,\mathrm{m}$ which corresponds to total number of node $n = 248572$. Time step is chosen as $\Delta t = 0.000196\,\mathrm{s}$. RBF-FD is used with support size of 7 (the node itself and 6 closest neighbors) and shape parameter of Gaussian basis functions is set to $\sigma_B = 70$.

FDM was used in 5-stencil formulation on a uniform grid with a comparable number of nodes $n_{\text{FDM}} = 250000$ – as given by the grid spacing of $a_{\text{FDM}} = 1\,\mathrm{m}$. The time step was the same with both methods.

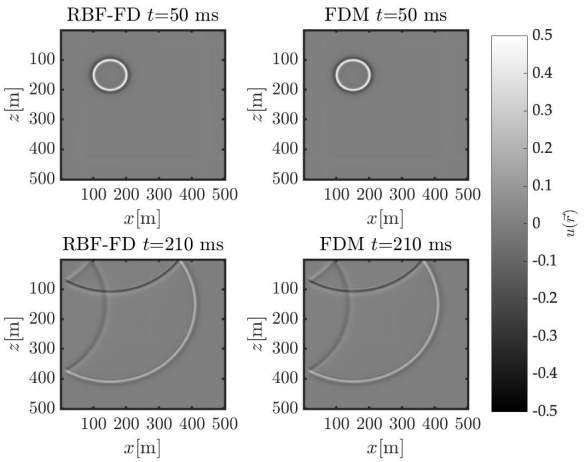

Figure 3. Values of the field u obtained by RBF-FD and FDM at various times.

The Figure 3 displays the comparison of the results from both methods. As positions of the nodes differ between methods, linear interpolation was used in post process. Snapshots of the wave field are provided at two times. We can observe the wave propagating in a perfect circle until it hits the boundary. At time $t = 210\,\mathrm{ms}$ the effect of absorbing boundary conditions can be observed

as the reflection from left boundary is reduced compared to the reflection from top boundary.

The RBF-FD solution generally agrees with the FDM in scope of max pointwise error $e \approx 10^{-2}$. Absorbing boundary conditions also appear to be just as effective in use with RBF-FD as they are in original form with FDM.

As there is special interest in state of wave field directly at the surface, the time evolution of the top row of nodes is presented in Figure 4 – the seismogram. The difference between the real wave field and the suppressed reflection from the side boundaries is more clearly visible. Again, results of both methods agree visually.

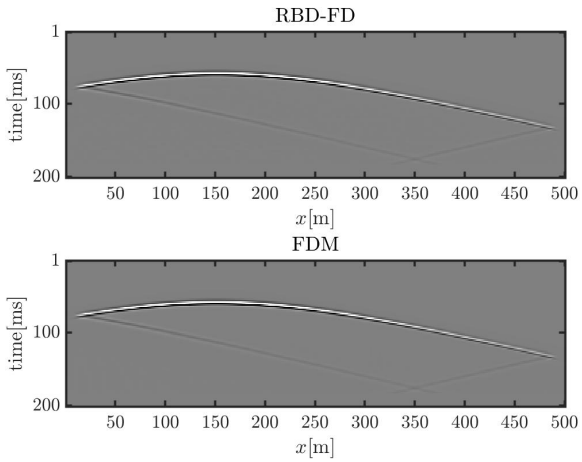

Figure 4. Comparison of seismograms computed using RBF-FD and FDM.

A) Computation time analysis

The most computationally demanding part of the code is the time loop where in each time step equation (12) is solved by performing spatial loop over all computational nodes. Due to the explicit treatment of time derivative, the iterations in spatial loop are completely independent, and can be therefore executed in parallel. The shared memory parallelization was implemented by *OpenMP omp parallel for* directive with static scheduling.

The execution time was measured using 1 to 8 threads as presented in Figure 5. The testing was done on a laptop computer with `Intel(R) Core(TM) i7-4750HQ CPU @ 2.00GHz` processor and 8 GB 1600 MHz DDR3 RAM. Code was compiled using `LLVM 5.0.1` for MacOS with `-std=c++11 -O3 -DNDEBUG` flags

Use of multiple threads had a positive impact on the calculation with speedups up to factor 3, as shown in Figure 6. One aspect holding back the effectiveness of the parallelization is the node placement process that takes place once at the beginning of the calculation and was not executed in parallel in this implementation. Parallelization of this aspect is left for future work.

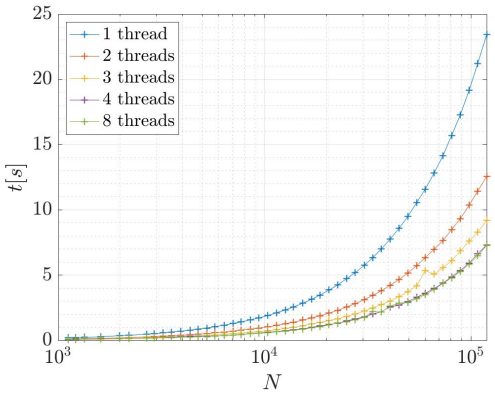

Figure 5. Time stepping – comparison of calculation time when using paralelization – log/lin scale.

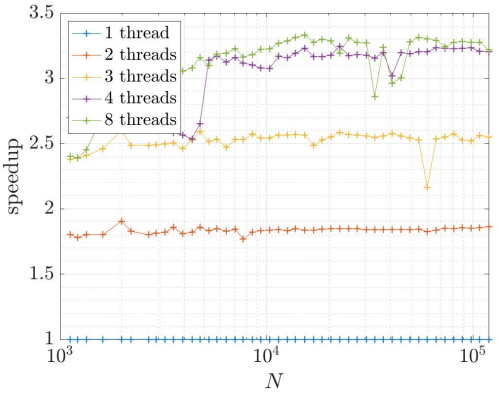

Figure 6. Time stepping – speedup when using paralelization – log/lin scale.

B. Velocity step

To demonstrate the advantages gained by using the more flexible RBF-FD method we present a second example, where the domain is divided in two regions and the boundary between them represents a step in wave velocity. The velocity field for the case is

$$v(z) = \begin{cases} 3000\,\mathrm{m/s}\,; & z < 250\,\mathrm{m} \\ 5000\,\mathrm{m/s}\,; & z \geq 250\,\mathrm{m} \end{cases} \tag{17}$$

The wavelength is linearly proportional to the wave velocity and for accurate simulation from 10 to 20 nodes per wavelength are required [10, 11]. This loosely translates to same requirement of 10 to 20 nodes per characteristic distance of the disturbance caused by the source. Ricker's wavelet was for purposes of this paper considered to be 3 characteristic distances long. In case of wave propagation in in-homogeneous media the computational nodes should therefore be distributed with density inversely proportional to the velocity field of the medium. As sudden jumps in node density tend to cause numerical errors, the node density follows the moving average of the velocity field instead of the field itself.

Again, Poisson Disk Sampling in conjunction with regularization algorithm was used for node placing. Fig-

ure 7 displays a part of the domain near where the gradual change in node density is observable.

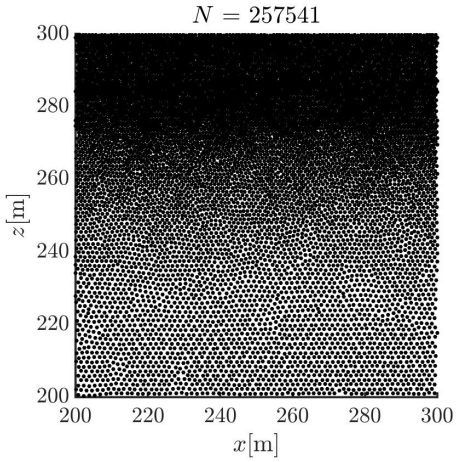

Figure 7. Node distribuition around the velocity step.

The size of the domain is kept at $500\,\mathrm{m} \times 500\,\mathrm{m}$. Roughly 250000 nodes are used with both methods. The time step is again the same with both methods, however it was reduced to $\Delta t = 0.00014142\,\mathrm{ms}$ compared to the first example to keep both methods stable. The RBF-FD setup remains the same as in the first example.

The source is located at coordinate $(250\,\mathrm{m},\ 200\,\mathrm{m})$, with $\sigma_R = 0.00106\,\mathrm{s}^{-1}$ and $\epsilon = 4\,\mathrm{m}$.

Without increasing the amount of computational nodes from the previous example, FDM with uniform node grid does not provide sufficient density everywhere inside the domain. In contrast, RBF-FD with variable node density provides 11.5 nodes per wavelength everywhere inside the domain, with roughly the same number of computational nodes.

Using the stability criterion for FDM [12, p. 205] we can compute the bound for Δt, at which the solution is still stable, which in our notation reads as

$$\Delta t \leq \sqrt{2}\frac{a}{v}. \tag{18}$$

From (18) we can observe that areas of high velocity cause instabilities when using FDM, if time step is not sufficiently reduced. However if the internodal distance a is itself proportional to velocity, the velocities in (18) cancel each other out. Explicitly writing the dependence of nodal density on the velocity field as $a = Cv$, where C s some constant, the stability criterion (18) simplifies to

$$\Delta t \leq \sqrt{2}C, \tag{19}$$

which is independent of v. In our implementation of RBF-FD, a is proportional to v and in turn problems with stability are avoided.

The results of simulation with RBF-FD method are presented in Figure 8, showing snapshots of the field at four different times. In addition to effects observed in the first numerical example, we can at time $t = 30\mathrm{ms}$ observe the internal reflection caused by the step in velocity. The superiority of RBF-FD solution can be best demonstrated by focusing on the area marked by a red rectangle. Figure 9 displays this area in greater detail, which illustrates the different behavior of RBF-FD and FDM.

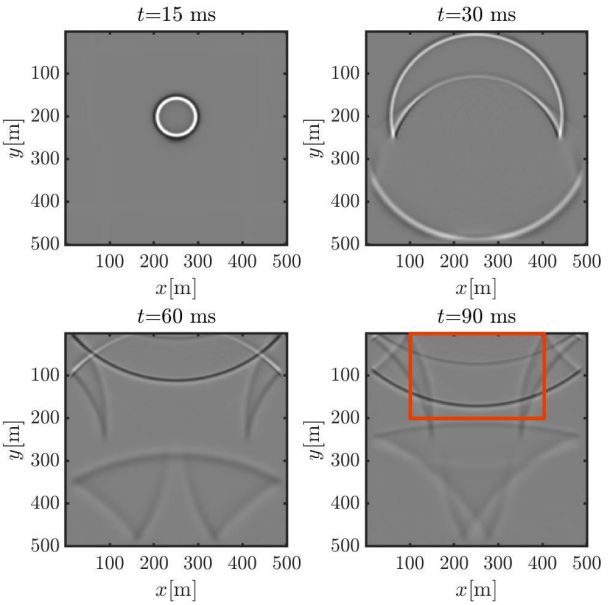

Figure 8. RBD-FD snapshots of wave field. Red rectangle depicts the area of interest.

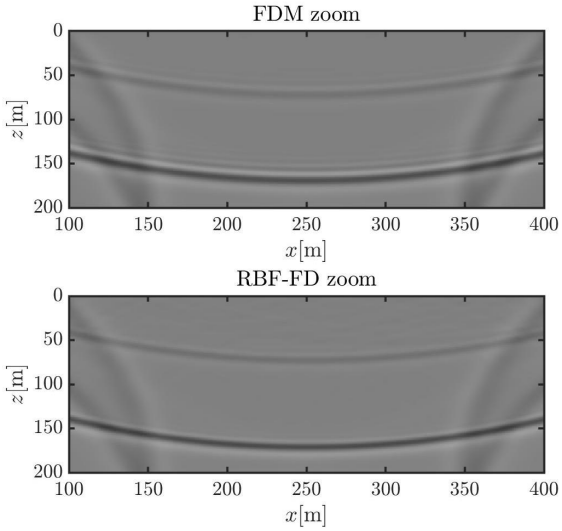

Figure 9. Comparison between RBF-FD and FDM solutions at time $t = 90$s on the part marked by red rectangle on Figure 8.

The numerical artifacts behind the main wavefront moving downwards on the FDM solution are easily visible, while the RBF-FD solution is artifact free. Artifacts that arise from variable nodal density are highly problematic in more complex use cases where they become difficult to distinguish from real reflections caused by changes in the medium.

However, the RBF-FD solution has some noise-like numerical artifacts. While much less prominent than the discussed artifacts in FDM solution, they are still undesirable. The cause is most likely the node density distribution at the discontinuity in the velocity field. One possible solution would be to slightly increase the node density in

the narrow region around the discontinuity. Unfortunately, this would require shorter time steps as a would not be proportional to v which would lead to instabilities.

V. Conclusions

This paper presents a RBF-FD solution of a time-domain acoustic wave propagation problem with absorbing boundary conditions, which was originally solved using FDM. The main advantage of the proposed RBF-FD solution is its flexibility regarding the positioning of computational nodes, which is exploited to solve the velocity step case with a refined nodal distribution. It is demonstrated that the refined solution is, as expected, superior to traditional FDM solution and that it can be relatively effectively executed in parallel on shared memory architecture.

Future research directions include further improvements to the node placement strategy, such as parallelization, and tackling more complex real world applications.

Acknowledgments

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Fitting Sum of Exponentials to Experimental Data: Linearization by Numerical Integration Approximation

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Abstract **- A solution to important and difficult problem of resolving the components of multi-exponential decay is presented. Often the techniques are chosen that are noise sensitive and their error poorly understood. A general, numerically robust and fast (real time) solution method has been developed. Noise attenuation and flexibility of the method are analyzed in detail. Its relevance for signal analysis from different relaxation processes, in particular NMR medical imaging is discussed. Multi-exponential decays are most often results of parallel, independent relaxation processes, decay of a mixture of radionuclides, parallel chemical reactions of the first order, etc. Inverse problem of finding the components with close decay constants in multi-exponential signal is inherently ill-posed because of non-orthogonality of exponential functions. The result is very sensitive to noise and chosen optimization methodology. The general solution for the problem of separating exponentials based on linear approximation through repeated numerical integration has been developed. The algorithm is based on the least squares method with the possibility of using non-negative constrains. Using linear approximation avoids problem with supplying a good initial guess, nonproductive iterations, and local minima. Algorithm also includes implementation of global method by Knutson.**

Keywords – fitting; exponentals sum; linearization

I. INTRODUCTION

The general solution for the problem of separating individual exponential functions form their summary experimental signal is developed. The method is inspired by Fosse's paper in which just a few simplest cases were presented [1]. Although Foss suggested that a general solution is possible, he didn't present one. The idea was further developed and used for selected cases by Matheson in analytical chemistry applications [2] and by Jeričević in digital imaging microscopy applications [3]. The development of global method by Knutson and coworkers shifted the emphasis in fluorescence signal analysis toward non-linear optimization approach [4]. The global method is using parallel measurements of the same fluorescence decay at different wavelengths and analyzing them all at once to remove ill-conditioning from the separation of exponentials.

II. THEORY

The general solution presented here is based on transforming the original equation into linear one and then solving the linear problem using the least squares method [5]. The solution was also presented in the US Patent 7,088,097 [6].

The steps in the method are as follows:

- Linearization by numerical integration method
- Solution of linear system of equations with or without non-negativity constrains
- Determining coefficients and roots of polynomial equation(s) based on linear system solutions. This step yields non-linear parameters, i.e. decay constants.
- Reformulating original problem using now known decay constants in order to compute pre-exponential terms.
- Testing and verifying the results by detailed error analysis

The linearization will be presented through two simple examples and general solution will be done by inference.

Here is the first, most simple example of monoexponential fuction:

$$y = Ae^{-kt}$$

$$\int_0^T y\,dt = A\int_0^T e^{-kt}dt$$

$$\int_0^T y\,dt = \frac{A}{k}(-e^{-kt}\,|_0^T$$

$$\int_0^T y\,dt = \frac{A}{k}(1.0 - e^{-kT})$$

Substituting experimental point (y_T)

$$-y_T \approx -Ae^{-kT}$$

yields:

$$y \approx -k\int y\,dt + A$$

Giving set of linear equations to be solved for k and A

$$y(t_j) \approx -k \int_{t=0}^{t=t_j} y(t)dt + A \qquad (1)$$

The integrals in the set of linear equations (1) are computed numerically.

The following example for biexponential function is a more complex and requires integrating the equations twice. The number of exponentials in the sum is equal to the number of successive numerical integrations.

$$y = A_1te^{-k_1t} + A_2te^{-k_2t}$$

Integration yields:

.

$$\int y\,dt = A_1\int te^{-k_1t}dt + A_2\int te^{-k_2t}dt\ .$$

$$\int y\,dt = \frac{A_1}{k_1^2}(-k_1te^{-k_1t} - e^{-k_1t}\,|_0^T + \frac{A_2}{k_2^2}(-k_2te^{-k_2t} - e^{-k_2t}\,|_0^T$$

$$= \frac{A_1}{k_1^2}\left(-k_1te^{-k_1T} - e^{-k_1T} + 1\right) + \frac{A_2}{k_2^2}\left(-k_2te^{-k_2T} - e^{-k_2T} + 1\right)$$

.

$$\int y\,dt = \frac{k_2^2A_1}{k_1^2}\left(-k_1te^{-k_1T} - e^{-k_1T} + 1\right) + \frac{k_1^2A_2}{k_2^2}\left(-k_2te^{-k_2T} - e^{-k_2T} + 1\right)$$

$$k_1^2k_2^2\int y\,dt = k_2^2A_1 - k_1k_2^2A_1te^{-k_1t} - k_2^2A_1e^{-k_1t} + k_1^2A_2 - k_1^2k_2A_2te^{-k_2t} - k_1^2A_2e^{-k_2t}$$

It follows

$$k_1^2k_2^2\int y\,dt = k_2^2A_1 - k_1k_2^2A_1te^{-k_1t} - k_2^2A_1e^{-k_1t} + k_1^2A_2 - k_1^2k_2A_2te^{-k_2t} - k_1^2A_2e^{-k_2t}$$

$$k_1^2k_2^2\int y\,dt = k_2^2A_1 - k_1k_2^2\left(A_1te^{-k_1t} + A_2te^{-k_2t} - A_2te^{-k_2t}\right) - k_2^2\left(A_1e^{-k_1t} + A_2e^{-k_2t} - A_2e^{-k_2t}\right) + k_1^2A_2 - k_1^2k_2\left(A_2te^{-k_2t} + A_1te^{-k_1t} - A_1te^{-k_1t}\right) - k_1^2\left(A_2e^{-k_2t} + A_1e^{-k_1t} - A_1e^{-k_1t}\right)$$

Substitute the approximation: $y \approx A_1te^{-k_1t} + A_2te^{-k_2t}$

$$k_1^2k_2^2\int y\,dt \approx k_2^2A_1 - k_1k_2^2\left(y - A_2te^{-k_2t}\right) - \frac{k_2^2}{t}\left(y - A_2e^{-k_2t}\right) + k_1^2A_2 - k_1^2k_2\left(y - A_1te^{-k_1t}\right) - \frac{k_1^2}{t}\left(y - A_1e^{-k_1t}\right)$$

$$k_1^2k_2^2t\int y\,dt \approx k_2^2A_1t - k_1k_2^2t\left(y - A_2te^{-k_2t}\right) - k_2^2\left(y - A_2e^{-k_2t}\right) + k_1^2A_2t - k_1^2k_2t\left(y - A_1te^{-k_1t}\right) - k_1^2\left(y - A_1e^{-k_1t}\right)$$

Second integration yields:

$$k_1k_2\iint y\,dt\,dt \approx k_2A_1\int dt - k_2\int y\,dt + A_2(1.0 - e^{-k_2t}) + k_1A_2\int dt - k_1\int y\,dt + A_1(1.0 - e^{-k_1t})$$

$$k_1^2k_2^2t\int y\,dt \approx k_2^2A_1t - k_1k_2^2t\left(y - A_2te^{-k_2t}\right) - k_2^2\left(y - A_2e^{-k_2t}\right) + k_1^2A_2t - k_1^2k_2t\left(y - A_1te^{-k_1t}\right) - k_1^2\left(y - A_1e^{-k_1t}\right)$$

$$k_1^2k_2^2\int t\left(\int y\,dt\right)dt \approx k_2^2A_1\int tdt - k_1k_2^2\int ytdt + k_1k_2^2A_2\int t^2e^{-k_2t}dt - k_2^2\int y\,dt + k_2^2A_2\int e^{-k_2t}dt + k_1^2A_2\int tdt - k_1^2k_2\int ytdt + k_1^2k_2A_1\int t^2e^{-k_1t}dt - k_1^2\int y\,dt + k_1^2A_1\int e^{-k_1t}dt$$

$$k_1^2k_2^2\int t\left(\int y\,dt\right)dt \approx k_2^2A_1\frac{t^2}{2} - k_1k_2^2\int ytdt + \frac{k_1}{k_2}\left(-k_2^2t^2A_2e^{-k_2t} - 2k_2tA_2e^{-k_2t} - 2A_2e^{-k_2t} + A_2\right) - k_2^2\int y\,dt - k_2A_2\left(e^{-k_2t} - 1\right) + k_1^2A_2\frac{t^2}{2} - k_1^2k_2\int ytdt + \frac{k_2}{k_1}\left(-k_1^2t^2A_1e^{-k_1t} - 2k_1tA_1e^{-k_1t} - 2A_1e^{-k_1t} + A_1\right) - k_1^2\int y\,dt - k_1A_1\left(e^{-k_1t} - 1\right)$$

$$k_1^2k_2^2\int t\left(\int y\,dt\right)dt \approx k_2^2A_1\frac{t^2}{2}-k_1k_2^2\int ytdt+$$
$$\frac{k_1}{k_2}\left(-k_2^2t^2A_2e^{-k_2t}-2k_2tA_2e^{-k_2t}-2A_2e^{-k_2t}+A_2\right)-$$
$$k_2^2\int y\,dt-k_2A_2\left(e^{-k_2t}-1\right)+k_1^2A_2\frac{t^2}{2}-$$
$$k_1^2k_2\int ytdt+$$
$$\frac{k_2}{k_1}\left(-k_1^2t^2A_1e^{-k_1t}-2k_1tA_1e^{-k_1t}-2A_1e^{-k_1t}+A_1\right)-$$
$$k_1^2\int y\,dt-k_1A_1\left(e^{-k_1t}-1\right)$$

$$k_1^3k_2^3\int t\left(\int y\,dt\right)dt \approx \left(k_1k_2^3A_1+k_1^3k_2A_2\right)\frac{t^2}{2}-$$
$$\left(k_1^2k_2^3+k_1^3k_2^2\right)\int ytdt-k_1^2k_2^2t^2A_2e^{-k_2t}-$$
$$2k_1^2k_2tA_2e^{-k_2t}-2k_1^2A_2e^{-k_2t}+k_1^2A_2+$$
$$\left(k_1k_2^3+k_1^3k_2\right)\int y\,dt-k_1^2k_2^2t^2A_1e^{-k_1t}-$$
$$2k_1k_2^2tA_1e^{-k_1t}-2k_2^2A_1e^{-k_1t}+k_2^2A_1$$

$$k_1^3k_2^3\int t\left(\int y\,dt\right)dt \approx \left(k_1k_2^3A_1+k_1^3k_2A_2\right)\frac{t^2}{2}-$$
$$\left(k_1^2k_2^3+k_1^3k_2^2\right)\int ytdt-$$
$$k_1^2k_2^2ty-2k_1^2\left(k_2tA_2e^{-k_2t}+A_2e^{-k_2t}\right)+$$
$$k_1^2A_2-2k_2^2\left(k_1tA_1e^{-k_1t}+A_1e^{-k_1t}\right)+k_2^2A_1$$

$$k_1k_2\iint y\,dt\,dt \approx t\{k_2A_1+k_1A_2\}-(k_1+k_2)\int y\,dt-y+A_1+A_2$$

Which finally gives the following system of linear equations:

$$y \approx -(k_1+k_2)\int y\,dt-k_1k_2\iint y\,dt\,dt+$$
$$A_1+A_2+t(k_2A_1-k_1A_2) \qquad (2)$$

The solution for linear system of equations (2) is given as

$$p_1=-k_1-k_2$$
$$p_2=-k_1k_2$$
$$p_3=A_1+A_2$$
$$p_4=A_1k_2+A_2k_1$$

The first two parameters define decay constants *k*, ie non-linear parameters and can be calculated by finding the roots of a second degree polynomial. After that two remaining linear equations can be used to compute pre-exponential parameters *A*.

Obviously, higher the number of exponentials is, the more complicated the equations become and computations more demanding as well. The number of multiple integrations and the degree of polynomial in nonlinear parameters correspond to the number of exponentials. However the general solution can be constructed by inference and it has the following form (N is number of exponentials):

General solution

$$p_1=-\sum_{i=1}^{N}k_i$$

$$p_n=-\sum_{i=1}^{\frac{N!}{(N-n)!n!}}\prod_{1}^{n}k_m \qquad m\in({}^{N}C_n)$$

$$p_N=-\prod_{i=1}^{N}k_i$$

$$p_{N+1}=\sum_{i=1}^{N}A_i$$

$$p_{N+2}=\sum_{i=1}^{i=N}A_i\sum_{j=1;\,j\neq i}^{N}k_j$$

$$p_{N+n}=\frac{1}{(n-1)!}\sum_{i=1}^{N}A_i\sum_{j=1;}^{\frac{(N-1)!}{(N-n)!(n-1)!}}\prod_{1}^{n-1}k_m \qquad m\in({}^{N-1}C_{n-1};\ m\neq i)$$

$$p_{2N}=\frac{1}{(N-1)!}\sum_{i=1}^{N}A_i\prod_{j=1;\,j\neq i}^{N}k_j \qquad m\in({}^{N}C_{N-1})$$

III. RESULTS AND DISCUSSION

The method and its corresponding software were tested using synthetic and real data from relaximeter and MRI.

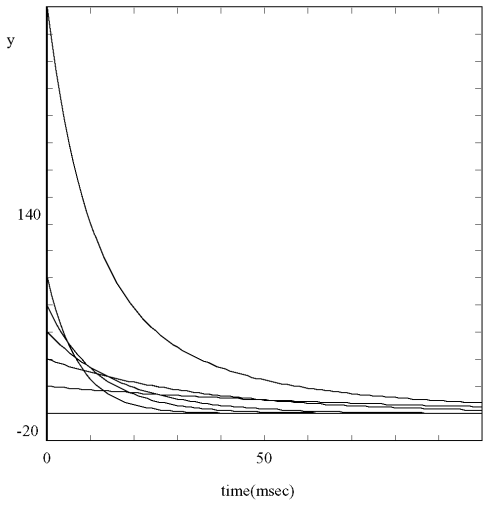

Figure 1. Theoretical input data containing five exponentials and data computed from components are completely overlaping as the upermost curve. Individual components are five curves bellow. Except for the numerical noise, there is no difference between input and restored data.

The theoretical no noise test was primarily done to test the general solution. The equations for five exponentials sum were never explicitly developed and fit is completely based on general solution constructed by inference from small number of components.

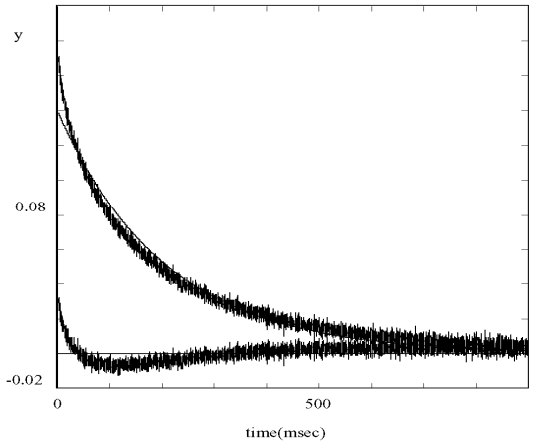

Figure 2. Input data from water saturated sandstone (upper noisy curve). Restored data using monoexponential function is upper smooth curve. The difference is lower noisy curve. Monoexponential is obviously underfit (not enough components)

The sandstone data in Fig.2 give the best fit with four components. Trying more then that for this data is not feasible. The difference curve is good tool for visually checking the quality of the fit. Results are shown in Fig. 3.

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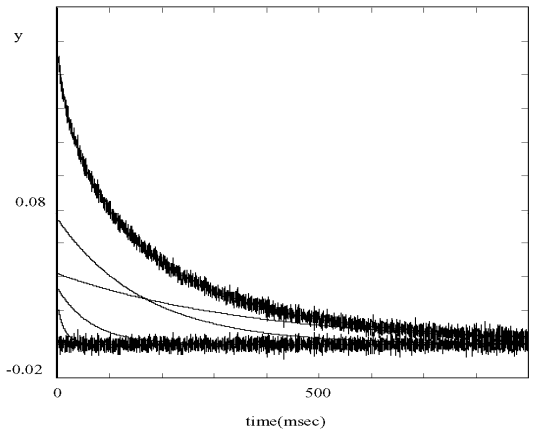

Figure 3. Input data from water saturated sandstone (upper noisy curve). Restored data using quad-exponential function is not visible due to overlap with experimental data. Lower smooth curves are individual components. The difference is lower noisy curve which is completely flat (except for noise) Quad-exponential is obviously a good fit

The speed of algorithm is practically a real time. Because optimization is linear there are no problems with initial guesses, non productive iterations or local minima. As such, the algorithm is fully automated and does not require attention from a user. This makes it a perfect candidate for processing large data sets like ones coming from imaging.

Fig. 4 shows real data coming from medical NMR imaging.

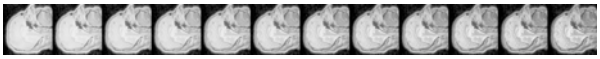

Figure 4. Time series of images coming from medical NMR imaging. Data are shown on a log scale. For this picture, images are also reduced in size in order to fit into single picture.

For such a short time series (12 images) only the monoexponetial fit is feasible. The results are shown in Fig.5.

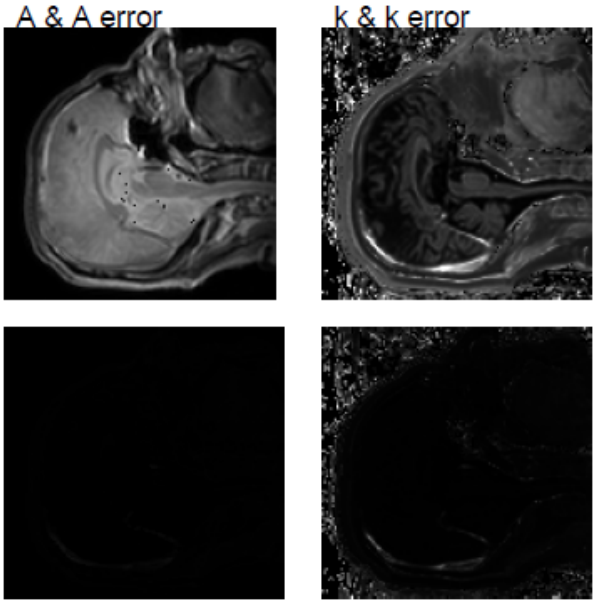

Figure 5. The results of monoexponential fit for MRI data. Left column is the initial intensity and its error, right column is relaxation constant and its error. Error maps are bottom row.

IV. CONLUSION

Fast and robust algorithm for finding the components of multiexponential signal was developed and tested with synthetic and real data. The speed and automatic mode of operation makes the algorithm particularly suitable for processing time series of images coming form MRI or fluorescence relaxation data. Global method [4] for fluorescence data processing is also implemented in the algorithm.

ACKNOWLEDGMENT

Thanks to Kurt Strack for inspiration.

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The Rainbow: Integrating Computing into the Global Ecosystem

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***Abstract* - Are we aware of the fact that what we develop today, the world we create – our children will have to live in it. Unintentionally, and with little or no self-awareness, computer science has crept into every aspect of life, or, better to say, almost every aspect of the natural and social environment has crept into the lap of computer science. Somehow much in the world today came to be the responsibility of Computer Science. Unfortunately, the development was so rapid and mostly stochastic that most of us, computer scientists and computer engineers, application, software and computing paradigm inventors and developers, did not even have a chance yet to realise the Responsibility we are taking on. The ecosystems we live in, from the ecosystem of the family to the ecosystem of social groups and groupings, from the ecosystem of the human body itself, to the ecosystem of the globaly interdependent economics, and from the ecosystem of the living beings sharing this world with us, up to the ecosystem of the whole Earth, those ecosystems are more and more being monitored, controlled and even steered by a mirriad of human-produced artifacts, all-pervasively being based on data processing equipment, or, commonly said, computers. It is very obvious that in modern days computer science leads an extremely influential role in all these ecosystems. It is also obvious that for its ideas and actions in those fields computer science has to take responsibility. In the overall "computing" ecosystem there is actually a kind of "evaporation" of information and requests upwards from Nature to Dew to Human to Fog to Cloud, and a "rain" of services and processed information from the Cloud downwards. Therefore the associative name of Rainbow – as an analogy to the sunray spectrum – an ecosystem in which we necessarily include both the "technical" and the "philosophical" aspects, or, in other words, both the Machines and the Humans. A consistent, robust and properly defined Rainbow Ecosystem will offer new possibilities of knowledge development and information usage for a very broad user base, it will enable proper maintenance of essential natural and human-generated ecosystems, and enable huge savings in many areas of effort, as well as providing novel applications and actively respond to changing economy, supply and business needs, while keeping the Global Ecosystem in natural balance. Proper and responsible cooperation between humans, machines, the environment and the nature, with the aim of freedom, security, prosperity and true betterment of life, is the only way forward.**

***Keywords* – Rainbow Ecosystem, Philosophy of Computer Science, Scientific Responsibility, Dew-Edge-Fog-Cloud Architecture**

I. INTRODUCTION

Our future is an extension of what we chose to do now. If we continue to make wrong decisions based on bad or insufficient information, our future may be an undesirable one.

Joe Nishizawa [1]

It is in human nature to be inquisitive and inventive. Thoughout the ages we tried hard to better our life, inventing a plentiful of marvelous inventions, from a roof, a wheel, a water-vessel, up to things that change our life into pure magic. Yes, as Arthur Clarke said almost fifty years ago, "*any sufficiently advanced technology is indistinguishable from magic*" [2]. Our present day world looks very much like science fiction, and sometimes even like pure fiction, from that perspective. Cars self-driving, global communicators in everyone's pocket, constantly being "glued" to touch-screens, talking aloud to nobody around on a street. Back then, some years ago, we could easily call many of today's passers by as being lunatic. And just another fifty years back, people would most probably be "scared to death" by the everyday "magic" we can order just by a touch or a voice.

And in modern days, with the all-pervasiveness of all kinds of "magical gadgets", to name them like that, independent of their real and often high usefulness, socio-psychologically we can percieve several trends. There is a high amount, specifically with the new generations, born into the connected world, of virtualisation of life, often showing a kind of "autism" towards the real life. Do those "virtual persons" actually represent the real persons, and the real-life person is just some "tamed aspect"? Then there is a high amount of fear in the general population of the possibilities of being followed, monitored, and even influenced. Unfortunately, that fear is actually a real possibility. Monitoring public spaces, knowing in which area each person's mobile phone is (this is actually technologically necessary for cell networks), many direct or indirect surveilance devices known, and many other real and unreal scenarios (like the fear that satellites can see you even inside your home, or that even when the phone is off it is possible to listen to you – some people even take batteries out) raise that fear in uneducated public. And then there is a fully grown lack of understanding of the technology presently used and pervasively introduced. The compartmentalisation of knowledge, that is in vogue throughout last hundred years, leeds to a high degree of forgetfulness, unfortunatelly even in the areas of technology we developed in last sixty

years, as with computer technology. And for the general public the gadgets "just work", the same way any magic "just works", for whatever deep reason. And then, there is also the excuse when something can not be done, as it is not provided by the computer programme (application), that "the computer does not allow this", or something in that vein. Even though it is clear to everyone that this is something which has to be possible to do – i.e. there is a lack of proper programming support. But things can not be done.

It is the role and responsibility of those who understand the technology we developed and intend to further develop to educate general population on *what is possible*, *what exists* and *how things work*. And it is the responsibility of the use of technology to allow the human to be the real judge and governor of the everyday life – extended with the use of technology, and not contracted in his freedom and action possibilities.

We are all aware of the fact that the door through which information processing diffuses into each and every aspect of not only our daily life and our human-built environment, but even of the natural environment, the Nature itself, including the planet Earth and the surrounding Space, that this door is ever widening. A huge amount of effort is presently given, all around the Globe, to furthering the development of what we commonly call "digital technology".[1] A huge amount of inspiration, thought and work is put into this revolutionary area, with the common vision of bettering our life, of expanding our possibilities and knowledge, and helping all aspects of our social and physical life.

However, this common vision of our civilisation (though not shared by all and everywhere) happened to be a spark of "beauty of future" which almost became a wildfire. The general development of new and new "Things" and "Applications" which sense and/or control all kinds of environments (physical, social, individual, collective, administrative, logistic, operational, communicational, natural) is almost completely stochastic, specifically in the sense of coordination of the vision. The wide field of Computer Science – including all its levels, from invention to pure and applied science, from hardware design to software development, from programming in all of its forms to ergonomics and general usability/appropriateness of its application – creeps with an ever faster pace into all aspects of all our environments. Or is it better to say that all aspects of all our environments almost suddenly, and, we could dare to say, unexpectedly, fell into the lap of the very young and novel Computer Science.

[1] Just as a sideline, though quite important one: the amount of terms in popular and even technical and scientific use which received aprioritised conotational fields, which by themselves do include the basic (and most important) meaning, but are percieved only by the "changed" basic connotative meaning, is constantly growing. "Digital" by itself, comming from the Latin word "digitalis", 'of or belonging to the finger', has a natural connotation of 'that which can be counted by fingers', therefore 'countable'. However, the implementation of "digitalisation of ..." could be done by anything which is not analog, i.e. by characters, clay tablets, or Quipus.

And, disregarding that ever existant, but fortunately always small, minority with "malicious intents", all the efforts are in good faith and with good intentions. However, there is an old folk proverb: "The way to Hell is paved by Good Intentions." It is quite harsh, but what it means is that not good intentions, but general wisdom shall be the way to pave a road towards Heaven. And, regarding the mentioned all-pervasiveness of Computer Science, General Wisdom is what is requested from all of us in this field of human endeavour. And General Wisdom, naturally, a-priori includes Huge Responsibility.

With this in mind, this article can be seen as a kind of initiator into a very important, but presently almost completely disregarded field of computer science – the Philosophy of Computer Science. The Philosophy of Computer Science shall be a pragmatically philosophic approach towards the whole field of that science, including all aspects of the environments in which it is applied, and specially regarding the Global Environment, as the future world our children and grandchildren will have to live in. And, naturally, as Philosophy it shall be well founded in General Philosophy, and specifically very well versed in Ethics and Ecology[2]. Generally Cybernetic principles shall be applied to the exploration of these fields.

There are three main aspects to be considered: the technological aspect, the humanistic aspect and the naturalistic aspect. We can regard them as three intertwined, heavily intercommunicating, but still apart dynamic systems.

From the techological aspect, in this moment, it is possible to envision that the next generation of the global information processing infrastructure will be built on four basic layers, or better to say, computing paradigms. So we can recognise the present day efforts in Dew Computing, Edge Computing, Fog Computing and Cloud Computing [3]. These efforts are primarily oriented towards integration of the "below the Edge of Internet" devices, found in everyday life, be they sensing, effecting or controlling, through the devices and services "on the Edge of Internet", into higher level cooperative efforts "above the Edge of Internet", raising through Fog Computing up to the Clouds, and then "raining", processed and coordinated, down to the level of "users", or again "below the Edge" towards the Dew Computing system(s) and individual Dew Droplets.

The humanistic aspect in its entirety is, unfortunatelly, extremely rarely explored. Though in all particular areas of computing the human benefit is the prime mover, generally efforts to understand the Ecology of the emerging global nature-human-machine ecosystem are rare. The beautiful paradigm explained in the previous

[2] As another example of the fact mentioned in Footnote 1, "Ecology" is a term mostly misunderstood in the vastness of its field of cybernetical exploration and global responsibility. The term comes from Greek words "οἶκος", 'house', consequently 'whole', and "λόγος", 'word', 'reason', 'discourse', in modern terms meaning "science". Therefore Ecology is actually the Science of the Whole, and as such, in its full extent, is an extremely important field regarding our future.

paragraph, looking through technological glasses, enables unprecedent possibilities of cooperation between all the "intelligent" things envisioned in the high aiming notions of Internet of Things and Internet of Everything. But is this Everything including Everyone and All Nature? How far, and for what purpose? Do we at all have any real (and humanistically realistic) idea what do we want to do with all the Things and Everything interconnected around the whole World? What do we gain with that? What do we loose? And even if we, in a fiction, connect all that in a meaningful way, are we certain that the world of Things cooperating all over the World is the world worth human living? Without being certain that the Human is the Governor, and not the governed one. Common human notions, like "ethics", "empathy", "love", "heart", "soul" "feeling" etc., are essential elements of any human life and society, irrevocably intertwined with "imagination" and "intuition" – all those philosophically, sociologically and psychologically (more or less) understood, but none of them technologically definable.

And than, yet another aspect of the use of modern technology: more and more often the amount of time necessary to "explain" to the machine what we actually need/want to accomplish (for whatever type of "explaining" the machine is designed for), if it is at all possible, far exceeds the time we would actually need to do it manually, or just by simple old-fashioned means. Just as a simple example, having a "smart home", where everything is remote controlled by touchscreen or voice, and much preprogrammed to do things as you would wish, is a beautiful experience... until your parents, keeping watch over your child, stay the whole evening in dark, as they have no idea how to command the lights to turn on. After a while comes a realisation that it is much easier to push a switch, or turn a knob on a simple thermostat. Is "digitalisation" actually always a good thing, as we like to proclaim?[3]

Finally, the naturalistic aspect, about which, except in the areas of energy consumption and sometimes polution (specifically the enormous amount of "last year's electronics" garbage), there is not much said. It is obvious that our civilisation drastically changes the natural balance of our planet. Not that we can actually harm the future existence of the planet and life on it (except if we nevertheless start a full-blown nuclear war), but we can and do make the living environment quite different for its present inhabitants, including all from viruses, bacteries, algae, insects, simple and complex plants, weed and trees, up to fishes, reptiles, birds, mammals and finally us, humans, as in a negative, so in a positive direction. Huge Responsibility is on us to try to understand where are we going with our furthering of modern day technology, and how to steer it towards better and not worse[4]. For that, we have to understand the minute homeostatic interrelationships of all living and non-living parts of the planet's ecosystem.

So, in addition to the "how"s of the so often discussed ideas about "bright future" of a specific, often isolated, field of interest, it is essential that we have a means to start exploring the "why"s: Why do we want to develop this or that? What particular, and what global benefit will it give?[5] And most important: Will our perception/wish/imagination of the "benefit" actually have positive, or negative outcomes in the Global Ecosystem, looking from a neutral viewpoint?

Well, not to give in to these bleak thoughts, let us shine a Sunray onto the field of Computer Science. Through the prisms of Clouds, through the mists of Fog and through the crystals of Dew, suddenly a Rainbow appears, colouring the space in archetipal categories.

In the following text we will try to give a possible global overview of a unified field of Computer Science and its integration into the Global Ecosystem, based on the colours of a Rainbow, and further elaborate this vast field of exploration – Rainbow Computing [4], [5].

II. The Rainbow

The Sunlight is a spectrum of different frequencies, and each of those colours has specific influence on the planet's ecosystem. In an analogy to that, we assign different colours to different segments of Computer Science, which each by itself and all together must be balanced, in a stable homeostatic and selforganising state, for the whole of our envisioned and emerging nature-human-machine ecosystem to function harmoniously. The application of Cybernetics to the existing/developing ecosystem [7], as a governing science exploring the systemic interrelations of these dynamic systems, is a must in these efforts.

The Rainbow of Computing, being both philosophical and technical in approach, necessarily includes the Nature, the Humans and the Machines. The colours of the Rainbow, as elaborated here, intend to describe the overal emerging Computer Science driven Ecosystem as an integrated living social and natural system. Within the description of each colour some future visions are given, pointing towards possible new developments, or pointing out specific weaknesses of the present approaches.

[3] Just as an example let us mention Digital television broadcast, introduced recently, generally and exclusively. The fact is that Digital television has much worse reception in areas of low signal strength and/or high interference than the previous analog broadcast, due to heavy decoding errors and freezes – did we think about it before, or is the amount of - when existant then perfect - pixels on a screen much more important than being able to follow the story transmitted? Not to mention the huge cost of refurbishing each and every previous television set – a cost imposed on everybody – to often get worse results.

[4] For example the low frequency digital sonar scanning of world oceans causes sometimes heavy nerve and other damage in whales.

[5] "We cannot sell petrol now, as our computer system crashed!", "Sorry, we can not perform your transaction, the system is down!"

III. The Colours of Computer Science

- ***Infrared*** – ***The Energy***.

  Energy Efficiency. Energy Cost/Benefit Ratio. Waste. Longevity and High Quality.

Our present civilisation is extremely energy hungry. Though some of the developments from the *green* area of environment control do promise certain energy consumption rationalisations, generally we can speek only about more energy consumption, as all of the information processing elements, in quantity deployed, presently grows exponentially [6].

A very important area of energy waste is a kind of "false pretense" of energy efficiency. Unfortunately, quite often the overal amount of energy (time, money, electricity etc.) necessary for the development and production of an "energy efficient" product surpasses the usability term of the product itself. In other words, we spend more energy on development and production (specifically the production) than the "efficient" product saves, as compared to some other previously used approach.

Other essential aspects of energy efficiency are the Longevity and High Quality. Both these aspects are presently deeply disregarded, both through perception and through intentional "lifetime management" in production.

From the viewpoint of general perception, any equipment which is older than a few years is being regarded as old and inefficient. But in many cases this may be completely wrong. Just as an example, a UNIX Workstation from mid 1980-ies can, though by comparison between consumption and processing power seemingly extremely inefficient, perfectly be a precise time-server and a web-server offering up to several hundred web page services per second. Probably many millions of web-servers all over the world never have to bear this amount of load. However, they use new or almost new computers (discarding into waste a slightly older one), which, though being even several thousand times faster in Instructions per Second, still consume mostly at least several times higher amount of energy, and, being so fast, spend most of their time idle[6]. Not to mention that the production energy cost, in all its aspects, is completely nullified after 30 years of usefulness. Do you really need that screeming fast multi-core, multi-processor, multi-gibibyte desktop computer to send and read e-mails and read and write documents? And with the ever growing "bloatware" in every necessary software package, is it really wise to buy a new and more powerful one every few years, or could you just use in peace what works well for you – even if it is "ancient", both as hardware and the appropriate software?

The second problem, the "life management" in production, more and more common in modern profit-driven economy, is something which has to be dealt with by economy and law. This aspect is closely related with waste and recycling (which by itself consumes high amounts of energy). It is quite interesting how presently economy can not imagine producing long-lasting products, and we, economically, survived quite well just a few tens of years ago, although producing High-Quality and very long-lasting products.

It is also essential to understand that the percieved cost of equipment and the actual energy costs are quite different, as in energy cost all costs – of exploration, mining, raw material processing, development, transportation, logistics, operational, administrative, and finally production and usage, including the basic environment costs for/of all people and machines involved, and the salaries (not the profits) – have to be included in the overall energy cost/benefit ratio.

- ***Red*** – ***The Root***.

  General machine architecture. Hardware and machine coding principles. Firmware. Basic operational necessities. Memory.

Though presently the computing equipment spreads in its usability from extremely small, yet quite powerful complete systems on a chip up to high-performance number-crunching or data-munching clusters, the basic hardware design principles and architectures are actually much based on historic development from the early days of computing, when many obstacles were to be overcome to get a viable computing machine at all. Consequently it is essential to rethink much of the present day hardware (and software) platforms, as many possible avenues of computer architecture have not yet been experimented with, or have been just forgotten [8], and the present day independent multicore serial processors approach, specifically due to a complete lack of proper human-oriented multi-processor/multi-computer programming principles and languages, is in many cases very inefficient. However, the quite recent development of General Programming on Graphics Processing Units shows huge advancements possible with a change of generic processing architecture.

On the other hand, the area of analog computing has been almost long forgotten. Analog and Hybrid (analog/digital) computer development stopped in the 1970-ies. The reason then was obvious – analog technology precision was well below the precision which could be achieved with digital components. However, through the extremely fast development of knowledge, inovation and technologies in analog electronic components (including extremely fast and high resolution D/A and A/D convertors, OP-amps, high speed simple components etc.), many a problem could be solved much faster, more convenient and with less power using analog computing principles hybridised with digital computers. Regarding the problems of "reprogramming" an analog computer in the early computing days, modern day FPGAs developed into FPAAs ("Field Programmable Analog Arrays") would enable huge possibilities of fast analog computing.

[6] Though the introduction of Cloud Computing partially solves the problem of under-loaded, idling computers, but only when it is practical to be used and overall cost-wise (including migration etc.) does, to the particular user(s), seem to give benefit.

Further digital hardware enhancements could be achieved by exploration of multilevel (i.e. not binary) computing hardware, which could bring an unprecedent speed-up of processing. Historically binary systems developed due to low resolution of intermediate electronic levels for exact processing. As already mentioned, huge advancements in electronic components precission easily allows present day usage of multilevel signalling, but this possibility is not yet used in computer hardware design.

Another very important area of exploration must also be long-term preservation of information. It is quite easy to see that extreme quantities of all kinds of documents (text, book, picture, video, experimental data...) presently stored on different types of materials (Tape, Hard Disk, CD, DVD, Solid State Drive...) will be extremely hard to be recovered in a span of less than 30 years from now, which is well within a human lifespan, not to think in historical or even archeological terms. Just try to recover your text written on some text editor on your Apple II 35 years ago. Or perhaps even a 5 inch floppy with a book you wrote on a PC, and now want to make a second edition. Do you have some very dear memories on a Digital 8 video, but the camera is long gone; or your valuable data CD just "forgot" everything?

- ***Orange*** – ***The Creativity Pool***.

  Stimulating Creativity. Teaching and Education. Managing Crative Ideas.

Regarding the vast possibilities new technologies offer, it is essential to adapt also the principles of teaching and to be creative in conceptualisation of novel approaches to the transfer of knowledge, from the kindergarten up to high and life-long education. Our society is getting more and more connected and dependant on computer technology in all its aspects, and only through proper civil education may we hope that the life in future will not get astray under overdependance on hardware and software devices of who knows what provenance.

The stimulation of Creativity is essential in Education, as Creativity is the main driving force of our civilisation, or better to say of all human life. But specifically we have to aim towards teaching in a way such as to present the world as an integrated Ecosystem, so that Creativity will always be oriented towards high level integrated visions and proper "why"s ("do we really need/want or even wish it to be"), and only consequently towards the "how we will do it".

The challanges posed by modern day, almost unpredictable, developments, and a future which may, or may not be what we wish for in our best dreams, necessitate huge efforts in creating creative solutions, often even to problems we ourselves introduced, almost always by ommission to "see the forrest from the trees".

- ***Yellow*** – ***The Appropriateness Filter***.

  Judging the Concrete Contribution of Some "Advancement". Judging the Global Ecosystem Balancing Effect of Some Idea.

Due to the heavy penetration of computing technologies in almost all areas of daily life and environment, and more and more all-pervading internetworking of all kinds of devices, from sensors and effectors, over vehicles to handheld mobile processing stations, health monitors etc., it becomes absolutely essential not to allow completely haphazard developments, specifically as we are also trying to introduce "artificial intelligence" (not natural!) into every-day life of much of the world population, and even much of the nature and human natural environment. Unfortunatelly, the term "artificial intelligence" means many things to many.

The terms "Internet of Things", and "Internet of Everything", and even "Cyber-Physical Systems" and "Cyber-Physical Systems of Systems" sound so catchy, great (*orange*) ideas... But do we really know what we want? Do we really want Everything (that is a lot!!!) to be internetworked by our feeble technologies? (Everything is anyway internetworked on the quantum level!)

The Appropriateness Filter must be there to test if the introduction of some "great" *orange* idea really contributes to concrete betterment of a specific field of endeavour, and does this (even betterment) enhance the overal stability and livability of the Global Ecosystem, or could that particular idea or realisation even be counterproductive or dangerous in a wider context. Although many ideas can be exciting, beautiful, or just fanciful, that does not guarantee a positive change to the civilisation, as they may be counterproductive in societal or environmental sense, where the *yellow* Appropriateness check shall be the judge.

Basically it is a philosophical, primarily ethical filter, which has to take into account a very large spectrum of humanistic and naturalistic scientific fields, considering the consequences of introduction into, and cooperation between all of the three basic levels of our emerging living ecosystem: natural, human and machine. In this area, after thorough scientific exploration, recommendations and standards, and in the most important and serious cases specific and generic laws, have to be introduced. The amount of *yellow* challanges is enormous.

- ***Green*** – ***The Nature, Environment and Health***.

  Care for General Ecosystem. Environment Monitoring and Control. Maintenance and Improvement of Health. General Well-Being, Not Only for Humans. Preservation of Natural Homeostasis.

This is the area which is most connected with our physical environment and our physical selves, incuding all kinds of small gadgets and environmental monitoring and control, be it wearable or stationary health oriented devices, or any sensors and effectors, from simple house-

bound air-conditioning to complex systems of chemical, humidity, acidity, temperature, seizmographic monitoring and control. Also early warning systems, prevention of wildfires, early earthquake warnings and other emergency scenarios, etc. Architecturally this field would primarily be the area of Dew Computing [9].

Another important application of Computer Science in this area is also the usage of computer control in agriculture on all levels – care about humidity, mineral content of soil, solarisation etc., as well as meteorological protection (e.g. hail prevention...). Carefully, ecologically aware, designed Dew Computing systems on this level would bring high benefits in high quality natural food production, and, naturally, consequently enable higher health standards of the global population.

As being the field most directly connected with the natural ecosystem, in this area special care has to be given to Ethical and Ecological concerns, as these devices directly sense and influence the physical state of human and environmental (natural) well-being.

- ***Blue – Communication***.

  Networks. Languages. Human-Machine Understanding. Knowledge Gathering.

Very often we talk about Information processing, Information Technology ("IT"), Informatisation..., using them almost as buzzwords. However, modern day development is aimed primarily towards Data. And Data is, naturally, not Information, as it lacks the context/meanining, therefore a huge amount of Data can not be generically converted into, or even regarded as, a huge amount of Information – therefore Knowledge is hard to obtain. And the communication between humans and computers and between computers themselves lacks any type of ontology, semantics or generic compatibility on the level of *what is communicated*, as well as *what is to be performed*. It is essential for the development of a future Global Information Services Environment to consistently approach this problem, effectively introducing Information Communication instead of Data Transfer, and raising the importance of High-Productivity Computing [10].

Only by introducing a consistent linguistic (semantic and syntactic) environment throughout the whole of the computing Ecosystem, that is by defining a global Ontology, and enabling Information, and not only Data, to be communicated, may we get to the point of full interoperability of computer and human based systems, where we can aim towards a Global Smart (Service) System, which would enable a large population to fully utilise the benefits of interconnectedness and computing infrastructures.

Present day human-computer communication is either based on some preprogrammed possibilities (and the general population mostly uses computer hardware and software for human-to-human communication, based on systems developed by somebody), or consists of tedious and extremely complex "programming" in "programming languages" which are, due to historical reasons, actually an upwards extension of machine code, and not a downwards definition of human language!

So actually both Computer Linguistics and Ergonomics are the main architectural elements in which a lot of development is necessary to properly cover this area, which, on the lowest level, should primarily be covered by Fog Computing [11]. Communication for specific functionality should be recognised by information filtering, and only messages of that information field shall be transferred to proper other devices, services or memories. This is, naturally, achievable only if the information context of transferred data is ontologically known.

- ***Indigo – Cooperation and Etics***.

  Ethical Cooperation. High Level Services. Complex Interactions. Collection of Huge Quantities of Information. Information Usage, Storage, Processing.

Extremely important in this area is the philosophical architecture and definition of Scientific Conscience through carefully developed Ethical principles, both in the exchange and usage of collected Information, and the prevention of future possible problems regarding unwanted and undesirable usage of computing technology.

Technologically on the architectural plan this would mostly be the area of Cloud Computing [12], as integrated in the Dew-Fog-Cloud ecosystem. Therefore it is important to implement Ethical and Cooperative principles throughout the effective Computing Hierarchy.

It is important to note that present day ad-hoc development and usage of the world's computing and communication pool is very inefficient, and that a search for Information and usage of Services is often a trial and error excercise for the human user. A consistent (*blue*) ontology with introduction of a generic semantic and syntactic linguistical ecosystem would start giving solutions for both the overcrowdedness of the present day data-space (by converting it into infomation-space), and the definition of behaviour rules (which can be embedded into the linguistical ecosystem itself).

Another aspect of future Computer Science development in this area will be the necessary "pruning" of redundancy, and definition of long term safe redundancy levels of information storage and knowledge preservation important to our civilisation.

- ***Violet – Interference, Optics, Quanta***.

  Protection and Expansion. Possible Technological Evolution. Non-intentional Human-Computer Interaction.

The dependence of our civilisation on computers and networks, on electrical and electronic devices of all kinds and provenances, is so huge that even short lasting disruptions of energy distribution, communication and processing systems can lead to unpredictable and most possibly unprecedent consequences, accross the spectrum

of the whole of human endeavour and everyday life, even including the balanced state of our natural environment. But we are all aware of the fact that our electronic equipment is very suspectable to failure, be it due electric or electromagnetic failures, discharges or just caused by quantum fluctuations in the unpredictability of interdependent timings and individual component behaviour tolerances.

A one sentence horror-fiction story will probably point towards the direction of our growing life-dependance on technological gadgets: "*One bright sunny day (although somewhere it was still night) all the mobile phones in the world decided to make collective suicide – they couldn't bear any more the amount of blabber they had to receive and transmit.*"

The modern day devices suspectability to failure is a constant threat to the whole of our society and environment, as our overgrown dependence on electrical systems, computer systems, wireless and satelite communications, being in the foundations of our social, political and everyday life, opens widely the doors to heavy general disruptions and disasters in the case of heavier blackouts (or even brownouts) of whatever technology based service or control. On the lowest survival level it is a simple fact that most homes do not even have candles or any non-technological means of heating.

And we just like to forget that our Sun regularly errupts huge storms of plasma, which, if "aimed" towards Earth regularly make large electromagnetic and electric storms in our atmosphere, which can regularly overload electric transmission lines, and, if very strong, can be directly harmful to solid state electronics of our devices. Our satelites are also generally very suspectable to malfunction in such conditions. Just as an example, a single lightning recently "killed" all modems, television sets, some amplifiers and video projectors (and probably some other equipment) in one street in Zagreb, Croatia, causing much irreparable damage and severely disrupting daily life until all equipment was replaced with new one. A global scientific view and important recomendations have to be developed in this field.

An area of important future research is also Inteference processing (let us ponder on animal echolocation – the frequency of sound emitted and the delays in return waves are extremely short versus reaction frequency of neurons)[7]. Interference processing, i.e. coding, processing and extracting information based on interference of information streams, may lead to new breakthroughs.

Presently we use optical components primarily for communication purposes. However, optical interference and spectral manipulation open up completely new possibilities, as both can be used for signal/data/information processing. To extend the analogy of a Rainbow, in interference and spectral manipulation computing very precise colour-coded ontological meta-data can be transferred by coding into specific light frequencies[8].

Future developments of Quantum computers may try to go into more "analog computing" avenues. For example the usage of quantum states based on Analog computing principles (i.e. not as Qubits, but as Qudigits, or perhaps even Qus).

An interesting and totally unexplored area is the energy/quantum level interference/interaction between humans and digital devices, as well as between different internal and external (communicational) computing device processes. Presently the amount of different processing tasks on any programmable device, programmed by different people and different societies or companies, is such that it is impossible to know what all is actually going on (being processed) on your device (specifically as many elements of the vast diversity of processes are so called "intellectual property", i.e. closed to general knowledge).

Consequently modern day technology users experience regularly "misbehaviour" of their devices, particularly when they are in a bad mood, nervous or angry. Although this area may seem to be from "the edge of science", it is very important to note that this type of "miscommunication" between humans and machines often causes serious stress for the human user, and it is Ergonomically essential to explore this area and find solutions to a smoother and less stressful computing based communication environment.

- ***Ultraviolet – The Visions***.

  Wisdom. Responsibility. Holistic Approach.

There are many Visions of the Future. And they are all different, depending on the person, the standpoint, even on religious views; depending on the field of interest and on the level of knowledge. And much on wishes.

Computer Science came to the point that it can not any more ignore global development visions of an integrated nature-human-machine supra-system, or, better to say, ecosystem, but it has to find courage, strength and means to properly, wisely and responsibly envision and embody a human-oriented resilient ethical, philosophical, ontological and architectural system of the future nature/human/machine civilisation, at least adaptable and harmless enough to enable future freedom of life, exploration, inovation and development, without harm to the humans and the natural balance of our planet and its surroundings.

And as ultraviolet light from our Sun is essential for the life on earth – so it may also be extremely harmful. The same applies to Visions, if not governed by Wisdom, Responsibility and Holistic Approaches.

[7] An example of the usage of inteference processing applied to reception phase detection, actually inspired by pondering on Bat echolocation, can be found in [13].

[8] As an example of a colour-spectrum based generic ontology of human endeavours (or life, if you prefer), see e.g. [14]. Such generic colour-coded categorisation may be very useful in information processing.

IV. Conlusion

The present article discusses the vast field of Computer Science primarily from a philosophical and pragmatical standpoint, by proposing a Rainbow-colour based cybernetic ecosystem encompassing nature, humans and human-built machines. Though the intention of this article was not to present principles and paradigms for forming a usable Information-processing Architecture, i.e. communication organisation, protocols, interlayer (inter-colour) coordination, interrelationships between various scientific fields and their proper connections throughout the spectrum etc., it is a viable and important idea to develop such a paradigm, principles and full Architecture, which could integrate many presently very discordant developments in a scientifically driven common responsible visionary effort.

The present day developments in the integration of Dew-Edge-Fog-Cloud layers, specifically in the emerging field of Dew Computing, can be regarded as first little steps on the (hopefully) proper path towards Rainbow Computing - integrating Computing into the Global Ecosystem.

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Visual modelling of WS-BPEL processes using BPMN standard

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Abstract - WS-BPEL (Web Service Business Process Execution Language) standard focuses on Web Services integration into units called processes which can contain quite complex behaviour, like loops, condition executions, parallel and synchronized behaviour, event-driven behaviour, behaviour for undoing already completed work, termination behaviour, variable manipulation and so on. Since, there are many constructs offered by WS-BPEL standard, their combination in business process design can result in quite complex behaviour which can be hard to design correctly when working directly in WS-BPEL XML syntax. Thus, there is a need for visual notation to visually design WS-BPEL processes and transform them into executable WS-BPEL XML code. Standard, proposed for visual design of WS-BPEL processes in this article, is BPMN (Business Process Modelling Notation) standard which offers a rich set of visual constructs and it is also based on XML notation in the background. The first part of the article focuses on defining pairs of constructs that are mapped between BPMN and WS-BPEL standard while the second part of the article focuses on algorithms of bidirectional translation between paired constructs of the two standards.

Keyword – WS-BPEL processes, BPMN modelling, visual modelling of WS-BPEL processes, BPMN to WS-BPEL transformation

I. INTRODUCTION

WS-BPEL [1] [1] (Web Service Business Process Execution Language) standard is based on XML notation and it is used for integration of Web services (called partners) into executions called BPEL processes that are further exposed as standalone Web services to the outer world. There are many constructs offered by BPEL standard and some of those are: constructs for communication with partners, variable manipulation constructs, constructs whose execution is based upon conditions, repeatably executed constructs, constructs for parallel and synchronized execution, constructs for event handling, constructs for error handling, constructs for compensation of a previously successfully completed work and so on.

Combination of constructs offered by BPEL can lead to quite complex designs of BPEL processes. Direct modelling using XML syntax can be quite challenging and not quite user-friendly task resulting in unwanted definition of BPEL processes. XML syntax does not offer quite good visual understanding of order of executions of BPEL constructs which results in a need to define visual paradigm for BPEL process design and later transformation of visual models into executable BPEL processes.

Standard proposed for visual modelling of BPEL processes in this paper is BPMN (Business Process Modelling Notation) standard which is also based on XML notation in the background. It offers a rich set of visual constructs which have their associated XML elements defined in the BPMN Schema.

This paper is focused on phases of visual design of BPEL processes. The paper is organized as follows. Section II represents overview of the existing work in the field of visual modelling of BPEL processes. Section III introduces BPMN fragments of executions that are used to visually represent corresponding BPMN constructs. Section IV introduces algorithms for transformation of BPMN executions into BPEL processes and backwards. Section V introduces implementation of bidirectional BPMN-BPEL algorithm presented in section IV. Section VI concludes the paper.

II. EXISTING WORK IN VISUAL BPEL MODELLING

When considering work of other authors in this area, authors in [3] used their own language *bliteC* that is used to facilitate BPEL process development and their *bliteC* models are later transformed into executable BPEL processes. In [4][5] authors have focused on models developed in UML language that are transformed into BPEL processes. In [6] authors have presented their way of presenting BPEL processes using BPMN notation, while in [7] authors have systematically analysed existing work in BPMN-BPEL transformation process, and they have concluded that there is a gap between the nature of BPMN and BPEL standards in general. In [8] authors have focused on identification of workflow patterns and on possibilities of their transformation into BPEL executable processes.

III. VISUAL MODELLING OF BPEL PROCESSES

As already mentioned in this article BPMN standard is proposed for visual modelling of BPEL processes. This section introduces BPMN elements that are used to visually represent their corresponding BPEL activities.

[1] in further text BPEL

Mappings between BPMN visual elements and corresponding BPEL elements is not necessarily one on one but sequence of BPMN elements can be used to visually represent one single BPEL activity. BPMN is based on XML syntax in the background just like BPEL standard so it is necessary to know XML *Schema* definitions of both standards in order to define proper transformations of XML fragments of the two standards. This section describes constructs offered by BPMN standard and afterwards it defines mappings between BPMN executions and BPEL activities on visual and XML level.

A. BPMN-BPEL mappings

BPMN graphs are based on BPMN elements connected using *sequenceFlow* elements while BPEL graphs are based on BPEL activities contained one inside of the other, i.e. BPMN graphs are flow based whilst BPEL graphs are block based. Different connection mechanisms form a gap between BPMN and BPEL graphs which must be overlapped when transforming from one to another. Figure 1 describes connection mechanisms of the two standards.

Mappings between BPMN and BPEL elements will be explained through categories of BPEL elements and it will be accompanied by figures.

The first category of BPEL elements are those for communication with services, ie. partners. The BPEL *invoke* activity, used for invoking operations exposed by partners, can be visually displayed using the BPMN *sendTask* element or by combination of the BPMN *throwEvent* (*messageEventDefinition*) element followed by the BPMN *catchEvent* (*messageEventDefinition*) element. Analogously, the BPEL *reply* activity, used for sending a reply to a previously invoked operation of a BPEL process, can be visually displayed using the BPMN *sendTask* or *throwEvent* elements. The BPEL *receive* activity, used for receiving partner's invocation of an operation exposed by a BPEL process, can be visually displayed using the *receiveTask* element. Generally, the BPMN *sendTask* and the *throwEvent* (*messageEventDefinition*) elements are used to visually represent activities for sending messages outside of the BPMN flow, whilst the BPMN *catchEvent* (*messageEventDefinition*) element is used for receiving messages into the BPMN flow which is visually represented using *dataAssociations* connecting sending/receiving BPMN elements with *dataObjectReference* elements. BPMN *dataObjectReference* elements are used to visually represent concrete usage of BPMN *dataObject* elements which are used for representing BPEL variables. The BPMN *interface* elements and *operations* contained inside of them are used to represent WSDL *portType* elements and contained *operations* inside of them.

The BPEL *pick* activity is used for executing contained activities after occurrence of exactly one of the possible events which can be either reception of the message or time event (exceeded time duration or reaching a specific time point). In BPMN graphs, the BPEL *pick* activity can be represented by executions nested between the *diverging eventBasedGateway* and the *converging exclusiveGateway* elements.

BPEL structured activities are used for controlling executions inside of BPEL graphs. The BPEL *if* activity is used for expressing conditional execution. Branches of the BPEL *if* activity in BPMN graphs can be expressed by executions nested between the *diverging and converging exclusiveGateway* elements.

The BPEL *while* and the *repeatUntil* activities, used for expressing repeated actions while condition is true, can be presented using the BPMN *subProcess* element containing the *standardLoopCharacteristics* element for expressing an evaluation condition. The BPMN *subProcess* element can also be used for displaying of the BPEL *forEach* activity. When used in this context, it contains the *multiInstanceLoopCharacteristicsElement* for expressing the behaviour of the *forEach* activity. The BPMN *subProcess* element can generally be used for visual displaying of the BPEL *scope* activities as well because it can contain private *dataObject* elements and executions like the BPEL *scope* activity. Since the BPEL *scope* activity can have attached *handlers* (*onMessage* and *onAlarm eventHandlers*, *compensationHandlers* and

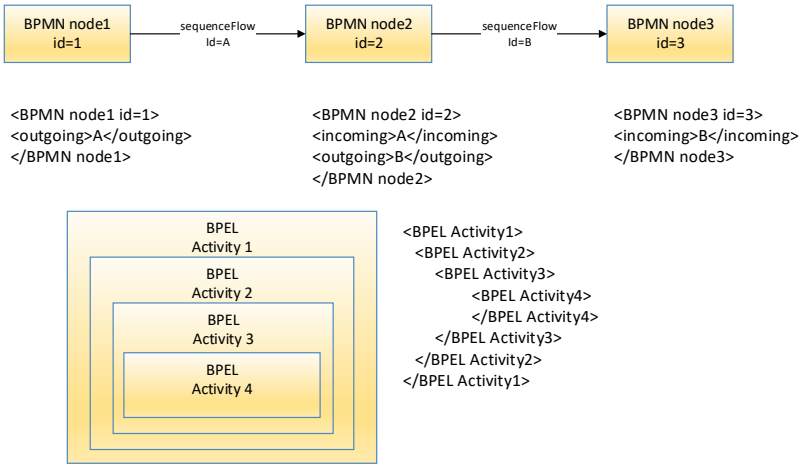

Figure 1. Connection mechanisms in BPMN and BPEL graphs centriran u stupcu

errorHandlers), they can be visually displayed inside of the BPEL *subProcess* using the contained inline *eventSubProcess* where the type of the *startEvent* of the inline *eventSubProcess* determines which BPEL handler is presented (Figure 2).

The BPEL *assign* activity, used for variable manipulation, can be presented using the BPMN *task* activity with associated *dataAssociation* elements that connect the *task* activity with the *dataObject* elements.

The BPEL *flow* activity is used for parallel and synchronized behaviour of contained executions. Synchronized behaviour is implemented using the *links* mechanism. Two synchronized activities are connected using the *link* where *transitionCondition* of the l*ink* is evaluated after the source activity is completed and its evaluation determines the status of the link. *JoinCondition* of the *link* is executed before the target activity is started and after statuses of all incoming *links* are known. Its evaluation determines if the target activity will be evaluated or not. False status, as a result of *joinCondition* evaluation, can be propagated or suppressed which depends on *suppressJoinFailure* attribute of the target activity. Possible synchronization scenarios inside of the BPEL *flow* activity and their BPMN representations are the following:

- more than one incoming link into the source activity – the BPMN *parallelGateway* precedes the source activity in order to wait for the statuses of all the incoming *links* to be known and it is followed by the *exclusiveGateway* in order to split cases of the *joinCondition* evaluation (true/false),
- *suppressJoinFailure* set to yes - from the preceding *exclusiveGateway* there is an alternative path that leads to the *assign* activity that sets the outgoing *links* statuses to false,
- *suppressJoinFailure* set to no – from the preceding *exclusiveGateway* there is an alternative path that leads to the error *endEvent* that raises the *joinFailure* error,
- more than one outgoing *link* from the source activity – after the BPMN *exclusiveGateway*, that is placed behind the source activity (which waits for the detection of statuses of the outgoing *links*: true or false), there is the *parallelGateway* with outgoing paths for every outgoing *link* from the source activity.

Figure 3 shows the possible described synchronization scenarios inside of the BPEL *flow* activity visually displayed in BPMN. Figure 4 displays all visual BPMN executions used for visualizations of BPEL activities described in section II.

IV. BPMN-BPEL TRANSFORMATION ALGORITHMS

Section II described defined mappings between BPMN executions and BPEL activities. Since both standards are XML based, it is possible to define algorithms for pattern recognition inside of BPMN and BPEL graphs and for bidirectional transformation between the two graphs. This section describes proposed algorithms for bidirectional transformation between BPMN and BPEL graphs.

All elements of BPMN XML graphs are organized according to the following structure:

- <definitions>root-level-elements
  <process>process-level-elements</process>
  </definitions>,

while all elements of BPEL XML graphs are organized according to the following structure:

- <process>root-level-elements
  <sequence>process-level-elements</sequence>
  </process>.

As already stated in section II, BPMN elements are connected using the *sequenceFlow* elements, whilst BPEL elements are contained one inside of the other. Examples of the connection mechanisms inside of the two graphs are:

- <BPMN-element1 id=”el1”>
  <outgoing>1</outgoing>
  </BPMN-element1>

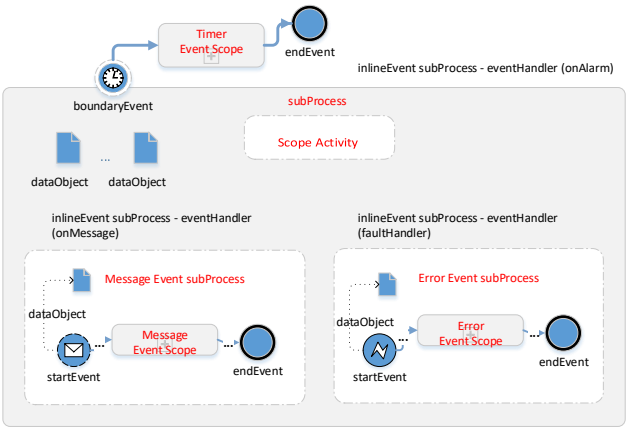

Figure 2. BPEL Scope with attached onMessage, onAlarm and errorHandler handlers visually presented using BPMN subProcess

<sequenceFlow id="1"
sourceRef="el1" targetRef="el2">
</sequenceFlow>

<BPMN-element2 id="el2">
<incoming>1</incoming>
</BPMN-element2>,

- <BPEL-element1>
<BPEL-element2></BPEL-element2>
</BPEL-element1>.

Sample connection mechanisms are visually displayed in Figure 1.

When transformation algorithms is executed in the direction from BPMN into BPEL, it is necessary to find start BPMN elements that visually represent start BPEL activities and those are elements that do not have incoming *sequenceFlows* and visually represent start BPEL activities (the BPEL *receive* activity or the BPEL *pick* activity with the *instantiate* attribute set to "yes"). Section II has shown the way the BPEL *pick* activity and the *receive* activity can be presented in BPMN graphs.

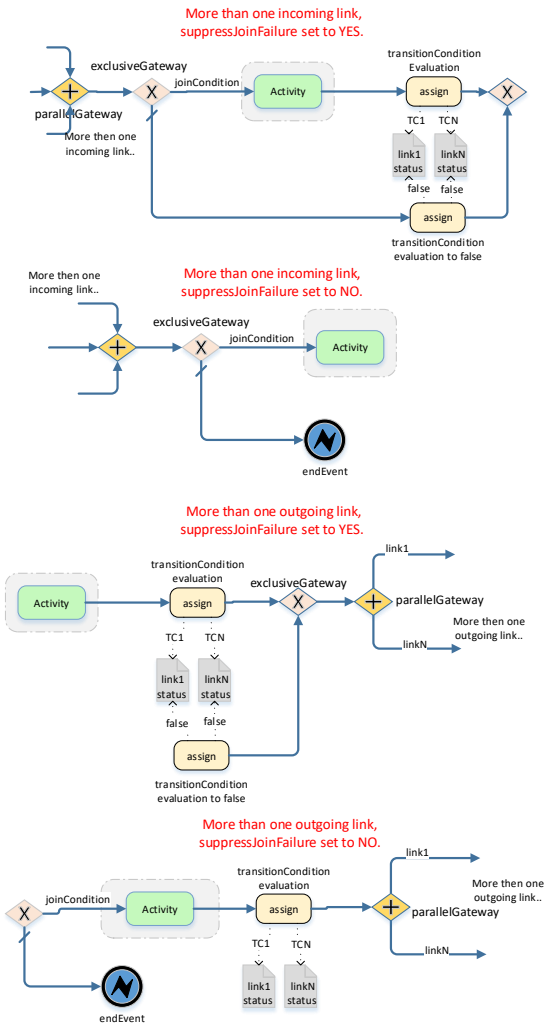

Figure 3. BPEL flow synchronizations inside of BPMN

When the *receive* activity is a start activity, it can additionally be presented using the *startEvent* node (*messageEventDefinition*).

After start BPMN nodes are found and translated into the start BPEL activity *receive* or *pick*, which is placed into the main BPEL *sequence* activity, the outgoing *sequenceFlow* from the start BPMN element is remembered in order to find the next BPMN element that is connected to it. When the next BPMN element is found, and it, or the BPMN execution starting with it, is transformed into the appropriate BPEL activity, the *sequenceFlow* leaving transformed BPMN execution is remembered. The process is repeated until the last visual activity is found, ie. BPMN element that has no outgoing *sequenceFlow* elements. Figure 5 shows the steps of the BPMN-BPEL transformation process. After the start BPMN element is transformed into the first child of the BPEL sequence activity, the *sequenceFlow* (id "1") is remembered. The second step is transformation of the BPMN execution (A and B) into the corresponding BPEL

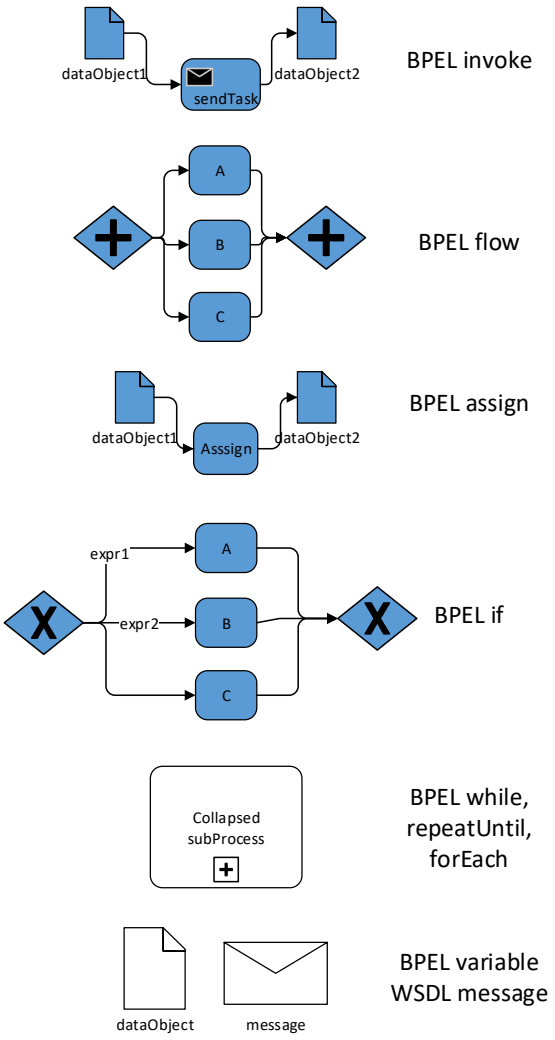

Figure 4. BPMN executions and corresponding BPEL activities

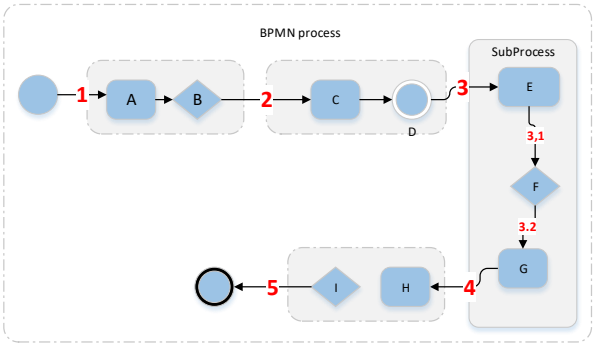

Figure 5. Steps of BPMN graph processing

activity and the *sequenceFlow* (id "2") is remembered until the last BPMN element is reached that has no outgoing *sequenceFlow* elements.

When transformation is performed from BPEL into BPMN, the starting activity is the main *sequence* activity. Algorithm traverses through the children of the main *sequence* activity in the descending order in which they appear in the main *sequence* activity.

When the first child of the main sequence activity is found, it is transformed into the starting BPMN element that does not have any incoming *sequenceFlow* elements.

Upon every generation of the BPMN execution from the corresponding BPEL activity, the *sequenceFlow* that is leaving the last generated BPMN element, is remembered in order to connect it to the next generated BPMN element. The process is repeated until all children of the main BPEL *sequence* activity are traversed and transformed into the corresponding BPMN executions. The analogous process is performed when transforming contents of the other BPEL activities, not just the BPEL activities contained in the main BPEL *sequence* activity.

The trickiest part of transformation between BPMN and BPEL is the process of generating BPEL *if* and *pick* activities since they can contain other BPEL *if* and *pick* activities nested to the arbitrary depth so the algorithm must be designed to enable detection of nesting to the arbitrary depth (Figure 6).

V. BPMN-BPEL ALGORITHM IMPLEMENTATION

BPMN-BPEL transformation algorithm can be implemented using any language that possesses constructs for XML manipulation: accessing and creating XML elements and attributes. Concrete authors' implementation of the presented transformation algorithm was realized using .NET programming language C# and Microsoft XML LINQ (Language-Integrated Query) technology for XML documents manipulation.

Mapping rules defined in section III present information that were used for recognizing the last found element in the input graph and for generating the new element in the output graph. Pattern recognition according to the defined rules was implemented programmatically while fetching the elements from the input graph and generating the elements in the output graph was implemented using XML LINQ technology. Steps of the

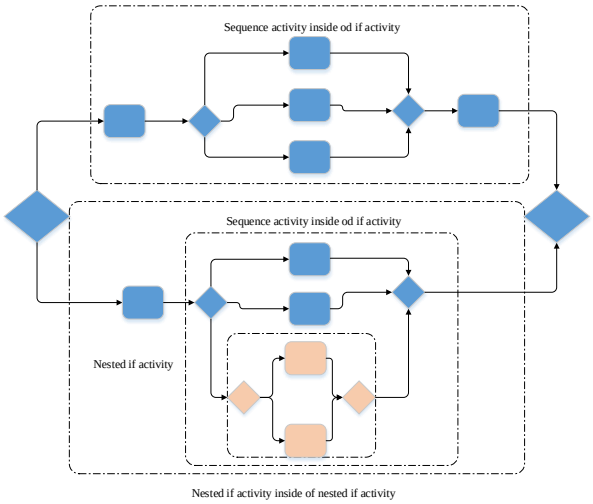

Figure 6. Nested BPEL if activities inside of BPMN graph

algorithm were implemented according to the ones presented in section IV.

Automatic recognition of BPMN executions that visually represent possible synchronized behaviour inside of the BPMN *flow* activity is due to complexity not currently implemented but it will be considered for implementation in the future.

VI. CONCLUSION

This paper has introduced concepts of visual modelling of BPEL processes using BPMN standard. It has given a proposal of BPMN visual executions that can be mapped to the corresponding BPEL activities and an overview of transformation algorithms where the main gap, that must be overcome, is the difference between connection mechanism of elements inside of BPMN and BPEL graphs. The paper has not described details of transformation algorithms but rather concept of its functioning. Special difficulty of the transformation, that is identified in the paper, is transformation of nested BPEL *if* and *pick* activities but the details of algorithm that implements it is not described due to its complexity and space problem.

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Algorithms for procedural generation and display of trees

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***Abstract* – Main goal of this paper is to explore in which situations should some procedural algorithm be used to generate a tree model. Each algorithm is modified so as to be able to generate a tree model whose shape resembles the required model. Space colonization algorithm, algorithm using particle flows and algorithm simulating a Lindenmayer system are compared depending on a time needed to generate a tree with similar complexity. The voxelization procedure of the model and its application in this context is explained. Method for generating a tree mesh on a graphics card using Bézier's curves is presented.**

Keywords – tree; procedural generation; space colonization; L-system; particle flow; voxelization; Bézier curve

I. INTRODUCTION

Modelling and animating trees for movies, computer games and simulations are labour intensive work. Trees are most commonly represented as static objects with minimal interaction with its surroundings. Main reason is the sheer complexity of organic trees. Fully grown *common oak* can exceed the height of 40m and have more than 100,000 branches.

There are many commercially available tools which can help with modelling the tree, but the process is still time-consuming. Procedural algorithms can mitigate the time needed to create a desired tree model.

In this paper we have compared 3 algorithms. Every algorithm as an input gets voxelized model and as an output produces same abstract tree data structure. This data structure is further passed to graphics card which creates a mesh for every branch.

Procedural algorithms to some extent try to simulate the real growth of a tree, but as there are many unknown variables, it is hard to capture the real world. We have chosen to compare space colonisation algorithm, algorithm using particle flow and algorithm simulating a Lindenmayer system. Each one takes a different approach to the same problem. Space colonisation simulates a competition for space. Particle flow algorithm exploits similarities between branching structures in trees and trajectories of particle simulations. L-system focuses mainly on rules at which branching happens.

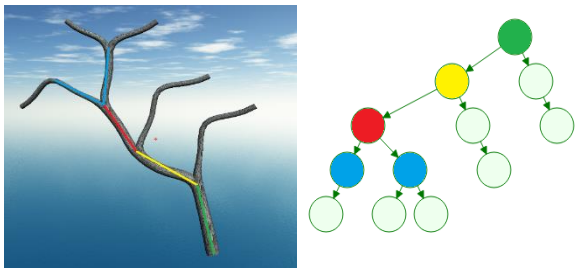

Figure 1. Rendered tree and its abstract tree structure

II. METHOD

In this section we will present the process of constructing a procedurally grown tree. Every algorithm is parametrized with a desired tree-crown size and voxelized model which we want to imitate.

Most common operation while generating a tree model with a desired shape is a test if some point is inside the model. While polygonal models for that operation have linear time complexity proportional to the size of a model, voxelized models have a constant time complexity. Main disadvantage of using voxelized models is a loss of precision, but with using 256^3 voxels and trees having irregular form there was no noticeable difference in a generated tree.

Models are voxelized with a variation of an algorithm using ray casting presented in a [1] and is described in the next section. Since the process of voxelization didn't take longer than a few seconds at the start of a program, there was no need for using a faster voxelization algorithm, like one presented in [2].

Every tree generator produces a tree data structure as demonstrated on a figure (1). From the perspective of a red branch, blue branch is its child, yellow branch is its parent, and green branch is its grandparent. Each node in a tree data structure stores its length and relative rotation to its parent branch. Main advantage with using abstract representation is that it reduces data that needs to be transferred to graphics card.

Abstract tree structure is converted on a graphics card to a mesh which is further rendered in a OpenGL graphics pipeline. This process is described in section VIII.

III. VOXELIZATION

To generate a voxelized model, we test if a centre point of each voxel is inside a model. Point is inside a model if the ray casted from the point intersects odd number of polygons, or in our case triangles. The ray we cast is always parallel to the Z-axis. That way, in the same time, we can test multiple voxels in the same column if they are inside a model. To speed up the algorithm, we project all polygons on a XY-plane and test which polygons affect which columns.

$$a_1X_1 + a_2X_2 + a_3X_3 = X$$
$$a_1 + a_2 + a_3 = 1 \quad (1)$$

Barycentric coordinates a_1, a_2, a_3 are defined by the linear equations (1) described in a [3] where X_i are vertices of a triangle and X is a position of a point. Column of voxels is intersecting a triangle if its barycentric coordinates satisfy $0 \leq a_i \leq 1, i = 1, \dots, 3$ condition. List of all affecting polygons is created for each column. Those lists are sorted by the height at which polygons intersect the column. That way, it is faster to count the number of intersected polygons for each voxel in a column.

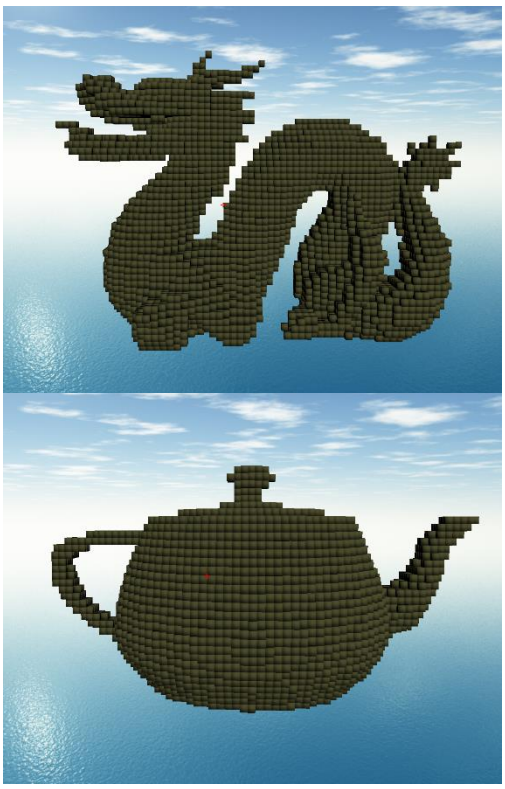

Figure 2. Voxelized models of the Stanford dragon and the Utah teapot

IV. SPACE COLONISATION ALGORITHM

Space colonisation algorithm has been introduced in a [4]. It was further expanded to 3D in [5] and used to construct a model of a tree. Algorithm has potential for other applications in different fields as presented in the [6] for creating a road network of a town and in the [7] for simulation of crowd dynamics. Algorithm is separated in two stages. Firstly, the model is filled with attraction points, then the algorithm creating branches is iteratively executed. Space defined by voxelized model is filled with attraction points. We have implemented linear distribution of attraction points in a voxelized model, but it is possible for example to arrange attraction points so that they are near the surface of a desired model. Resulting model would then have more branches near the surface.

We have implemented a variation of the space colonization algorithm using octree data structure presented in a [8], which has a complexity of an $O(m * n * \log(p))$, where n is number of iterations, m is number of finished branches and p is number of attraction points.

Every iteration consists of finding all attraction points close to every generated branch. Those attraction points are then written in a list for that branch. At the end of an iteration, new branches are created with the formula (2), where $\vec{n}$ is a vector representing a direction of a new branch, s is position of a current attraction point, v is the end position of current branch and S is a set of all attraction points affecting current branch.

$$\vec{n} = \sum_{s}^{S} \frac{s - v}{||s - v||} \quad (2)$$

$$l_b = l_{min} + \frac{l_{max} - l_{min}}{1 + e^{depth-10}} \quad (3)$$

Length of a branch directly affects the complexity of a generated tree, because smaller branches need more iterations to cross the same distance. Length of a new branch is calculated according to formula (3). l_{max} and l_{min} represent maximum and minimum desired length of a branch in a tree. Depth of a branch is the number of edges between a root branch and current branch in the abstract tree structure and is represented by variable $depth$.

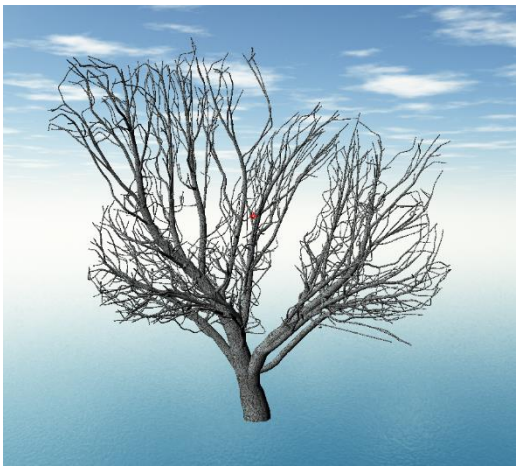

Figure 3. Stanford dragon created with space colonisation algorithm

V. ALGORITHM USING PARTICLE FLOW

We have implemented a variation of algorithm presented in [9]. It has been used in a [10] to generate trees that are imitating the branching structure from a photograph of a tree. By using image recognition and the help of human it is possible to generate a vector field which navigates particles so that their trajectories imitate a tree. Our implementation does not use vector fields and only forces that affect particles are global gravitational force and attraction forces between particles.

Algorithm using particle flow is also separated in two stages. Firstly, the space defined by the voxelized model is randomly filled with particles, then the positions of particles are iteratively calculated based on their last positions, masses and forces that affect them. Branches are constructed from trajectories that particles have passed through. New branch is created when the particle has passed minimum distance from the last created branch. Particles that are close enough are merged together and branches created by their trajectories are also merged.

$$\vec{F_i} = \sum_{j}^{N} k * m_i * m_j * \frac{x_j - x_i}{\|x_j - x_i\|^2} \quad (4)$$

Force on each particle is calculated with formula (4). Every particle affects every other particle with force proportional to their masses (m_i, m_j) and inversely proportional to their distance. Constant k is affecting overall force between particles. Positions of currently observed particles are x_i and x_j.

New velocities and positions of particles are calculated by the semi-implicit Euler method:

$$v_i = v_{i-1} + \Delta t * \frac{\vec{F_i}}{m_i} \quad (5)$$

$$\mathrm{x_i} = x_{i-1} + \Delta t * v_i$$

For simulation, it is necessary to define a Δt time step so that it is precise and fast enough. We chose 10ms as a step for generating a tree model.

When merging particles, it is possible to choose different combinations of particles which will be merged together. Greedy approach for every particle finds all particles that are close enough and instantly merges them. That approach introduces randomness in constructing a tree model, which suits the nature of the algorithm. Formulas (6) are used for merging particles in a bigger particle. Heavier particles influence more on a final position and velocity of a new particle. Variables $x, \vec{v}$ and m define position, velocity and mass of a new particle, while $x_i, \vec{v_i}$ and m_i define position, velocity and mass for merging particles.

$$x = \frac{\sum m_i * x_i}{\sum m_i}$$

$$\vec{v} = \frac{\sum m_i * \vec{v_i}}{\sum m_i} \quad (6)$$

$$m = \sum m_i * \vec{v_i}$$

VI. ALGORITHM SIMULATING A LINDENMAYER SYSTEM

Lindenmayer system is a type of a formal grammar which is suitable for describing fractal patterns in plants. It has been in use from 1968 and has been thoroughly studied and described in [11]. Visualized results obtained by L-systems convincingly simulate plants.

Like all formal grammars, L-system has a list of symbols V, starting symbol ω and production rules P. List of symbols can contain final symbols which cannot be further expanded. L-system is executed iteratively, and in every iteration, all active symbols are replaced with new symbols, with the help of a production rules. Result of executing a L-system is a list of symbols.

We have simulated the process of generating a tree by L-system. Algorithm can be executed until desired number of branches or iterations has been reached. Every symbol represents a branch in an abstract tree structure.

Every branch that doesn't have children are considered as an active branch. In every iteration one active branch is chosen which will produce its children. Number of children are calculated by the exponential distribution:

$$p(x|\lambda) = \lambda e^{-\lambda x} \quad (7)$$

Direction of growth for a new branch is calculated by addition of a random vector to the direction of growth of a parent branch. That way new branches are created without unnatural twists. If the direction of growth of a parent branch is parallel to the y-axis then figure (4) represents probability distribution of a new direction of a growth. Red colour represents most probable direction, and blue colour represents least probable direction. Newly created child branch is accepted to be active branch if it is inside the voxelized model.

Variations can be made to the algorithm by using different distributions for number of children, different distributions for direction of growth and different order in which active branches are selected for producing children.

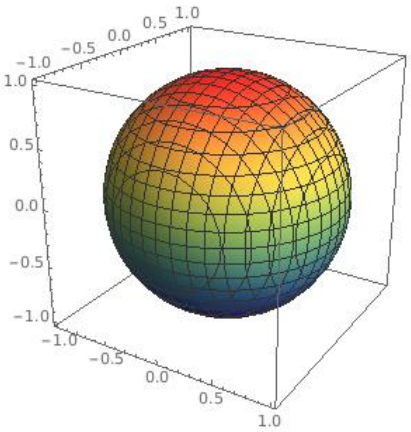

Figure 4. Probability distribution of a new branch direction

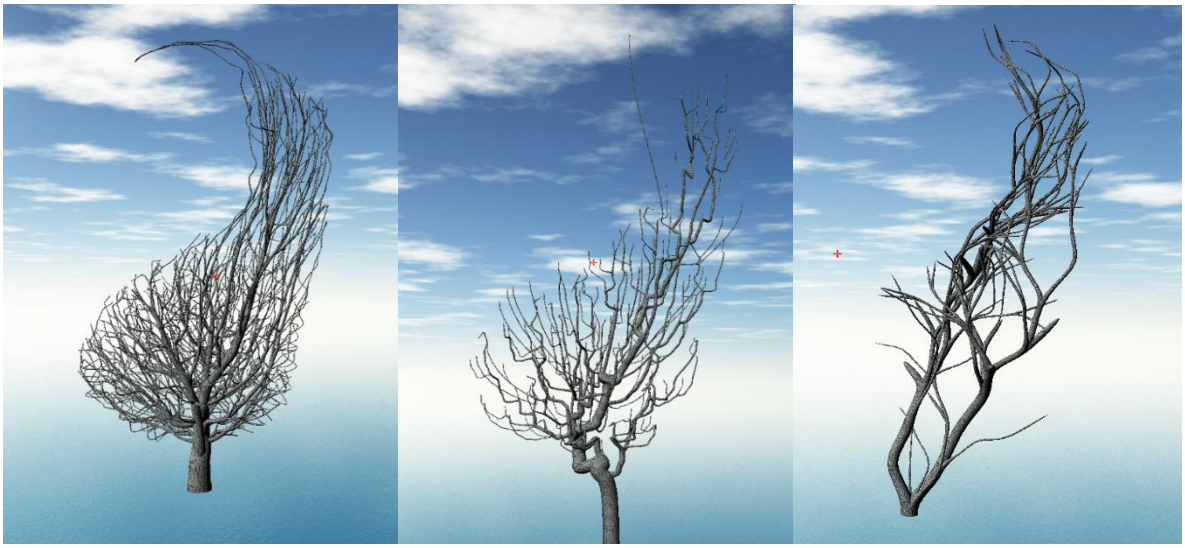

Figure 5. Resulting trees created with algorithms: space colonisation, particle flow and L-systems

VII. COMPARISON OF ALGORITHMS AND RESULTS

All three algorithms are successfully filling desired shapes and producing satisfying branching structures. Both space colonisation and particle flow algorithms can generate a tree structure that is not necessarily fully inside a desired model, but that problem can be solved by pruning the undesired branches.

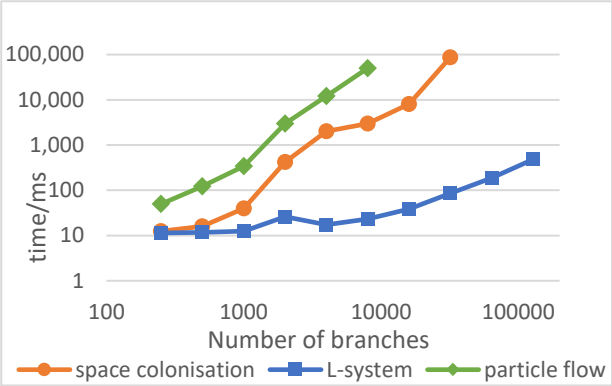

Figure 6. Time needed to create a desired number of branches

Figure (6) compares algorithms based on a speed at which they can create branches in a single tree. Both axes are on a logarithmic scale. Algorithms were tested on a single core of an AMD Ryzen 5 2400G with a clock rate of 3,6GHz.

Main advantage of using the L-system algorithm is its speed. It is possible to create many trees and branches in a short period of time, which is very useful for programs like flight simulator, where trees may need to be created in a real time. Algorithm is fast mainly because it doesn't care about already created branches. It has been recently used in a [12] with combination of adaptive level of detail algorithm to generate a forest in a short period of time. Another advantage is that it is easy to implement new rules which trees or other plants follow. L-system does not follow as good as other two algorithms a model we want to imitate with a tree, so it is not suitable for that task.

Main reason that particle flow is slower than other two algorithms is that it needs more iterations to generate a single branch. If time step in iteration is increased, then the simulation would not be precise enough and branches would pass more often one through another not detecting each other's presence. In comparison to space generation it can produce less intersections of branches.

Negative aspect of using particle flow is that it is hard to implement a new set of rules that would produce different types of trees. It has many parameters that need to be fine-tuned to get a satisfying result. Furthermore, as branches are created from leaves to the trunk, it is hard to predict on what depth will the branch be. That information would be useful to produce branches of different lengths depending on the position to other branches. Branches can be created after the simulation is over by storing data about every trajectory, but that way algorithm uses much more memory then needed. It is also possible to get too many branches connected to the same parent branch. For these reasons it is inferior in comparison to the other methods of generating tree models. Useful application of this algorithm would be for filling a tree model with leaves.

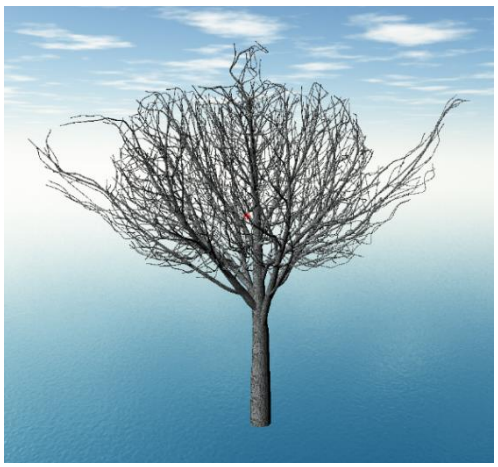

Figure 7. Space colonisation algorithm with the model of Utah teapot

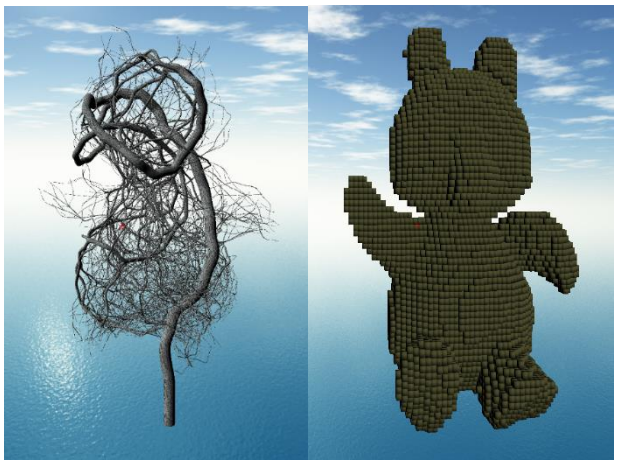

Figure 9. L-system algorithm with the model of a teddy bear

VIII. RENDERING THE TREE

Main goal of an algorithm for rendering a tree is to take an abstract tree data structure and convert it into a tree mesh. Algorithm can be executed on a CPU (central processing unit) or on a GPU (graphics processing unit). Advantage of running algorithm on a GPU is that we can dynamically change a shape and positions of branches in a tree while still maintaining a real time rendering. For average generated tree there was 0.5MB of data stored as a tree data structure. For that example, full mesh had 17MB of data. Main disadvantage of using GPU is that it is hard to do post processing of a tree mesh, like joining overlapping vertices of a branches which have the same parent branch.

Formula (8) from [13] is used to calculate radiuses of every branch, where x is exponent in a range of [1.8, 2.3] and it is dependent of a tree species we are trying to simulate. In our simulation, we used exponent of a 2.

$$r_{parent}^{x} = \sum_{every\ child} r_{child}^{x} \qquad (8)$$

To create a mesh of a branch, we need to know a radius of current and parent branches, furthermore we need to know positions of current, parent and grandparent branches. In total that is 11 floating point numbers. Creation of a tree mesh is done in a geometry shader in the OpenGL graphics pipeline.

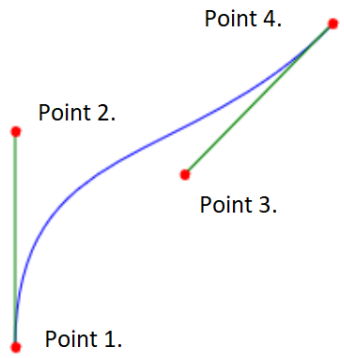

Figure 10. Cubic Bézier's curve used for rendering branches



Figure 11. Particle flow algorithm with the model of a bird

Main idea is to create a mesh that follows the Bézier's curve defined by the branches end points. Bézier's curve is defined by four points. First point is the end point of a parent branch. Second point is translated end point of a parent branch in direction of its growth. Third point is created by translation of a current branch end point in a negative direction of the current branch growth. Fourth point is the end point of a current branch. By choosing those points we get first derivation continuity between connecting branches.

To create a mesh around a branch we define vertices on a Bézier's curve in equal distances. Each vertex is the centre of a circle whose normal is parallel to the tangent of the Bézier's curve in that vertex. Radius of a circles is linearly interpolated between radius of a parent branch and a current branch. Newly created vertices are connected via triangle strip and passed further down the graphics pipeline.

Tree can be rendered statically and dynamically. Static rendering means that the data about positions of branches is not changed. Static rendering is fastest method of rendering a tree, because all data can be stored on a graphics card and it doesn't need to be changed. Dynamic rendering means that the tree structure and/or branch positions are changing in response to external stimuli. Dynamically

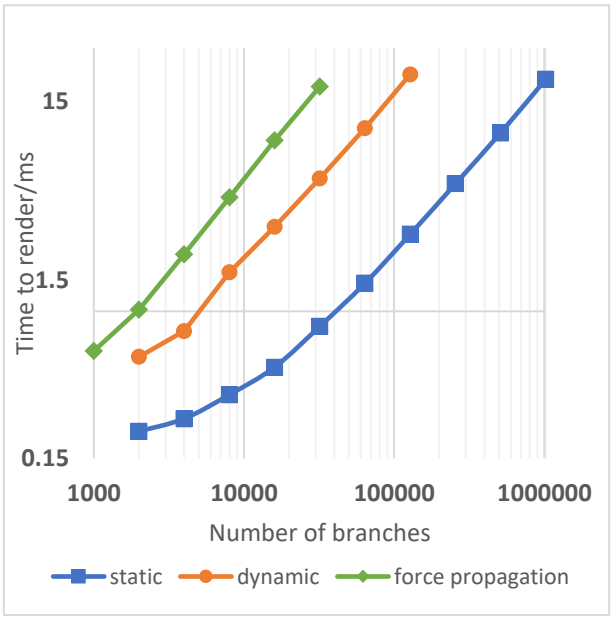

Figure 12. Comparison of different types of rendering

changing data about each branch, independently of other branches, costs us more processing power as seen on Figure (12). It would take even more processing power if we would like to simulate real world bending of branches in the presence of wind, with force propagation algorithm as presented in [14]. These rendering speeds are obtained on setup with a Titan V GPU.

IX. THE CONCLUSION

This work presents a variation to procedural generation algorithms so that they can generate trees with desired model shape. Their speed of generation and their positive and negative aspects are compared.

If it is necessary to create lots of trees in a short period of time, then it is best to use L-system algorithm. If we would like to create a tree with a desired shape, then the space colonisation and particle flow algorithms are much better suited. Models created with these algorithms are suited for simulations, movies and video games.

Voxelization of a model is explained. Results and speed of it are satisfactory. There are faster and better algorithms that parallelize voxelization but are more complex to implement.

Method for creating a tree mesh from an abstract tree data using Bézier's curve is presented. This method guarantees a first derivation continuity which produces meshes without unnatural twists.

ACKNOWLEDGMENT

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Microservice-oriented Approach to Automation of Distributed Scientific Computations

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Abstract - We offer a microservice-oriented multi-agent approach for solving computationally complex problems arising in the course of scientific and applied research in some subject areas. The computational experiments specificity of a considered class of problems is stipulated by the exponential increasing runtime due to increasing dimension, multivariate calculations of the different input data of the problem, as well as the variability of a mathematical model and algorithm for solving the problem. The use of microservices provides reusability, ease of updating the components of a distributed application and its cross-platform and allows operating with modularity properties in new conditions of distributed computing when inter-module communication is provided only through the message passing mechanism. The designed software platform for the offered approach automatizes both the development of a distributed microservice application based on an applied program package and the organization of decentralized management of microservices composition. New mechanisms for deploying and updating microservices support the synchronization of cloud knowledge bases and one installed on a user's computer, providing an additional opportunity using Dew computing paradigm that combines the concept of Cloud computing with the capabilities of the user's local computers. The practice of scientific computational experiments has shown the effectiveness and convenient in the usage of the offered approach.

Keywords - multi-agent control; Cloud computing; microservices; knowledge base synchronization; microservices deployment.

I. INTRODUCTION

In recent years, the questions of automating computational operations in the field of studying the dynamics and structural-parametric synthesis of control systems became very important in order to determine both the set of requirements for dynamic functioning indicators (for example, stability margin) and the set of required dynamic properties to which the system behavior should correspond [1]. Formation of the dynamic appearance of the control system and the associated complex of research projects carried out at the level of mathematical models, analytical and numerical methods of their studying. The process of investigating the control systems dynamics is a sequence of multivariate calculations — computational experiments. At each step of this sequence the structure and values of model parameters, methods and techniques vary, and planned calculations are performed. Future research direction is selected in dependence of experimental results estimation.

The primary objective of this research is to develop the infrastructure (instrumental and software environment) for automation of using the modern computing technology for qualitative analysis and parametric synthesis of dynamic control systems, in particular, binary dynamic systems (BDS), using tools and methods of knowledge bases and evidence-based programming. The development of models and methods for the study of the BDS dynamics is closely connected to the development of Boolean modeling technology, also related to our scientific interests.

The offered automation technology for high-performance scientific computing during the research in the mentioned above subject areas, in which algorithmic knowledge and ensemble programming play a fundamental role, here and after called HPCATAMP (High Performance Computing Automated Technology for implementation of Applied Microservices Package). Under the notion of ensemble programming, we mean the programming style in which an ensemble of ready-to-use (reusable) software event-driven components are integrated based on self-organizing mechanisms to solve a problem. The decentralized discrete-event calculation model is used. The primary concept in this technology is the concept of an application program package (APP). More accurately, the APP is a knowledge package representing one of the kinds of an intellectual system. The APP functional software is developed base on a modular principle. According to this principle, functional software is a set of basis, relatively simple, autonomous computational modules, the composition of which can be used to solve all the problems of the considered class. The microservice technology is appropriate for implementing APP based on the cloud computing paradigm. The distributed microservice model is represented by a set of small, loosely coupled, replaceable, interacting with the use of lightweight communication mechanisms autonomous microservices [2] that implement the functions of the component (modules) of the application. The applied program package implemented on the base of microservices will be called the applied microservice package (AMP).

The tendency of intensive development of research related to the creation and support of the functioning of resource-intensive distributed applications based on microservice architecture is observed in recent years. It actualizes both the improvement of existing approaches to the organization of interaction between microservices and the development of new ones. The majority of the

research is related to the use of microservice technology in the field of IOT, microservice modeling is applied mainly in the business areas, while research related to scientific computing receives little attention. The complexity of difficult exhaustive problems with the properties of large-scale, openness, unpredictable dynamics, and component mobility determines the relevance of the development of microservice-oriented software for their solution. The proposed approach to automating the solution of such problems is subject-oriented, combining the advantages of microservice and multiagent technologies, in contrast to the existing ones. Correspondently with this approach the rights to perform microservices are delegated to intelligent agents functioning on the base of a discrete-event model and decentralized control of the process of solving an applied problem based on direct semantic interactions whose information support is the knowledge base and computational field [3, 4].

HPCATAMP technology is designed according to the offered microservice approach consists of models, methods, algorithms, software, and tools developed by the authors, and is oriented for research in the mentioned above subject areas. These tools are intended for creating and functioning control a microservices ensemble and automate the following steps of this process:

- Microservices implementation on the base of the package modules.
- Creating and configuring of the agents of a multiagent system (MAS) for managing computations.
- Creating and configuring of the problem statement agents (PSA).
- Deployment and testing of the microservices;
- Update and synchronization user data.

The HPCSOMAS-MS tools considered in this paper are a development of early version HPCSOMAS 2.0 presented in [4], which has undergone significant changes, discussed in section III. For instance, the mechanisms for deploying and updating microservices that support synchronization of cloud- and knowledge bases installed on the user's computer are new in HPCSOMAS-MS. The synchronization ability provides an additional opportunity to operate using the currently developing Dew Computing paradigm, combining the concept of cloud computing with the capabilities of the on-premises computers [5].

II. Related Works

Microservices became a popular architectural style in software development [6]. The dynamism of the cloud computing environment, the complexity arising during the research in the subject areas of the difficult exhaustive problems having the properties outlined in Section I, leads to the intensive development of microservice-oriented software for their solution based on self-organization and the multi-agent approach [7, 8]. As an application of multi-agent technology in the implementation of the microservice architecture, there are works [9] and [10]. In [9], an automated lightweight «Microflow» approach is proposed for orchestrating semantically annotated microservices using agent-based clients. An example of using the multi-agent system for decentralized self-adaptation of microservices based on Docker containers [10] is described in [11]. Authors recount various developments of self-adapting systems based both on a centralized approach [12] and on decentralized [13] or hierarchical [14] one. Distributed organization and decentralized management are indicated in [15, 16] among the main criteria for the quality and reliability of such software systems. In the same works, the disadvantages of using central node are associated with poor scalability, lack of reliability and data confidentiality issues. Multi-agent management of an ensemble of microservices based on direct interactions of agents provides better adaptability to dynamic environments and higher reactivity to external influences compared to indirect interactions [17, 18].

Taking into consideration the disadvantages and advantages of the above approaches, we use self-organizing MAS to organize decentralized management. Instead of using the program description of microservices choreography, as opposed to existing works, our approach uses a discrete-event model of the functioning of MAS agents, to which the rights to perform microservices are delegated. Informational support of direct semantic interaction of agents is a distributed knowledge base and computational field [19].

III. HPCATAMP Technology

A. *HPCSOMAS-MS Architecture*

HPCSOMAS-MS includes two new high-performance computing (HPC) automation subsystems based on the microservice approach. The first one is HPCMSBD (HPC Micro Services Building and Deployment) for building and deploying microservices. The second one is HPCMSMC (HPC Micro Services Multiagent Control) for managing the interaction of microservices (Fig. 1). With the help of HPCMSBD, the reactive CMA (Computational Microservice Agent) agents based on software modules and intelligent distributed control agents DSA (Distributed Solving Agent) are created in the form of microservices. The HPCMSMC subsystem automates the configuration of CMA- and DSA agents and supports their interaction during the problem solving based on a discrete-event model. HPCSOMAS-MS includes tools for updating microservices and synchronization of the agent's knowledge bases (KB) and user's databases (DB). As a KB, there is a computational model of the subject area, distributed the way that each agent has limited knowledge of both the capabilities of other system agents and the computational field (CF) topology as a whole. Interconnections of package modules and parameters are stored in the local KB of DSA agents.

A subject area (SA) is the fundamental feature of intellectual AMP. The SA is understood as a set of information about SA objects and the functional relationships between them, as well as the possibility of setting the problem in a non-procedural way: "calculate the values of objects from B^0 set with the names b_1, b_2, ..., b_n having the values of the objects from A^0 set with the names a_1, a_2, …, a_k ". Non-procedural problem formulation will be denoted here and after as

$T = (A^0; B^0)$. A non-procedural formulation is transformed using planning tools into a problem solving scheme. On the base of the cloud computing paradigm, the planning of a problem solution scheme is carried out as a logical inference on a distributed computational SA model. The formalism in the form of a computational model [3] is used as the basis of the SA specification language.

B. Computational Model and Computational Field

The computational model is represented as a set of SA parameters and functional relationships between them. Each functional relation is implemented by a software module that calculates the values of the output parameters from the specified values of the input parameters. The CF is a set of networked logical computational nodes on which DSA agents are installed. The functionality of each agent is determined by the requirements for the inclusion of an agent-related module in the computational process of applied problem solving. A logical node is a physical computing resource, which can be: a set of processor cores and nodes of a computing cluster, a personal computer, a virtual machine, a mobile device. The zero value of the field is a trigger for the inclusion of the corresponding module in the process of solving an applied problem. The CF is discrete, the numeric value of the field in each node is calculated by the agent depending on CF state and in according with the rule of the field propagation over the network. The zero value of the field is a trigger for the inclusion of the corresponding module in the process of solving an applied problem.

C. Problem Statement Agent

For non-procedural problem statement on a distributed computational subject area model, the Problem Statement Agent (PSA) web-interface is provided. In the KB of PSA agent, the interconnections of modules and nodes of the CF are stored. In distributed and (or) cloud computing, the PSA agent is installed on dedicated computing nodes and is the entry point to the system. Another option (using Dew Computing technologies) allows installing the PSA agent with the minimum required functionality (DPSA agent) on the on-premises computer. Following the paper [5], we define our approach to the organization of calculations using AMP as the AMPiD category (Applied Microservices Package in Dew).

The user is provided with a PSA-interface for forming a problem solving request. For the non-procedural problem statement, the "Problem Solving" table is used. The user selects the SA model. As a result, a list of parameters appears, where the required parameters in the "Input" and "Output" columns should be marked. After the first step of the problem solving, two situations may arise. In the first case, an active group of agents will be formed (which will ensure that the output data values are determined by the given input data values at the stage of a joint solution of the problem), and the user will open a form for entering parameter values. In the second case, the user will receive a message that the problem cannot be solved. PSA- and DPSA-agents also support the operations with the following objects: the dictionary of SA parameters; microservices that implement the

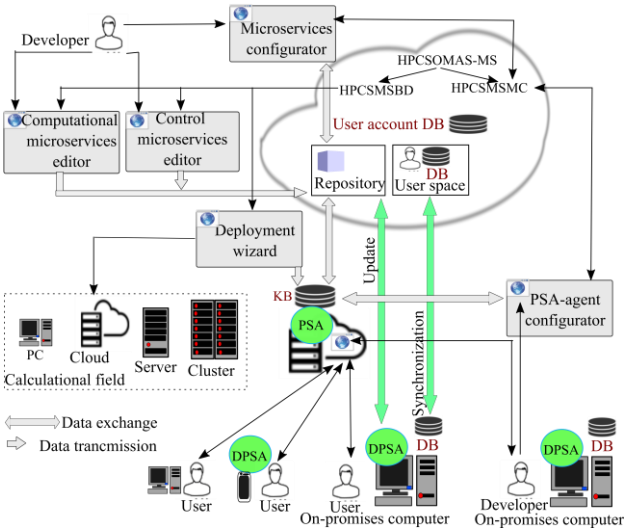

Figure 1. The scheme of interactions of HPCATAMP components

functionality of applied subject modules; CF logical nodes associated with a specific computational resource; list of agents delegated to execute modules. Only the administrator and the developer of AMP have access rights to these objects. The screenshot of the PSA-agent for developers interface is shown in Fig. 2.

D. DSA Agents

A group of DSA agents performs decentralized control of solving the problem in AMP based on direct interactions. The mean to coordinate the behavior of agents in the formation of a group, and in the stage of joint actions is a way to control the behavior of agents "by the input data readiness" (event control). The developed by author discrete-event finite-automata model FSMwVW [3] is used as a behavioral model of the agent. At the stage of joint actions, having executed the module, the agent again goes into a waiting mode for input data or a signal about the completion of calculations. The agent includes a message decoder, a message handler, and a timer system (Fig. 3).

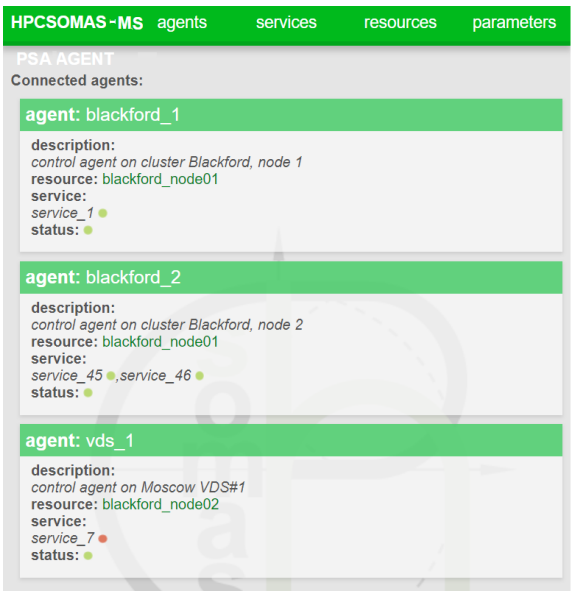

Figure 2. PSA web interface for developers

Messages are stored in a queue and processed in the order they received. The DSA-agent type has the following basic modifiers: ordinary / control (consecutive / parallel). The control modifier is used for DSA agents with a predicate whose validation is performed before running the CMA agent. Parallel DSA agent is installed on the logical nodes of the CF, which corresponds to a multiprocessor computing resource.

E. Microservices Deployment

The architecture of the developed platform provides the resources for the automatic deployment of microservices and the installation of PSA-agents in automatic mode. The user needs to enter the values of required parameters in a web-interface of deployment service and select a set of microservices from a list. Installation of these microservices and additional software (if necessary) performs automatically with correspondent to given parameters.

The examination of the operability of microservices is performed correspondently testing described in [2]. The composition of the active group of agents, formed by the problem statement, is stored in the KB of the PSA-agent. In case of updating of the microservice, the active groups are automatically determined by the KB, in which this microservice is included, and the retesting caused by the update is automatically carried out only for these groups.

F. Synchronization

Under synchronization, we understand the process of keeping user space objects in the cloud resource and on an on-premises computer in an identical state. The synchronization is customizable: it is performed in automatic mode (by default), according to a timer signal, in command mode.

The synchronization service monitors the connection with the computers of d-users who have a DPSA-agent installed on on-premises computers. This information is entered with the user registration in his account – the Install field the «D» value is set. The value of this field is «C» for users working in the cloud. While internet connection lost, new data may appear in the cloud user space - the results of calculations made at this time. These updates are recorded in the table of updates. When an internet connection is restored, the cloud and local d-user space are synchronized using the update table (only objects specified in the synchronization service configuration settings). The configuration settings include lists of objects and synchronization modes. The results of the work are synchronized on a mandatory basis; the choice of the other objects is optional. By default, the automatic mode is used, in which the fixation of updates begins when the network connection to the Internet is lost, and synchronization is initiated when the connection is restored (Fig. 4).

User space is structured. Parameters, computational modules, computational experiment results, database, task templates are distributed in different folders. Information about significant results, including the date, the name of the result file, the name of the template, the solver, the time of the decision, is recorded in the user database. The task template contains launch data - the task name, the actual parameters, set by entering a value or a file name. A user may restart task with this template.

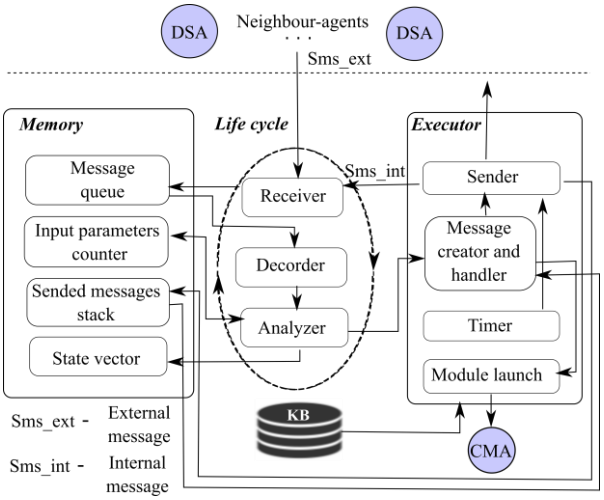

Figure 3. DSA agent architecture

IV. THE EXAMPLE OF AMP APPLICATION

Scientific studies, in which the proposed technology is used to build AMP, are carried out in several directions, listed in the introduction and described in [20, 21, 23]. The solution of computationally complex scientific and applied problems in the qualitative analysis of binary dynamic systems based on the Boolean constraints method [22] and parametric synthesis of feedback stabilizing connection for binary dynamic systems based on a logical approach [23] reduces to solving the systems of Boolean equations and requires creation of the Boolean models. Therefore, studies related to the development of Boolean modeling technology and the development of efficient parallel solvers of Boolean equations are carried out. Correspondently, multivariate calculations are required for the estimation of the model correctness, testing and

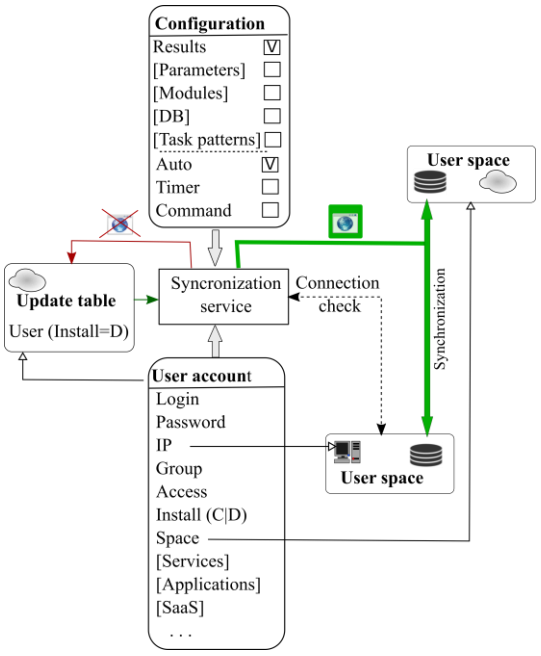

Figure 4. Syncronization cheme for Internet connection break

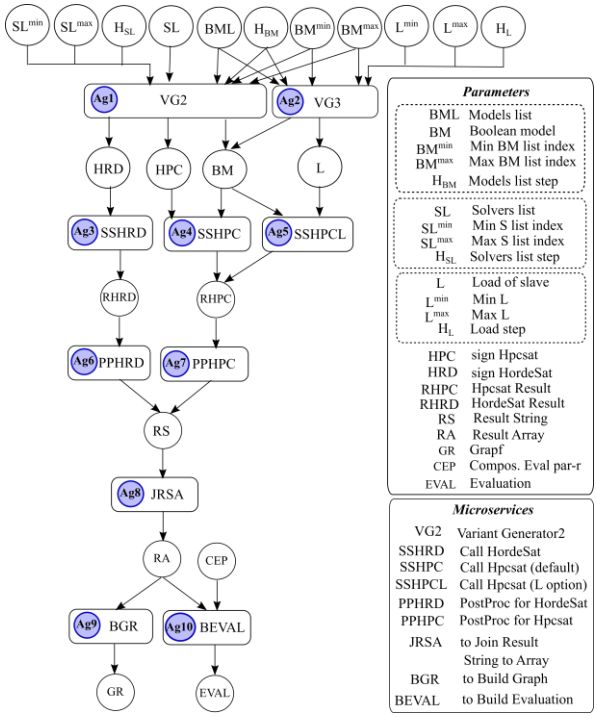

Figure 5. Fragment of computational model

comparing the solvers, as well as evaluating the effectiveness of these solvers depending on the launch parameters. So we developed AMP based on HPCATAMP technology. This AMP includes a set of microservices intended to construct the Boolean model and solve the system of Boolean equations. These microservices are deployed correspondently there specifications (system and resource requirements). On the base of the proposed approach, a computational model of multivariate calculations is developed. As an illustrative example, we present a fragment of this model (fig. 5) for solving the problem of comparing two parallel MPI solvers HordeSat and developed by authors Hpcsat [24] and evaluating the efficiency of Hpcsat depending on the loading of slave processes (expressed by the number of subtasks [24]). The following briefly describes the parameters and functionality of microservices.

The VG2 microservice is designed to generate the next calculating variant (pair selection, BM model from the BML input list, starting with BM^{min} number to BM^{max} number with H_{BM} step and solver from SL solver list with H_S step) and logical parameters ($HRD \oplus HRP=1$), for conditional launch of HordeSat and Hpcsat solvers correspondently by microservices SSHRD and SSHPC. The VG3 microservice is designed to generate the next calculating variant (pair selection, BM model from the BML input list and the slave process loading L changing from L^{min} to L^{max} with step H_L). Variants generators VG2 and VG3 automatically change processor number p as $p = 2^k$ from k=6 to k=9 (for this illustrative example). The RS parameter is the result of the work of the solvers. In case of multivariate calculations, the RS result is processed by the PPHRD and PPHPC post processors (for HordeSat and Hpcsat, respectively). All RS of the variants are collected in an RA array, and then the GR graphic is plotted. The BEVAL estimates joined results RA and calculate scalability metrics [24]. The parameter CEP is a

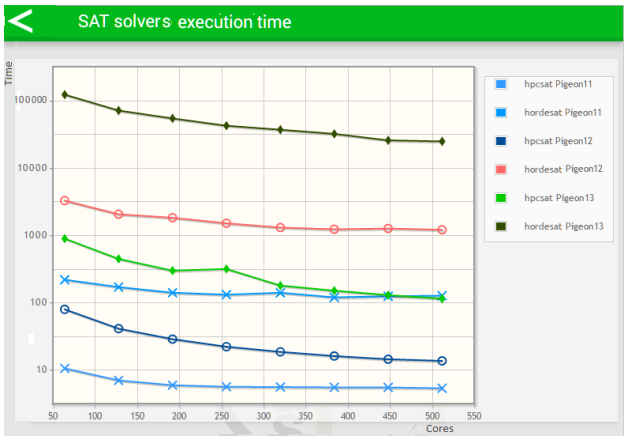

Figure 6. Comparison of solvers runtime.

composite parameter and includes simple, in particular, the type and object of estimation.

To compare solvers, let us add to the list of Boolean models (BML = {Pigeon11, Pigeon12, Pigeon13}) the problems of "pigeons and holes" of different dimensions. Solvers list SL = {HordeSat, Hpcsat} includes two solvers. To solve the problem of comparing solvers, the user needs to formulate the problem $T = (A^0 = \{\text{BML}, SL, BM^{min}, BM^{min}, H_{BM}, S^{min}, S^{max}, H_S\}; B^0 = \{\text{GR}\})$ (non-procedural formulation) using web-interface of PSA agent. As a result of logical inference on the computational model the active group of agent AG1 = {Ag1, Ag3, Ag4, Ag6, Ag7, Ag8, Ag9} is formed for solving the problem. Agents Ag3, Ag4, Ag5 is implemented as parallel. These agents are installed on nodes of a computational cluster. Fig. 6 shows the results of this problem solution. As results show, developed Hpcsat solver has an advantage in comparison with existing HordeSat.

Analogously, to solve the problem of loading dependency, the user needs to formulate the problem $T = (A^0 = \{\text{BML}, BM^{min}, BM^{min}, H_{BM}, LS^{min}, LS^{max}, H_L, \text{CEP}\}; B^0 = \{\text{EVAL}\})$. Corresponding agents group is AG2 = {Ag2, Ag5, Ag7, Ag8, Ag9}. Let the BML include testing UNSAT 3CNF [24], the dimension of which changes from 400 to 440 (variables number). Let L value increase in 4 times at each step (1, 4, 16, 64). Parameter CEP sets as CEP = {MARK|L|Hpcsat} to estimate the dependence of Hpcsat scalability from launch parameter L. The results of estimation are given in table 1. Metrics C_1, C_2 and C show contribution correspondently to a processors number, problem dimension and their integrated contribution [24] in the efficiency changes (the only parameter increasing when another launch parameter is fixed). These results allow concluding, that the increasing load of the slave processes helps to hold up decreasing of the efficiency for testing 3CNF (C_1, C_2 and C increase with increasing L). Agents Ag9 and Ag10 perform processing results and are less demanded on a resource. Such agents may be installed on the on-premises computer and, for example, to estimate received results while internet connection fails. The formed AG1 and AG2 group's structure are stored in KB of HPCSOMAS-MS. Suppose that one of the microservices is update by a developer. The deployment service uses this information about the group structure for automated testing and

TABLE I. METRICS

Loading	C_1	C_2	C
1	-0,00956	-0,07615	-0,00911
4	-0,00371	-0,06357	-0,00768
16	-0,00154	-0,04019	-0,00489
64	0,000452	-0,02908	-0,00332

launches tests only for groups, which include this microservice. Based on the above example, we can conclude that the user is given the opportunity to focus only on the problem formulation when conducting his research using describing above AMP developed on the base of offered technology.

V. CONCLUSION

The new technology and its basement software and tools are developed to automate scientific computations based on the proposed approach to the creation and operation of an applied microservice package, significantly reducing user time and efforts during computational experiments.

ACKNOWLEDGMENT

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Serverless architecture for workflow scheduling with unconstrained execution environment

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***Abstract*—Cloud computing, together with all its boons, has taken the world of computing by a storm, reaping benefits across various domains. Introduction of serverless computing, and more precisely Function-as-a-Service (FaaS), removed many orchestration and maintenance issues that system designers were facing. This inspired an emerging field of research on utilization and optimization of serverless computing. Existing body of work on this topic is, to the best of authors knowledge, focused on using serverless functions (e.g. AWS Lambda, Google Cloud Functions) exclusively. Such functions suffer constraints in the context of their execution environment, time or available space. In this paper we present a more general approach that improves upon existing architectures that revolve around cloud functions. By leveraging AWS Fargate technology, we propose a fully serverless and infinitely scalable architecture that is based on producer-consumer pattern and can be shaped to satisfy wide range of requirements. As worker nodes, Docker containers are used, which helps avoid aforementioned constrains. This concept is put to use in a system for acquisition of high frequency data.**

Keywords **-** cloud computing; serverless architecture; Function-as-a-service; scientific workflow

I. Introduction

Cloud computing presents an increasingly useful proposition both for research and industrial applications. In particular, a recent development in this area is serverless computing. In the early years, the term "serverless" referred to applications that relied on peer-to-peer communication or software solutions that reside on client side only. In the context of cloud computing, serverless usually refers to models where developers don't need to worry about server deployment and use SaaS platforms or services such as Google Apps.

In the recent years, however, the term "serverless computing" mostly refers to server-hidden solutions where which are centered around functions (hence Function-as-a-Service or FaaS), and hide how the scaling is performed. The terms serverless and FaaS have considerable overlap, but both are useful and relevant [1].

At this moment serverless is still an emerging technology. Researchers evaluate possible application domains and attempt to measure and compare serverless to other cloud-based or traditional approaches.

One important advantage of serverless computing is that it shifts the burden of workflow orchestration to the service provider. With traditional Infrastructure-as-a-Service (IaaS) model, user needs to provision virtual machines, manage resources as needed, and to handle various run-time issues such as faults, inconsistencies etc. With FaaS developers only care about the operational lifecycle of individual tasks [2].

This however comes at a cost. Functions are typically constrained by their transient nature, which includes limits on execution time as well as total storage space. This limits the usefullness of FaaS for certain application domains such as high frequency data acquisition.

In this paper authors propose a novel architecture which represents a truly serverless model. The core idea of this approach is to combine AWS Lambda with the new AWS Fargate technology to bypass the limitations of FaaS. Docker containers are used for persistent execution and storage. Thus, an infinitely scalable architecture is achieved that can be shaped to satisfy a wide range of requirements. Another core concept used in this paper is the well-known producer-consumer architectural pattern. Here authors show how such pattern can be applied to a serverless architecture. This approach is further validated with application to acquisition of high frequency (HF) data such as social network traffic.

Remainder of this paper is structured as follows: Chapter 2 contains a review of the state of the art in the field of serverless and FaaS architectures and workflow management. This is confounded by the relative novelty of the field and the wide spread of topics of interest to the authors. Chapter 3 presents in detail the proposed architecture, while Chapter 4 describes its application in the field of HF data acquisition. Finally, Chapter 5 presents conclusions and directions for further research.

II. State-of-the-art

This section provides an overview of a serverless function-as-a-service (FaaS) technology, citing its features and showing how it can be used outside of a web development domain. In order to setup background for main contributions of this paper, we highlight limitations imposed on most recent advances that rely on serverless technology.

Introduction of a FaaS technology was aimed towards relaxing deployment efforts for Web based applications. It abstracted away details of setting up a server that would host an application and serve it online. This type of abstraction is first in line of *serverless* products offered in cloud.

Cloud providers who enlist FaaS enable programmers to setup execution parameters (network settings, firewall, environment variables, ...) via web interface or configuration file. Moreover, cloud provides have full responsibility of managing underlying infrastructure, which comes with nice feature of implicit scalability. This means that provider controls a number

of executors in response to load on service. Thus there is no need to plan server configuration, monitor its execution nor consider upgrade strategies.

Besides all that, serverless functions come with financial benefit, as users only pay for time during actual resource utilisation (i.e. time spent processing user requests). This is in contrast of traditional computing, where server demanded constant uptime and resources (power and money) are consumed for entire duration.

Even though the term Function-as-a-Service came into common usage only after introduction of Amazon Lambda (in 2014) [1] there are already notable contributions on ways of utilisation of this technology. Beside practice in web application domain, special attention is devoted to serverless architectures for scientific workflow execution. Malawski et al. [3] build upon existing scientific workflow execution contributions and present improvements rooted in serverless philosophy. Similarly, Ao et al. [4] used serverless functions to refine traditional video processing pipeline. While acknowledging many benefits of their approach, authors of both papers acknowledge rather harsh limits imposed by serverless functions summarised in Table I. Additionally, cloud functions are *stateless*, in sense that each new execution has no memory of any previous executions. This is acceptable for certain application, but certainly limits the scope of FaaS usability.

In their attempts to overcome some of these limits, Peréz et al. [5] propose Serverless Container-aware ARchitectures (SCAR). This approach utilises *udocker* [6] tool to execute custom containers inside AWS Lambda execution environment. However, udocker only deals with one aspect of cloud limitations (specific set of languages) and, due to its simplicity, is limited to only simpler containers and doesn't support advanced system and networking configuration. More importantly, execution time and space restriction is still present. Other direction of going around predefined set of programming languages and cloud specific execution model is to write converters into supported languages. In this line of research, Spillner et al. [7] proposes Podilizer, tool which takes source code of Java project, and outputs AWS Lambda function units. Similarly, Jonas et al. [8] consider PyWren, conversion tool aimed towards Python source code. Since cloud providers are steadily expanding their lists of available programming languages, risk of becoming obsolete is omnipresent. Moreover, outputs of these converter tools are tied to one specific service of one specific cloud provider (Amazon Web Services in this case), which is great disadvantage when considering tools generality.

A. Serverless functions peculiarities

Beside the already mentioned limitations, serverless functions come with inherent properties that set them apart from traditional computing paradigm and thus require dedicated effort. As pointed out in [3] and [9] debugging and end-to-end testing sometimes require deployment to the cloud. This is due to the fact that some of the internal cloud mechanisms are invisible to end users and thus hard to replicate in development environment. Moreover, based on a fact that each cloud provider offers unique interface to FaaS, Soltani et al. [10] pointed that FaaS based systems result in *vendor lock-in*, i.e. they are devoid of any possibility to transfer (system or some of it's parts) to other cloud provider. This means that users are unable to exploit differences in cloud providers and combine benefits of each. Soltani et al. [10] are the first to suggest extension of serverless service with multi cloud compatibility, but their approach is still in theoretical phase.

While black-box scalability brings benefits it also removes control over granularity of tasks in system. As pointed out by [3] this blocks expansion to applications that are computationally "heavy". One such example is HPC applications which are driving modern research, and thus any advancements in this area are more than welcome. Moreover, such rudimentary control over resources available to workers can lead to underutilisation of resources. In complex workflows, where individual stages of work can have diverse nature (e.g. highly parallel stage with larger number of weaker parallel processing units followed by sequential stage that requires considerably more resources), a big gap between available and required resources would reflect negatively on associated costs.

III. Serverless architecture for workflow scheduling with unconstrained execution environment

In this section we show our approach to working around some of the biggest limitations that plague all current serverless systems. We present an architecture for a system that is free of constraints on its execution time or runtime environment. Moreover, we show how this architecture offers improvements in aspects of multi-cloud capabilities, end-to-end testing, debugging and error handling.

Given that our architecture uses consumer-producer [11] pattern to communicate jobs to worker nodes, this naming convention is observed for system components. Figure 1 depicts proposed architecture. Going bottom-up, we first encounter **consumer**, which represents abstraction of a execution environment i.e. worker in the system. As such, consumer is to be defined as a (Docker or other) *container*. This means that, in addition to the source code, developers write a configuration file that specifies runtime details (operating system, libraries installed, environment variables, ...) and ship it together with application.

The information contained in described configuration file is combined with hardware specification (CPU and RAM available) for a given type of worker and used by **consumer cluster** (or dedicated intermediate service e.g. *build server*) to create *container image* which can then be executed. Consumer cluster houses all active consumers. It is tasked with monitoring load (in terms of CPU and RAM utilisation) on consumers, and regulating the number of available workers. It is a requirement that cluster has mechanisms to autonomously regulate this number, but also to provide interface for manual override.

In addition, the cluster performs *monitoring* on all individual consumers in the form of a health check. This means that a

	AWS Lambda	Google Cloud Functions	Azure Functions
Execution time (s)	300s	540s	No limit
Disk space	500 MB	Consumers memory resources	5 TB
Number of functions	No limit	1000	10
Parallel Execution	1000	400	No limit
Language	Node, Python, Go, Java, .NET Core, Ruby	Node, Python, Go	Node, Java, Python, C#

TABLE I
UPDATED LIMITS OF CLOUD FUNCTION INFRASTRUCTURES
SOURCE: MALAWSKI ET AL. [3]

command is executed periodically on all containers to ensure they're functioning properly. All *unhealthy* workers, i.e. ones that are not able to accept new or process existing jobs, ought to be shut down and, together with their currently active jobs, replaced with a fresh worker. Catalogue of live workers and their corresponding jobs is stored in **middleware**. Another function of middleware is that it facilitates infrastructure for producer-consumer communication. More precisely, it provides an interface to components higher in chart (Fig. 1) to send payload towards workers. This puts a restriction on main components (consumer and producer) in that they have to support the technology provided by the middleware, and one could argue that this leads to component coupling. As we show later, middleware can be implemented as a (key-value store) database, where keys would correspond to consumers unique ID and value holds all relevant information about corresponding consumer.

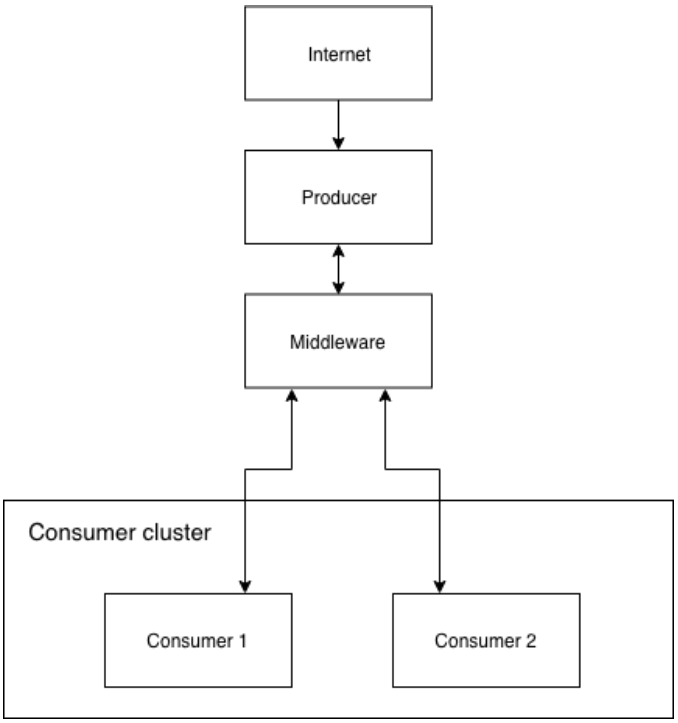

Fig. 1. High level overview of architecture

Another consequence of described approach is that each consumer must keep its state inside middleware. Further, during its initialisation phase, consumer has to construct an unique ID. In the simple case, a random alphanumerical string could suffice, but in a more complex system in addition to this unique part, consumers can encode information on their type into ID. This would mean that specific workers (i.e. workers optimised for specific type of work in the workflow) can quickly be identified.

Described set of information is crucial for proper functioning of a **producer**. It is a component at the edge of the system, and provides entry point into it. It offers an interface to *list, modify, and monitor* system state[1]. Listing is simply querying middleware for workers catalogue, while modification of system state implies *starting or stopping* jobs. Finally, monitor function provides the way to check if specific consumer is able to accept a new job. The primary audience of this monitoring function is the *consumer cluster* which uses it to determine if a worker is healthy. Internally, when invoked by consumer cluster with a worker ID as a parameter, monitor function will produce a *dummy job* that is sent to the specified worker and an acknowledgement is expected within a predefined time frame. If consumer responds in a timely manner, monitor (and consequently consumer cluster) will conclude that the container is healthy, otherwise it is unhealthy.

Job scheduling can be implemented inside producer but it is not an imperative. Since list and start job interfaces are offered on a service level, it is the issue of implementation whether scheduling logic will be implemented inside producer or built on top of it. As job scheduling algorithm heavily depends on application domain, it is also responsibility of an implementation to define such procedure.

A. Comparison with State-of-the-art

Here we compare aspects of improvement offered by the proposed architecture versus state-of-the-art endeavours summarised in Section II.

Most importantly, as workers (consumers) in the proposed architecture are (Docker) containers, their runtime environments are arbitrary and therefore strict restrictions of FaaS are eliminated. As cluster offers mechanism to manually override number of available workers in the system, users have option to fully regulate worker distribution. Coupled with the fact that the specification of amount of CPU cores and RAM is unrestricted, it is clear that users enjoy full control over granularity of workers and the entire system.

[1]System state is a mapping between consumer ID and its corresponding state.

Serverless functions are inherently stateless, but here individual consumers can be shaped into unconditionally stateful service. Improvements in terms of debugging, end-to-end testing and multi-cloud capabilities are rooted in the fact that workers are Docker containers. As containerised applications can be executed in a plethora of execution environments, and are based on standalone software, rather than an interface of a specific cloud provider, developers can debug (and test) application in local environment. In terms of multi-cloud support, great improvement is made since some parts of the system (i.e. producer, middleware, consumers) can be reside in any cloud provider (as long as they implement appropriate communication protocol with other components).

Unfortunately, at this time AWS is the only provider that can fulfil the requirements of consumer cluster (AWS Fargate service). However, it is natural to expect that other names in cloud provider discourse (e.g. Google Cloud, Microsoft Azure et al.) will offer similar services in future and provide even less coupling with a specific cloud provider.

IV. High frequency data acquisition system

In this section an implementation of the architecture described in previous chapter is demonstrated, which represents a production system. By harnessing the power of a new service offered by Amazon Web Services – Fargate – a fully serverless high frequency data collection system is presented, which shall be elaborated later. This description corresponds to an actual system used commercially by employers of one of the authors.

For brevity reasons, many details of the collection system in question shall be omitted, focusing on the aspects relevant to this paper. In that manner, the focus is on implementation details of system components and, for comprehension reasons, some of the requirements on the system are cited.

System should support data collection from arbitrary sources with focus on sources with high frequency (HF). These can range from social networks and stock exchange to different types of message boards and news portals. It is easy to see that mentioned data sources require different approaches for data collection and thus system cannot impose any sort of technology stack lock-in. Furthermore, system should provide the end user with an interface to add new collectors, or to stop the existing ones. Finally, high frequency data sources often imply asynchronous communication, so an event-driven approach would be beneficial. While, different discourses define ”high frequency” very differently, here we consider sources where data is generated asynchronously and at least 10 times per second.

To make a system usable by the end users, the implementation of a **producer** component should include the outward interface. This would give them control over the collection process. This component is a ”lightweight” service in the sense that it handles incoming collection requests, identifies which consumer to schedule the job to, and finally produces the job to the consumer (i.e. the worker instance). The scheduling algorithm is placed in the producer rather than built on top of it. A rather simple logic of keeping the total number of jobs on each consumer as similar as possible proved effective for the intended use case. Such service is suitable to be written as FaaS, AWS Lambda with NodeJS runtime is used for this component. It offers endpoints as follows:

- GET:/ - lists all active containers and their jobs
- GET:/monitorSingle?id=X - checks health of container X
- POST:/ - starts new jobs based on request body (in JSON format)
- DELETE:/ - stops existing jobs based on request body (in JSON format)

Avoidance of technology stack lock-in comes in the form of Docker containers and is already embedded into consumer component from template architecture. To support asynchronous communication that might result from HF sources, a Node.js application is used as its runtime is already founded on the premise of event-driven programming [12].

Technology that was instrumental for this contribution is **AWS Fargate** which is used as a consumer cluster. Input for Fargate cluster definition is an array of *services* that will be supported. Each Fargate service is a collection of tasks. Ultimately, tasks contain information on container image, number of CPU cores and amount of RAM memory available to that task. Health check command can also be defined for each consumer in the task definition. This feature is utilised to forward producers endpoint to consumers so a health check cycle can be established.

Additionally, scaling rules can be defined with respect to CPU and RAM usage for each service individually. In contrast to the state of the art solutions, here users have explicit knowledge and control over their system in respect of hardware resources without the traditional burden of such perogative. As this collection system has only one type of workers, collection cluster has one service, which contains exactly one task within which exactly one container is defined. Such layered construction provides fine grained granularity and load control, while not posing as a great overhead for simpler needs. Middleware is a Redis key-value store database. Keys in database correspond to container IDs, while values are their state. As both consumer and producer and written in NodeJS, we are free to use Kue [13] library to facilitate the producer-consumer pattern.

V. Conclusion

This paper provides an overview of serverless technologies and considers existing body of work in the field. More precisely, it highlighted the state-of-the-art in workflow scheduling systems that are implemented on top of a serverless architecture. After identification of the biggest drawbacks of such approaches that lessen their effectiveness, the paper presents a novel approach that removes these drawbacks while keeping original benefits and applicability. The proposed architecture eliminates crude restrictions (limited execution time and environment). Also, the suggested solution brings improvements in terms of application debugging, end-to-end testing and multi-cloud support. Ultimately, the described architecture is showcased with a high frequency data collection system.

Astronomy workflow Montage [14] is often used as a benchmark to evaluate performance of similar systems. Evaluation of our system on said benchmark would certainly serve as a great supplement to initial proposition. Further work should be done in the direction of further generalization of this approach, as well as development of tools for automated deployment, debugging and analysis.

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Comparison of data aggregation from a wireless network of sensors using database sharding and foreign data wrappers

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Abstract—**In this work two built-in database technologies were compared and applied to aggregation of data from a network of sensor equipped data collection nodes in a real manufacturing environment. The methods investigated are: data sharding and foreign data wrappers. The availability and feature set differences of the methods on some popular database management systems was compared and then a detailed case study on PostgreSQL DBMS was performed. For testing the concept in more realistic environment the sensor network was implemented using a number of Raspberry Pi computers with local relational database and with wireless connectivity to main aggregation database running on a much powerful server computer. Both database methods were applied on all nodes and the server and performance was measured for different types of aggregation queries. The very same data aggregation concepts presented here could be applied to any sensor network or to any Internet of things network.**

Keywords- database sharding; database foreign data wrappers; distributed data collection. IoT, fog computing

I. INTRODUCTION

Every industry has an increased problem in integrating an ever increasing number of machines from different generations to a real-time monitoring or management system and to existing enterprise resources planning (ERP) information system. To implement an automated *data collection* from a number of various machines in an industrial plant, emerging Internet of things (IoR) [1], [2] and *fog computing* [3] were investigated. The basic premise is as follows. Every technical or industrial system has somewhere an array of sensors. With some additional electronics added, data from any of the sensor could be hijacked and read with no noticeable consequences to operation of the original machinery. Additional sensors then could be added to any machinery or subsystem to cover additional measurements like environmental temperature, humidity, noise or to proxy various software interfaces. In this work, the hijacking is performed by a small computer that it will be called *data collection* or *DC node*.

The node should be cheap, as it will be mass deployed to all kinds of DC points, and enable seamless network connectivity. The data collected by a DC node could then be integrated into a management information system (MIS) for further analysis. The method could be applied to almost all kinds of machines with sensors or even to other software interfaces. This looks like a kind of problem that can be addressed by the IoT paradigm. Therefore, a cheap wirelessly connected network device like Raspberry Pi or Arduino was a good candidate. Both devices were considered. Arduino is attractive from the interfacing point of view and as a Real time system, but networking options for the microcontroller are quite limited and either additional modules and software or more expensive computer like versions are required. On the other side, stock Raspberry Pi 3rd generation (shorter RPi3) provides fast wired and wireless networking option even with Power over Ethernet at a similar price point. Raspbian OS (http://raspbian.org) is Linux Debian distribution based and thus offers a wide ability to use more general programing tools that can make interfacing to other software systems with XML, JSON and other Web protocols much easier. Moreover, in the later phase of the system development it will be used for other, more diverse purposes, like interfacing to a machine internal Modbus or CAN protocols or other OPC, SCADA, Web or RPC software interfaces. Initial assessment of the RPi 3+ reveals that the module could be used for fully fledged embedded software development and that an Arduino could be attached to the Pi and programmed from it like from a contemporary personal computer.

However, much more interesting finding was that various database management systems (DBMS) could be used on board. Initial benchmarks of popular MySQL and PostgreSQL open source databases had shown that both databases could perform quite a number of simple CRUD transactions per second and subsequently could be used to postprocess collected data on demand. NoSQL databases were considered as an alternative to standard relational databases like in [4].

It was expected that the initial deployment will contain a few dozens of DC nodes attached to various machines of different types (mostly measuring operation speed from sensors). The sensors in such a widely distributed system could generate a large amount of data in everyday operation. Many of the monitored processes or sensors could generate a number of measurements per second and a lot of this data is not needed all the time everywhere or in the central MIS. Like in the aforementioned *fog computing* it was assumed that a lot of the *edges* (the DC modules) process the data and the less granular data is forwarded for further processing. In more modern terms, we can say that the system will transform from the fog to the cloud computing.

Once the decision about the platform was made, other considerations were taken into account, for instance how to aggregate all the DC node data stored into local databases considering various options like in [5]. Nevertheless, many proposed modern IoT data aggregation methods assume introduction of some middleware, available by many software platforms of diverse manufacturers, which is then used in conjunction with other quite sophisticated software. Yet such an approach requires quite a steep curve in learning, many proposed systems being in quite an early stage of development, and more significantly they can easily break our basic assumption of hundreds of affordable DC nodes everywhere in a production. As this is quite a new area of research, new products and solution emerging on market every day, a ready-made long-term solution was looked upon. It is expected that on the mass consumer market a mass production of internet connected consumer devices will bring IoT closer to reality. But, the IoT paradigm is expected to change a lot in the coming years. Many innovative and many big companies are entering the game, and foreseeably it can bring vendor lock-in and sometime the resources required to store data to a cloud will be prohibitive from time and development perspective. Long-term stability and availability of any platform could also be in question. As discussed in *free and open source systems* a provide good basis for the future, and these options will be considered in the future work.

Hereby, an alternative and quite readily available approach is proposed: standard or emerging built-in database mechanisms are utilized to create a virtually monolithic database from which all involved parties can get the sensor or even aggregated data needed for further processing. Two basic principles, that make this seamless, are already present in many commercial and open source SQL DBMSes. Two most important approaches were investigated: *SQL foreign data wrappers* (FDW) [6] and *database sharding* [7]. Both methods are available in or for PostgreSQL with just slight variance. The PostgreSQL is already available as a package on Raspbian Stretch distribution.

In the Chapter II the design of a data collection node will be presented, while FDW use is explained in the Chapter III and in the Chapter IV sharding. In the Chapter V two different techniques for aggregating acquired information are compared and the experience in implementation tradeoffs discussed. The following research will be outlined in the Chapter VI.

II. DATA COLLECTION ON A COMPUTING NODE

As explained above, the local computing modules used were contemporary Raspberry Pi 3. Variants B, B+ and A+ were used. B models have wired network and 4 USB ports, while A+ has only wireless networking and a half a GB of RAM while B models have 1GB of RAM. The B model has a quite powerful 1.2 GHz ARM design processor with 4 cores. Plus (3B+, 3A+) models have slightly faster CPU (1,4MHZ), but more importantly provide better and faster network connectivity (1GH Ethernet and 802.11b/g/n/ac, BLE). Permanent storage is on Secure Digital (SD) cards with read/write rate of about 80MB/s. This is kind of processing power that can be found in a modern entry to mid-level consumer smart-phone. Quick benchmarking of the DC module had shown that the software can register and then store to database about hundreds of transactions per second (sensor readings expected are at most a few times in a second). Some measurements of speed of different cards from popular manufacturers shows significant differences between SD cards, but our measurements for our DC application had shown no significant difference.

Raspberry Pi provides so called GPIO (*general purpose input-output*) interface for connecting to various digital and analog signals. More than two dozens pins could be used at time for analog or digital inputs and outputs. On all UI pins built in pull-up resistors are programmatically configurable. The digital interface is 5 V TTL compatible. There are many modules and adapters on the market that ease connecting to GPIO.

Small and fast daemon program was written in C that collects data on interrupt from GPIO and stores the sensor reading in local PostgreSQL database. The data collection nodes were connected by wireless network infrastructure and by a proxy server to t central server with aggregation base. Every sensor has its ID from the global MIS nomenclature and combination of the DC node, machine id and sensor id additionally identifies the sensor. One machine can have more than one DC node connected to various sensors. Majority of the sensors just registers a pass of a new item in production, typically on a conveyor belt. In almost all production lines sensors ware positioned on places where products are quite equally spaced thus passing under the sensor is quite regular in time. Slight variation of passes is attributed to uneven gaps or stacking of items that is a normal phenomenon on every conveyor line.

The sensor readings obtained in real production were quite stable and most of the jitter obtained was caused by bad positioning or choice of sensor. By combining multiple sensors on a same machine accuracy was further improved.

The concepts presented here is already partially implemented in cooperation with a commercial printer plant.

Figure 1. Network of wirelessly connected data collecting nodes in a production plant

III. DATABASE CONNECTIVITY

Depending on the configuration type. Typical sensor will generate about tens or even hundreds of thousands of entries to database daily. Encoding just the start and end time stamp with help reduce number of passes stored and the number of entries could be reduced just to hundreds or mostly thousands of entries daily. The number of sensors that a plant should collect can reach from a few dozens to many hundreds of sensors and the worst-case scenario a million of records could be generated.

Some kind of partitioning is present in most modern database systems. The following table summarizes basic support for foreign data wrappers and sharding in some of the most popular DBMS.

DBMS	Built-in support foreign data wrappers	Sharding support
Microsoft SQL	+	+
MySQL	-	+
Oracle	-	+
PostgreSQL	PostgreSQL, ODBC, JDBC, MySQL, SQLite, Oracle*	+, Citus
SQLite	-	-
MongoDB		+

IV. FOREIGN DATA WRAPPERS

Different methods for integrating remote data to central storage were investigated. The first approach, described in this chapter is use of *foreign data wrappers* (FDW). The FDW mechanism is part of SQL:1999 [8] standard and is supported by many DBMSes.

PostgreSQL has support for different foreign DBMS-es including its own (see Table I). Before using a FDW appropriate extension should be installed. Typical declaration of foreign server and database mapping is shown on the Figure In brief: a foreign data wrapper points to a remote server with appropriate user and replicates a remote table to local table. There are many options that can be applied to FDW. Fields in foreign database should be mapped one by one by column name and type, but there is also an option to map whole structure from foreign table with the following SQL command:

```
SELECT * FROM sensor1 WHERE condition1
UNION
SELECT * FROM sensor2 WHERE condition2
…
UNION
SELECT * FROM sensorN WHERE conditionN
```

Union of all queries may be used to retrieve data for any remote table. Unfortunately, ordering or limiting the result of a subquery is not feasible. The invocation of the commands for many sensors could be tedious and something better should be used for many mapped tables. The invocation is compared with a number of queries from a shell script using *psql* command line interface, and the FDW invocation was much faster.

The FDW mapping does not copy any data but redirects any query to the remote database server and table. Typical query

```
CREATE EXTENSION postgres_fdw;
CREATE SERVER node001
FOREIGN DATA WRAPPER postgres_fdw
OPTIONS (dbname 'dc', host 'node001'');
CREATE USER MAPPING
FOR usehere  SERVER node001
OPTIONS (password '****', "user" 'userther');
CREATE FOREIGN TABLE public.sensor001 (
-- data fields maped on remote server
-- OR
 ) SERVER dc001 OPTIONS ( table_name
'sensor_table');
```

Figure 2. Code for accessing data from FDW on PostgreSQL

should explicitly union the tables from all remote locations what could be tedious. For every DC node the procedure from the Figure 1. is repeated. To ease the mapping a special function for mapping a server could be created, or some external shell script could be invoked. The central database system ends up with a number of tables for every remote sensor. After that MIS can refer to remote tables in a similar manner, parametrizing just the sensor table name. For any remote server individual access right could be defined.

The foreign database mechanism is quite efficient while the remote server is accessible but becomes a problematic when a remote server is down or otherwise unavailable. Fortunately, queries for an inaccessible server are terminated immediately, depending on a time-out parameter set in the connection option.

In PostgreSQL [9] foreign tables could not be mapped to a cached local data. The data sensor table could by copied on a trigger to an aggregation table with all data in one place where a query from a MIS may refer to the sensor ID instead of table name that contains ID in the table name. Triggers could be optimized on slower network.

Compared to separate query from a shell or PHP script to get data from about a dozen nodes preliminary tests show a quite good performance and status of all nodes in a case of a few dozens of active nodes is retrieved within a seconds while query from a script polling DC nodes takes a few seconds. In the process main database server establishes a parallel set of connections to remote server and query results are asynchronously retrieved quite faster than we were able to do directly from an web application using the data to display sensor state and measure speed.

The problem is if a machine in print plant is powered down but, in that case, we do not show instantaneous data and assume that a machine is down. Historical data in that case could not be accessed. We solved that problem with periodical refresh of a view containing all items in one place.

It is assumed that all nodes are capable enough to collect all sensor data continuously while the attached plant machine is operational and operating. The amount of the data on the local DC node could be overwhelming to transfer it all, so we reduced the data to a special local view with only a number of recent items and aggregated data and mapped data from just these views to aggregation table.

```
-- create server connection and user mapping
-- as shown before for FDW and partition
CREATE FOREIGN TABLE sensors (
-- sensor table fields…
) SERVER dcnode001;
-- and connect to the
CREATE FOREIGN TABLE sensor005
    PARTITION OF sensors [criterion]
SERVER dcnode001;
```

Figure 3. Code for horizontal partitioning a table shard in the PostgreSQL

V. DATABASE SHARDING

Sharding [10] is a database mechanism which enables partitioning of a larger table to a set of smaller distributed databases that contain a subset of rows of the table in a number of remote tables. In PostgreSQL sharding is done as shown on Figure 3. In some systems it is rather referred as *horizontal partitioning*, as the table rows are split across a number of a database servers where each server manages a number of rows by some criterion (PostgreSQL allow) In our DC node case each shard contains data for a set of sensors connected to a DC node. The partition is limited to a sensor or a DC node or to a machine depending if more then one DC node was required for a machine. Our remote sensor table has machine, node and sensor ids and it is used as criterion to partition the table. Once the partitions are created the table acts as a large sensor table and no special queries is required.

The sharding mechanism is transparent to a developer and a developer sees a unified structure for queries. Older versions of PostgreSQL did not have support for sharding and it was implemented with Citus extension (http://citus.org). CREATE PARTITION constructs for table partitioning are include from version 9.6 and are further improved the process it in the recent version 11. Unfortunately, current Raspbian Debian Linux distribution called Stretch does not include but version 9.6 which has limited support for partitioning. Thus, a manual compilation and some struggle with the installation from source or some beta builds is required. In configuring Raspberry Pi. Once a node was built the SD card with distribution was cloned and deployed on a number of testing nodes.

The process of sharding for a table is slightly simpler then FDW, but still requires a lot of repetitive SQL code. Some scripts and functions were used to automate the process on a number of node. First partitions on central database server should be defined and then propagated to DC nodes. The table structure is the same. In the end organization of database for sensor readings is partitioned across different DC nodes. While in FDW arbitrary tables could be created on different sensors and then they are imported to the system and joined with UNION command that offers some flexibility in merging data for different sensor table organization.

VI. CONCLUSION AND FURTHER WORK

Two different mechanisms for database were presented. The FDW enables connecting to other DBMS, while sharding does not allow this. Performance wise, both mechanisms offer similar level of performance for typical operations required, but in the case of node failure they behave quite differently. While FDW blocks for a while missing node and simply returns empty dataset, sharding dos not lock and does not wait and offers better response. However, FDW enables mixing different tables and has a number of functions that were utilized to copy some data to local table and enable some caching. The both of the designs are currently in real production use. Some shortcoming noted here are addressable. For a production network of sensors with near real-time requirement using a database mechanisms is a cost effective and simple implementation until better and simpler middleware is available.

Two different approaches for storing and integrating data collected from many sensors were measured for data collected in a real production plant. The first one is FDW which is shown to provide a good balance between data availability and performance. The approach requires use of explicit specification of the tables on remote nodes. The data is retrieved on demand and to reduce the load only a portion of data should be requested as access to all nodes could show as overwhelming for the network infrastructure.

Flexibility could be achieved with smarter implementation of views on the node. On the other side database sharding provides more flexible, where data is collected on a number of distributed computed modules connected by TCP/IP network in a PostgreSQL database instance. The data on the node is integrated to remote central storage on demand and as a backup. Limited dataset on the DC unit were replicated to centrally.

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CT Metal Artefacts Reduction Using Convolutional Neural Networks

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***Abstract* – Artefacts caused by the presence of metallic implants and prosthesis appear as dark and bright streaks in computed tomography (CT) images, that obscure the information about underlying anatomical structures. These phenomena can severely degrade the image quality and hinder the correct diagnostic interpretation. Although many techniques for the reduction of metal artefacts have been proposed in literature, their effectiveness is still limited. In this paper, an application of a convolutional neural networks (CNN) to the problem of metal artefact reduction (MAR) in the image domain is investigated. Experimental results show that image-domain CNN can substantially suppresses streaking artefacts in the reconstructed images.**

Keywords – computed tomography; metal artefacts; convolutional neural networks

I. INTRODUCTION

The presence of metallic implants and prosthesis within the patient body often cause severe artefacts on computed tomography (CT) scans and may hinder the correct diagnostic interpretation. When X-rays pass through a metal objects, depending on its size and composition, several different physical effects negatively affect the measurements in the detector; most notably are the effects of photon starvation and beam hardening. These effects introduce the artefacts that appear as the dark and bright streaks and/or dark and bright shading between metal objects, especially sever in the region tangent to the boundaries of two objects.

Over the last four decades, many algorithms have been developed to reduce the metal artefacts [1, 2], such as iterative reconstruction methods and projection modification methods based on either projection data or reconstructed images.

Most metal artefact reduction (MAR) methods are based on the projection modification, in which data contaminated by the metal objects are refined in the sinogram domain according to the knowledge obtained from the uncontaminated data [3-6]. A crucial step is a segmentation of the metal regions in the projection data. The corrupted data are often replaced by the data synthesized by an interpolation technique, re-projection from a prior image, or combination of both.

Several iterative reconstruction MAR algorithms have been developed to overcome the limitations of projection-based methods [7, 8]. Iterative reconstruction methods are in general less susceptible to streaking and nonlinear partial volume artefacts caused by metal objects relative to analytical reconstruction methods. Although promising, the application of these methods in commercial CT scanners is hindered by extensive and time-consuming computation, especially for the large data sets.

However, hybrid MAR methods are also proposed by several researchers [12, 13], that combine two or three MAR techniques, thus fusing the merits of various MAR techniques.

Image-based MAR techniques are also proposed in [9-11], and they use the information from the adjoining slice of an affected one to detect its corrupted areas and remove them. Recent papers present an application of deep learning to image-based MAR, because the deep learning has ability to extract detailed features and learns patterns from large datasets [14, 15]. Also, in [16, 17], the techniques that employ a deep learning to correct metal-induced beam hardening in the projection domain are presented.

Inspired by the success in the image processing and the pattern recognition filed [18-20], in this paper we apply the convolutional neural network (CNN) to reduce the metal artefacts in CT images. We train the network to create an end-to-end mapping of CT images with metal artefacts to their corresponding resulting artefacts-corrected images. CNN contains a very few layers, where the first layer can be interpreted as a feature extraction, followed by the non-linear filtering used for a features mapping and the last layer is used for the "synthesis" of the mapped image features.

The rest of the paper is organized as follows. Section II describes the data generation and the convolutional neural network design and training. In Section III, the experimental results and analysis of the proposed method are given. Finally, Section IV gives discussion and conclusion of the relevant issues.

II. METHODS

A. Data generation

At first, all training and test MAR data are generated, and they include artefact-free and metal-corrupted images.

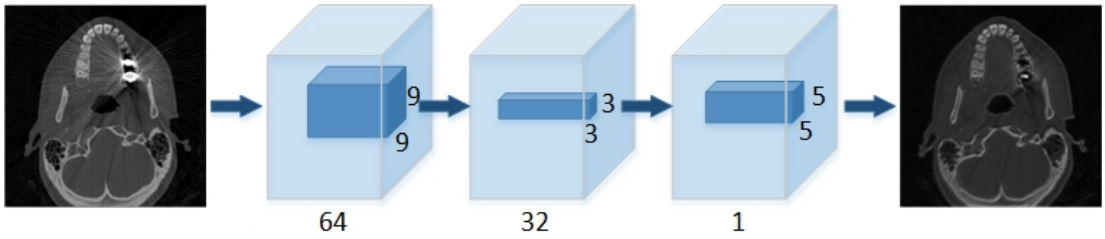


Figure 1. The configuration of the convolutional neural network for metal artefact reduction

To ensure that the MAR algorithm works for real cases, the dataset contains the images obtained by the simulation of the metal artefacts on clinical CTs using the Radon transform of various simulated 2D objects. Sizes, angles, positions and types of objects are carefully adjusted, so that the simulated images are close to the clinical cases. All images are the same size, 512x512 pixels, and some of them contain severe artefacts. For training, we generated 10000 cases with metal materials. The artefacts-free images serve as a ground truth and target of the network. Three images were reserved for the testing and they are not used in the training process.

B. Network design and training

The network structure used in this paper is shown in Fig. 1. It is a simple CNN with three convolutional layers. This network can learn enough artefact features from the input image slices. With the exception of the last layer, each layer is followed by a rectified linear unit (ReLU) to introduce nonlinearity.

The first layer is the feature extraction layer, and contains 64 filters with a 9x9 convolutional kernel and the sliding step is 1. After the transformation of the ReLU activation function, a 64 different feature maps will be obtained. This layer extracts a series of features of the input image including the angles, edges, contours, as well as the dark and bright streaks of artefacts. The second convolutional layer represents nonlinear mapping layer with a 32 filters and 3x3 kernel convolved with the output of first layer. Using this layer, the artefacts and the object are almost separated. A 32 different feature maps are obtained after ReLU unit. The last layer sums the estimates using 5x5 kernel to convolve with the output of the second layer and forms final output image. The padding in each layer is set to 1 so that the size of the output image is the same to the input.

CNN is implemented and trained using Matlab on PC. The initial weights of filters in each layer were randomly set. The base learning rate was 10^{-5}, and the training process took about 25 hours. The loss function was the mean square error between the artefact corrected image and the ground truth (the artefact-free image).

III. RESULTS

The network performance was tested using three images with metal artefacts: two images are dental CT, and one is a hip CT image. These images served as the input to the network. In the case of hip image, artefacts are severe due to large implant size. The CNN significantly reduced the streaking artefacts in all types of images.

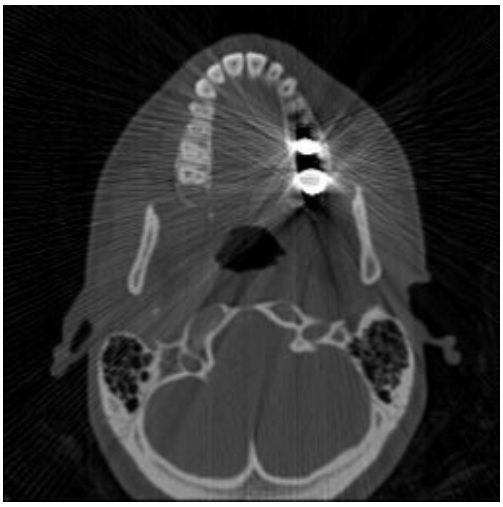
Figure 1 and 2 show the performance of the proposed method for two dental CT scans. The figures depict: (a) the slice with artefacts, (b) the image restored with proposed CNN MAR approach and (c) the image restored using image-based MAR [11]. The slice with artefacts on Fig. 1(a) contains two metal objects positioned closely to each other, so the artefacts are more severe than those on Fig. 2(a). They obscure more information about the anatomical structures. The restored images (Fig. 1(b) and Fig. 2(b)) show that the proposed method reduces significantly the streaking artefacts and the noise, preserving the anatomical structures such as teeth, bones and cavities. However, the performance of the method for the first case is slightly decreased and black regions between teeth can be noticed in the Fig. 1(c). Image-based MAR reduced the metal artefacts, but it introduced some new artefacts and deformation in the resulting image.

Figure 3 shows the results of metal artefacts reduction for the patient with a hip implant. As can be seen from the Fig. 3, significant part of the metal artefacts has been reduced with both methods, especially the bright artefacts around the implant, but some newly introduced artefacts can be observed. There remain some areas that the CNN cannot recover for these challenging cases, and the loss of texture is evident (Fig 3(b)). In the case of image-based MAR, an artefacts are related to the choice of the neighboring slice without artefact: since the metal artefacts caused by the hip implant are propagated through several slices, first neighboring slice without artefacts can be farther away from the slice of interest and can contain somewhat different anatomical structures.

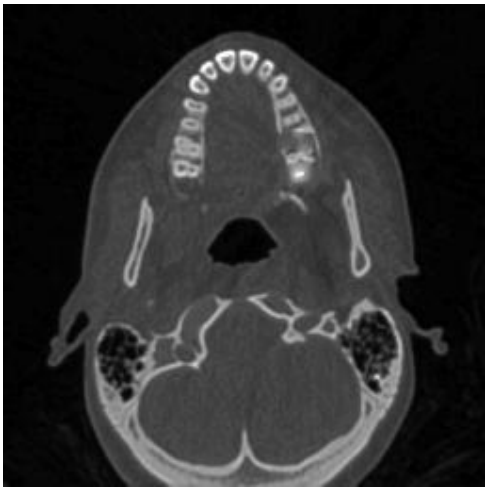
Quantitative analysis given in Table 1 show that the CNN MAR yielded better image quality than image-based MAR proposed in [11] as measured by the structural similarity index (SSIM) measure and the root mean square error (RMSE). The improvement of the CNN MAR over image-based MAR is clear.

TABLE I. Case-by-case image quality metrics of SSIM and RSME calculated for the CNN output and the image-based MAR compared to the ground truth.

	Metric	***CNN***	***Image-based MAR***
Case 1	SSIM	0.8205	0.7012
	RSME	27.8103	84.2717
Case 2	SSIM	0.8308	0.6533
	RSME	33.6702	45.2498
Case 3	SSIM	0.7075	0.6104
	RSME	143.6687	165.5168



(a)

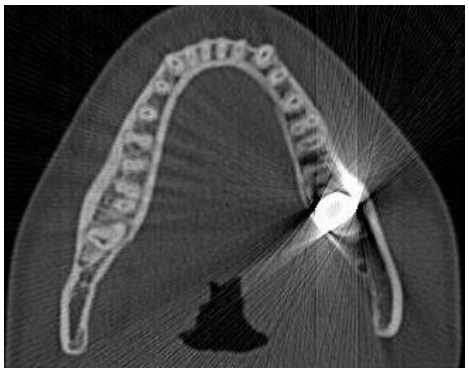


(b)

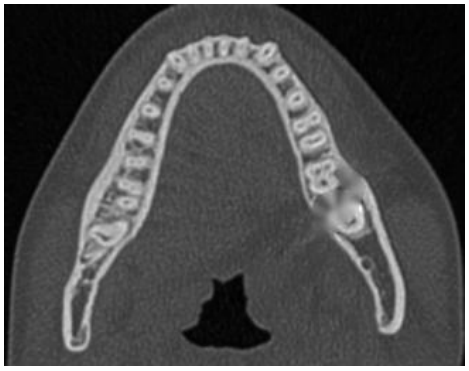


(c)

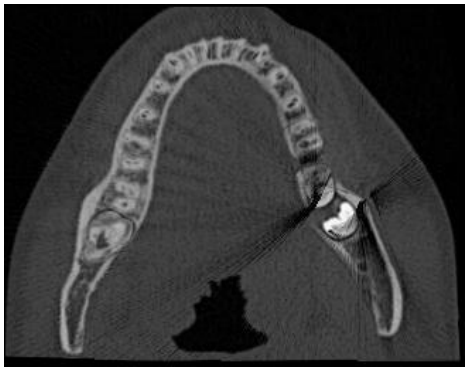
Figure 2. Case 1: (a) The slice with an artefacts; (b) the CNN MAR image and (c) the image-based MAR corrected image



(a)

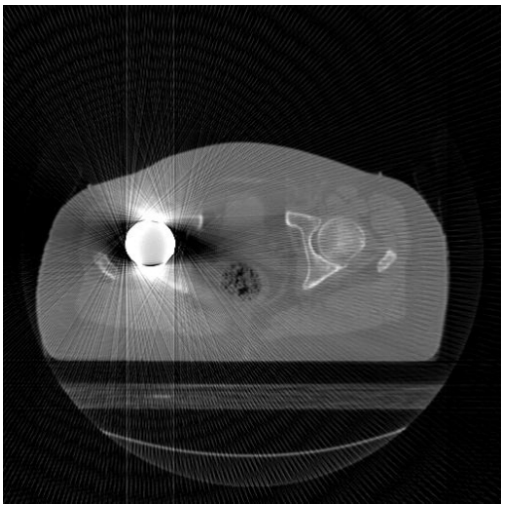


(b)

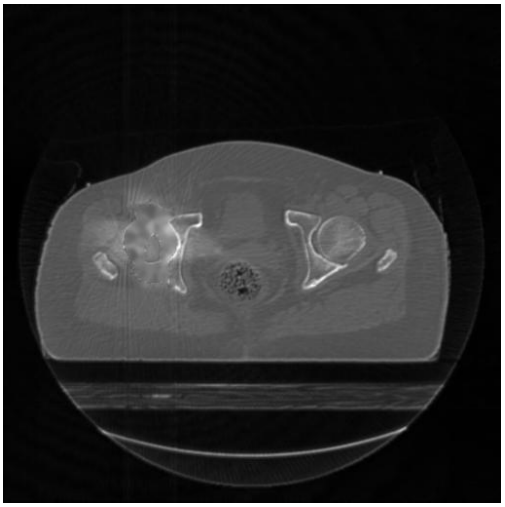


(c)

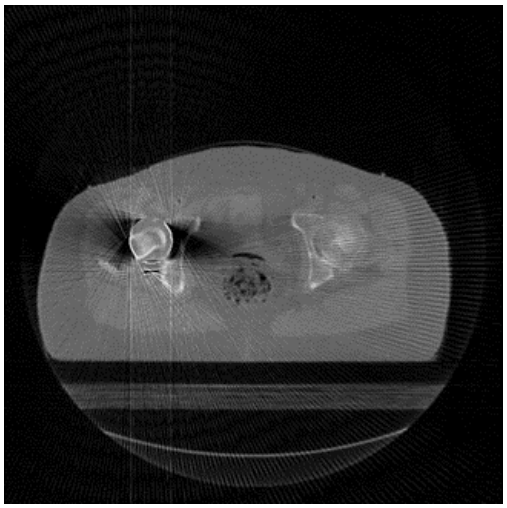
Figure 3. Case 2: (a) The slice with an artefacts; (b) the CNN MAR image and (c) the image-based MAR corrected image



(a)



(b)



(c)

Figure 4. Case 3: (a) The slice with an artefacts; (b) the CNN MAR image and (c) the image-based MAR corrected image

IV. CONCLUSION

This paper explores the potential of the convolutional neural network for reducing the metal artefacts in CT images.

Strength of the CNN MAR lays in its ability to learn and fuse information from different images to avoid strong artefacts and to restore fine structures near the metals. However, the CNN can hardly remove all artefacts and mild artefacts are usually remained. Also, in the case of larger areas affected by the artefacts, the loss of the texture in the affected image area is evident.

Here, a simple CNN with only three layers and rather small dataset has been used, but obtained experimental results are promising. A network with more layers can further improve the performance of MAR algorithm, and that will be focus of the future work.

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Improved nucleus segmentation process based on knowledge based parameter optimization in two levels of voting structures

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***Abstract* – Digital analysis and biomedical image processing has become important part within modern medicine and biology. Digital pathology is just one of many medicine areas that is being upgraded by constant biomedical engineering research and development. It is very important that some of disciplines as nucleus detection, image segmentation or classification become more and more effective, with minimum human intervention on these processes, and maximum accuracy and precision. Improved optimization of nucleus segmentation methods parameters based on two levels of voting processes is presented in this paper. First level includes hybrid nucleus segmentation based on 7 segmentation algorithms: OTSU, Adaptive Fuzzy-c means, Adaptive K-means, KGB (*Kernel Graph Cut*), APC (*Affinity Propagation Clustering*), Multi Modal and SRM (*Statistical region merging*) based on optimization of algorithms parameters along with implemented first level voting structure. Second level voting structure includes segmentation results obtained in the first level of voting structure in combination with 3rd party segmentation tools: ImageJ/Fiji and MIB (*Microscopy Image Browser*). A definite segmented image of a nucleus could serve as a generic ground truth image because it is formed as a result of a consensus based on several different methods of segmentation and different parameter settings, which guarantees better objectivity of the results. In addition, this approach can be used with great scalability on 3D-stack image datasets.**

Keywords - biomedical engineering; image segmentation; nucleus segmentation; ground truth segmentation; methods of segmentation;

I. INTRODUCTION

Medical diagnostics has significantly changed over past years. Process of digitalization allowed further involvement of biomedical engineering into every aspect of disease treatment, or medicine overall.

Now, with 4th industrial revolution happening beneath human civilization, biomedical engineering has become more important than ever. Having high-throughput data, machine learning methods and techniques, superior computer resources, it is necessary to incorporate as many fields as possible in order to get best possible results.

With digital pathology considered, it is important to have precise, robust and fast segmentation process, which involves as less human interaction as possible. In order to allow medical team better starting point for future actions, automated and reliable segments are required. The same applies to nucleus segmentation.

It can be difficult to identify single algorithm or single way to make segmentation as precise as possible. Usually, each of the methods has its advantages, but also its disadvantages.

Study in this paper offers novel approach in nucleus segmentation, and segmentation in general. With combination of multilevel and multi algorithm approach, study offers segmentation with higher reliability, accomplished by fusion of different aspects and methods, and in that way making initial generic ground truth model. Complete process will be demonstrated using Arabidopsis thaliana dataset.

The rest of the paper consists of five sections. In section 2, some of the related work is referenced and described. In section 3, dataset and way of project implementation is presented. In section 4 complete development process is given, and final results are discussed. In section 5 conclusions are made. In section 6 acknowledgments are given.

II. STATE OF ART

Many papers include nucleus segmentation based on individual algorithms used in this paper. Automated segmentation of cell nuclei in cytology pleural fluid images using OTSU thresholding is achieved in [1]. Other papers also demonstrate usage of OTSU in nucleus segmentation [2] [3] [4]. In [5], sequential usage of OTSU and Adaptive K-means clustering is made. Multimodal approach, featuring watershed and active contours is proposed in [6].

In [7] [8], global overall state has been described, in nucleus segmentation, detection and classification. Examples of various papers have been shown, with usage of different algorithms, some of them being local adaptive thresholding, G-cuts, K-means clustering, watershed algorithms etc.

Contour-based minimalistic model cell nucleus detection had been demonstrated in [9].

In [10], automatic cell nuclei segmentation of BCH (*Breast Cell Histopathology*) images is proposed, with usage of combined techniques, such as wavelet decomposition, multi-scale-region-growing, SVM (*Support Vector Machine*) algorithm for images feature extraction

etc. In [11], Affinity Propagation Clustering is proposed as new approach for grayscale image segmentation, and makes comparison to Adaptive K-means and Fuzzy-c means algorithms. Fuzzy –c means algorithm, in combination with circular shape function, is used for nucleus segmentation in [12]. K means clustering for image and nucleus segmentation is used in [13] [14]. Three step approach, using initial nucleus segmentation, with inter and intra discriminative information is demonstrated in [15]. In [16], nucleus segmentation using Gaussian mixture based shape models is demonstrated.

Many of papers include one to maximum three steps in segmentation process, combining previously mentioned work. At the time of writing this paper, there were no published papers that involve multiple usage of same resulting algorithms, with combination of voting structures on multiple levels.

III. DATASET AND EXPERIMENT MODEL DESCRIPTION

In this research 3D microscopy images [17] [18] was used, made available by GReD (*Genetique Reproduction & Development*), which is a Research Center at Clermont-Ferrand. Dataset consists of 3D multipage images, providing 77 wild and mutated samples of Arabidopsis Thaliana plant. 39 examples belongs to mutated class, and 38 examples belong to wild class. Each of the samples is saved in .tif format, as previously mentioned, including various number of 2D multipage images (number is not deterministic, it varies from sample to sample), in that way providing full 3D stack image.

All experiments in this study are made in MATLAB [19]. One sample from dataset is shown in figure "Fig. 1".

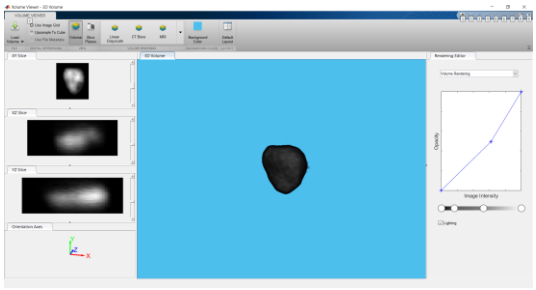

Figure 1. 3D image sample in Volume Viewer (MATLAB)

Each of 3D stack samples is processed as multipage 2D images. In a manner of reverse engineering, 3D image can be segmented by enrolling individual slices of each 3D stack, making batch 2D segmentation, and finally again connecting all 2D slices for resulting 3D segmentation image. This process is described in "Fig. 2".

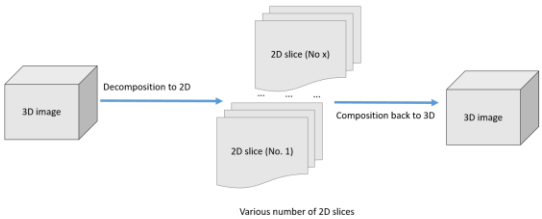

Figure 2. 3D image decomposition

The segmentation process is applied to the sequence of 2D images in two steps. The first step refers to the local segmentation in the MATLAB environment and GUI tool, and the second step relates to the global segmentation. The last step also uses GUI MATLAB tool for global voting segmentation process, which results in final segmentation image. Each of these steps will be described in next paragraphs. Diagram of multilevel segmentation is shown in "Fig. 3".

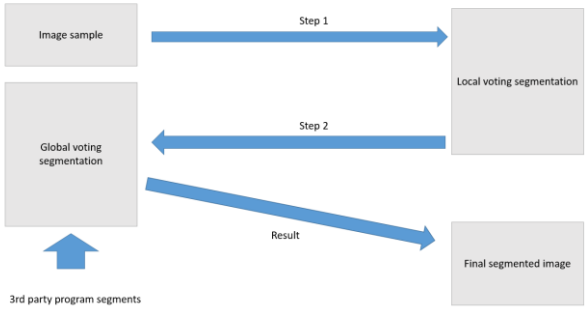

Figure 3. Multilevel/multistep segmentation, local and global

A. *GUI local voting structure tool for 2D and 3D segmentation*

As mentioned before in paper, first step of multilevel segmentation is implemented in MATLAB GUI tool, developed by authors of this paper. It provides interface for both 2D, and 3D segmentation (with multipage batch method). Interface for 2D segmentation provides choice of selecting 2D image for segmentation, while interface for 3D segmentation provides selection of 3D stack image. GUI interface is shown in "Fig. 4".

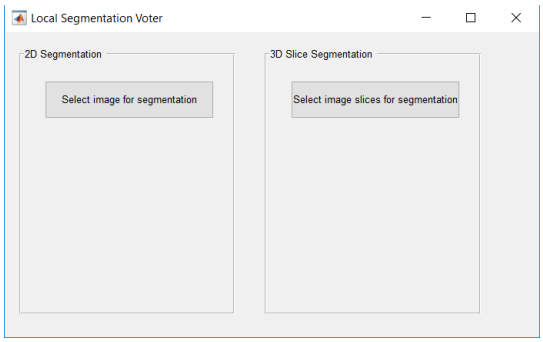

Figure 4. MATLAB GUI tool for local voting segmentation

After image selection, this tool implements multi algorithm knowledge based voting mechanism. Individual knowledge based segmentation of image is made by following 7 algorithms: OTSU [20], Adaptive Fuzzy-c means [21], Adaptive K-means [5], KGB (*Kernel Graph Cut*) [22] [23], APC (*Affinity Propagation Clustering*) [24] [25], Multi Modal [26] and SRM (*Statistical region merging*) [27].

Full process uses 3 operators: combinatorics, median and voter.

1) *Knowledge based optimization*

KB (*Knowledge Based*) optimization includes 11 deterministic values for each algorithm parameters, using linear approach combinatorics operator for parameter's values. That means that each method provides 11

segmentations, with parameter values linearly selected within domain. This only applies to first image slice. Resulting segmentation is median segmentation of calculated 11 segmentations. These segmentations are sorted by the number of pixels equal to 1. Median is determined by formula:

$$Median = A_{\lfloor \frac{n+1}{2} \rfloor} \quad (1)$$

Where

- n represents number of segmentations, in this case 11
- $A_{\lfloor x \rfloor}$ is x-th segmentation, in previously sorted manner
- $\lfloor x \rfloor$ (floor of x) is the biggest integer, which is not bigger than x.

Parameter values of median are saved, and used for segmentation of other slices. In this way, more robust and scalable results are made. KB optimization is shown in "Fig. 5".

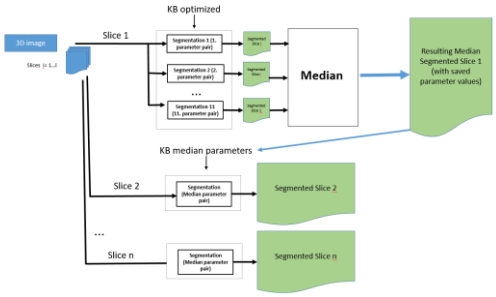

Figure 5. Individual algorithm segmentation with knowledge based optimization

2) *Local voting structure*

After individual KB optimization of segmentation process, voting mechanism calculates resulting segment. Formula for voter operator is given below:

$$new_pixel_{ij} = \begin{cases} 1 & if \sum_{every\ matrix} pixel_{ij} \geq \frac{n}{2} \\ 0 & if \sum_{every\ matrix} pixel_{ij} < \frac{n}{2} \end{cases} \quad (2)$$

Where i,j represent row and column of pixel in segmentation matrix, and n represents number of input segmentations (in this case n = 7),

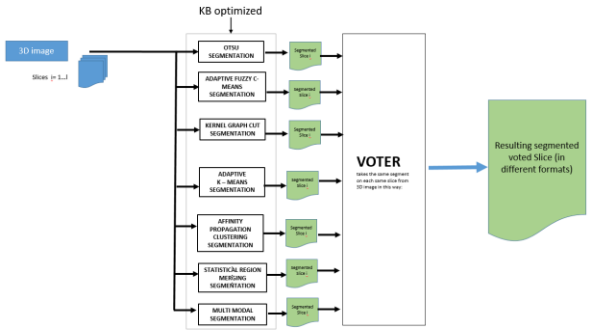

Figure 6. Full local segmentation process

Each of the resulting algorithm-individual segmented slices (that consists of values 0 and 1) are injected into voting structure, and considering the fact that there are odd number of algorithms, value of each pixel can be determined successfully. At the end of process, tool provides resulting segmented image in both MATLAB variable and image format. Full process is shown in "Fig. 6". Voting mechanism is shown in "Fig. 7" (and just for demonstration purposes, it is assumed that samples are in 2x4 dimension).

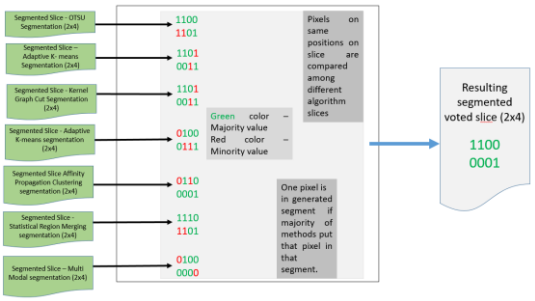

Figure 7. Voting mechanism/structure inside of local segmentation process

B. *Global voting segmentation*

Global voting segmentation also includes GUI tool developed by authors of this paper. It provides voting segmentation for 2D segmented slices, and can be also used for 3D multipage segmentation also.

This step includes segmentation made by 3rd party programs, NucleusJ (ImageJ/Fiji) [28] [29] and MIB (*Microscopy Image Browser*)/MATLAB [30].

1) *NucleusJ*

NucleusJ is a simple and user-friendly ImageJ plugin dedicated to the characterization of nuclear morphology and chromatin organization in 2D/3D [18]. It offers many image processing tools, including segmentation. Process of segmentation in NucleusJ is shown in "Fig. 8".

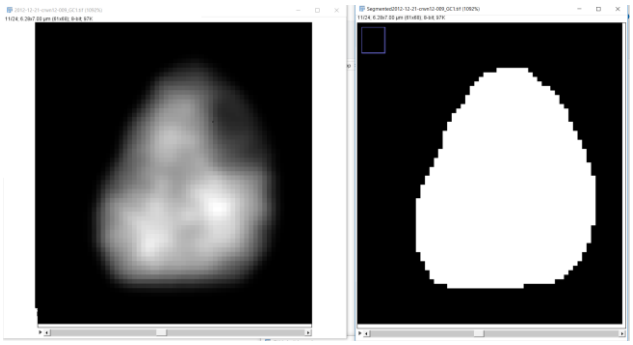

Figure 8. Result of NucleusJ segmentation, preview of one slice

2) *MIB*

Microscopy Image Browser (MIB) is a powerful MATLAB plugin for advanced image processing, segmentation and visualization of multi-dimensional (2D-4D) light and electron microscopy datasets [31] [32]. Process of nucleus segmentation of given dataset is shown in "Fig. 9".

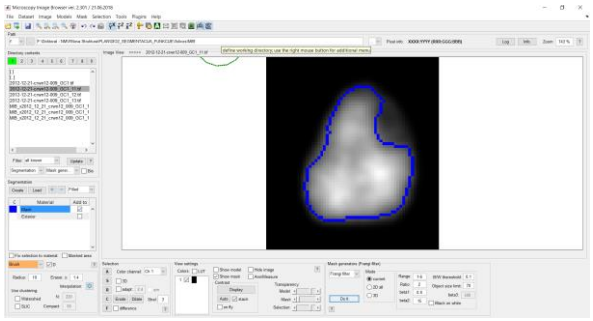

Figure 9. Process of MIB segmentation

3) *Voting process*

GUI tool provides choice of segmented image, done by local segmentation process, NucleusJ, and MIB, as it is shown in “Fig 10”.

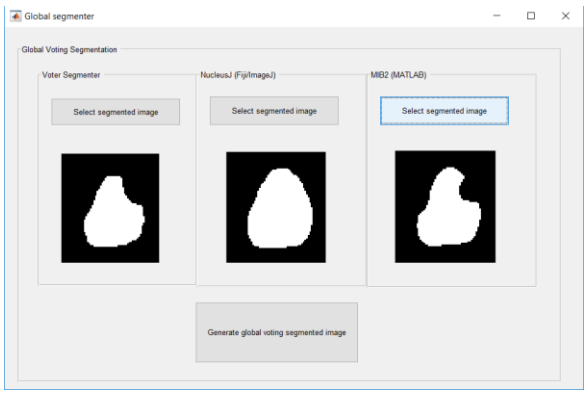

Figure 10. Global segmentation GUI tool, in process of obtaining of resulting segmented slice 1

After that, each of selected segmented slices are processed through global voting structure. There are odd number of selected segmented slices, so it is possible to calculate each pixel's value.

End result of this stage is final global voted segmented image of selected slice. Complete global segmentaion process is shown in „Fig. 11“. Global voting mechanism is shown in “Fig. 12” (and just for demonstration purposes, it is assumed that samples are in 2x4 dimension, with same assumed local segmented slice in “Fig. 5”).

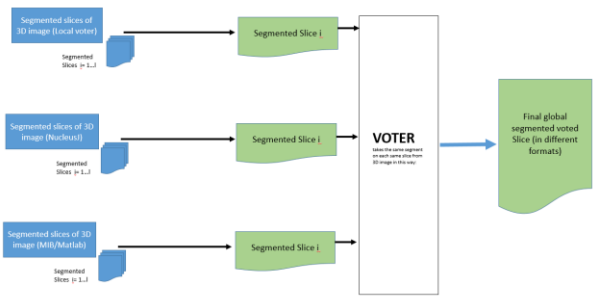

Figure 11. Complete global segmentation process

In this way, it is possible to make segmentation process on every slice, sample or dataset.

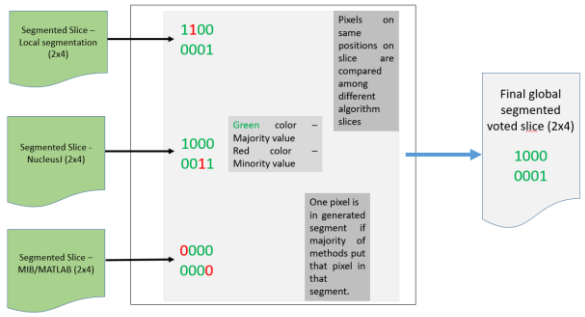

Figure 12. Voting mechanism/structure inside of global segmentation process

IV. PROCESS DEMONSTRATION AND RESULTS DISCUSSION

For demonstration purposes, complete segmentation process is done on one sample of the dataset, taking 3 individual 2D slices from middle part of 3D multipage image collection. Nevertheless, same process can be applied on full dataset. Slices are shown in “Fig. 13”.

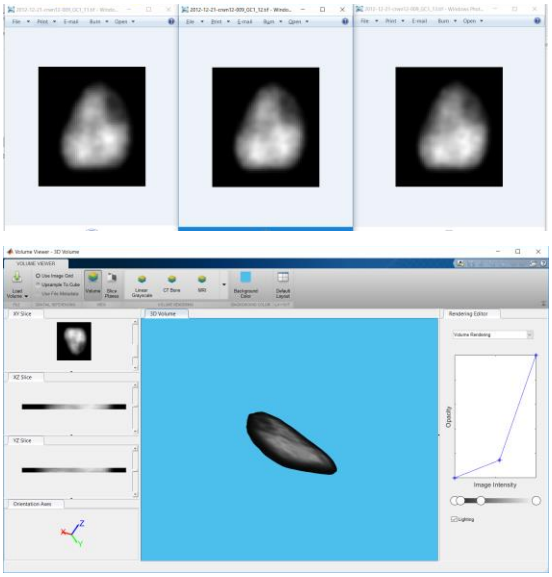

Figure 13. 3 slices in 2D and 3D

These 3 slices are then processed through GUI tool for local voting segmentation. Results and segmented images are shown in “Fig. 14”

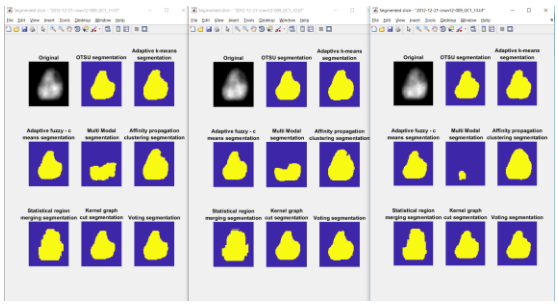

Figure 14. Local segmentation on 3 slices, resulting and algorithm-individual segments

After this step, nucleus segmentation through 3rd party programs NucleusJ and MIB is made. Resulting segmented images of this process are shown in "Fig. 15" and "Fig. 16" for NucleusJ, and "Fig. 17" and "Fig. 18" for MIB.

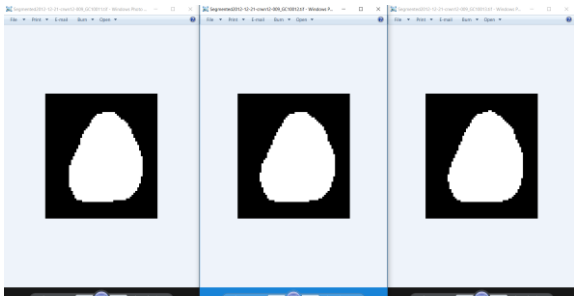

Figure 15. Nucleus J segmentation on 3 slices

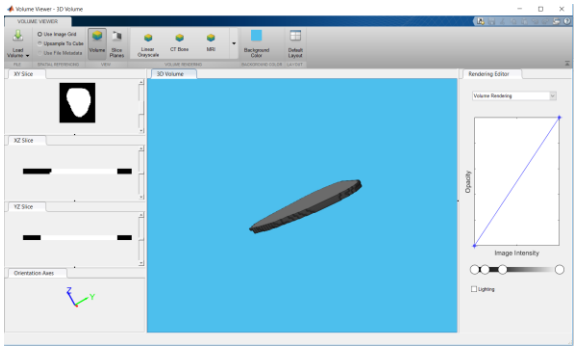

Figure 16. 3D preview of 3 NucleusJ segmented slices

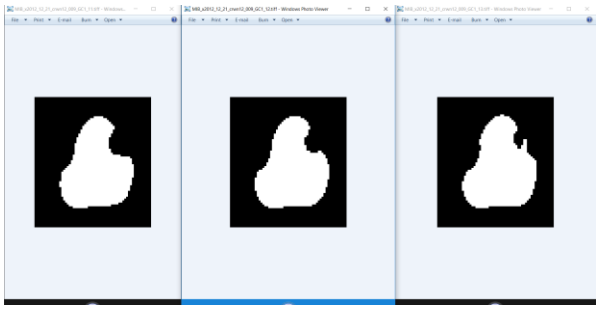

Figure 17. MIB segmentation on 3 slices

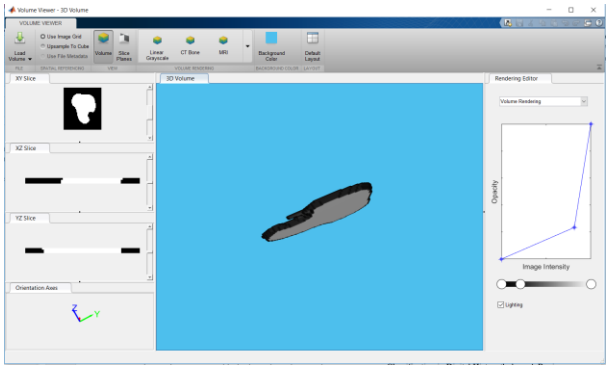

Figure 18. 3D preview of 3 MIB segmented slices

Finally, all data is ready for second, final step, global segmentation voting process. This final product can be called generic "ground truth". This is done through second GUI tool. Results of second and final step are shown in "Fig. 19" and "Fig. 20".

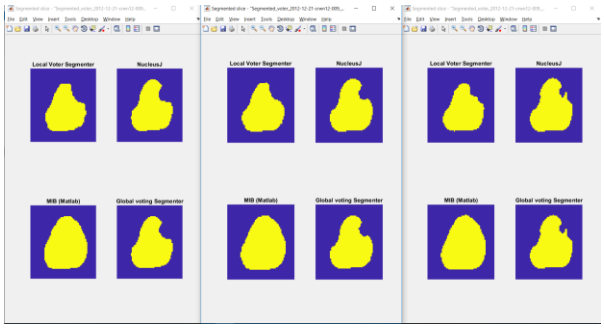

Figure 19. Comparison of individual 3 slice in global segmentation

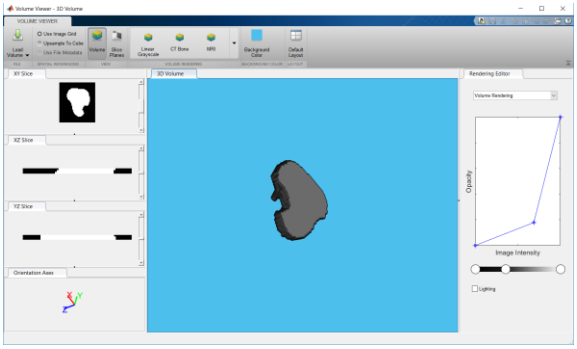

Figure 20. 3D preview of global voting segmented slices

If first step is analyzed ("Fig. 13"), it can be seen that Multi Modal algorithm had noticeably different segmentation results than other algorithms. But, with voting mechanism, those articulations were corrected, so final segmented image from local voting segmentation process was unaffected.

In second step, on "Fig 18", Local voting segmentation process had a smaller amount of segment identification in upper right corner of image. But, after global voting segmentation process, it can be seen that final segmented image has included the majority of detected segment. Also, it can be seen that MIB segmentation was a bit wider, but other 2 algorithm were able to balance segmentation through voting process.

V. CONCLUSION

This study offers more objective process of segmentation. The study used nucleus dataset, but this process can be repeated on any kind of fluorescent microscopy dataset. With described GUI tools, this paper's segmentation process becomes scalable and easy-to-use.

With usage of multilevel and knowledge based optimization of more algorithms in voting structures, study demonstrated that resulting segmented image has higher reliability than results got from individual algorithms.

Furthermore, this approach offers easy second step algorithm replacements along with continuous usage of given GUI tools, with no need for additional coding.

This paper' study is considered as introducing gradational step in the computation of generic automatic/semi-automatic ground truth segmentations for biomedical images.

Future work will involve further progress in image acquisition and analysis approaches that meet the specific challenges of plants and will allow imaging and segmentation of plant nuclei using generic ground truth image algorithms based on deep learning neural networks.

VI. ACKNOWLEDGMENTS

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Correspondence Analysis Applied to Large Scale Evo-Devo Data

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Abstract **- Correspondence analysis (CA) is an exploratory method used for visualizing and understanding high dimensional data. It is mostly applied to contingency tables. Although the method has been used in various fields for decades, including bioinformatics, to our knowledge it has not yet been applied to the evolutionary analysis of gene expression data during developmental process. In this paper we present the application of the CA method to linking evolutionary age of genes and their developmental expression profiles. As a test dataset, we used evolutionary age of genes obtained by phylostratigraphic approach and expression data collected during development of a model microorganism. The obtained results show that CA could complement current approaches for coupling evolutionary and developmental information at the molecular level.**

Keywords - correspondence analysis, evo-devo, phylostratigraphy, dimensionality reduction.

I. INTRODUCTION

The size and dimensionality of a dataset obtained from a biological experiment can be a limiting factor in exploring, visualizing and understanding the data. To address this problem, a dimensionality reduction method can be used. Correspondence analysis (CA) is one approach of this kind, which is based on singular value decomposition [1]. Correspondence analysis is designed to work with categorical variables and its input is a contingency table, i.e. the two-way table (2D matrix) where observations can be associated with two categorical variables (represented by rows and columns). Moreover, unlike related principal component analysis (PCA) [2], the CA can project points for both variables in the same low dimensional space, allowing the insight into their correspondence.

The origin of correspondence analysis dates back to 1900s [3], and its modern version was developed by Benzécri in the 1970s [4]. It has been used for decades in various fields such as market research [5] and medical research [6]. In bioinformatics, CA was applied to the analysis of amino acid composition in living organisms, genotyping data [7], and analysis of microarray data [8].

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In this paper, we show the application of CA to linking evolutionary age and expression levels of genes over development phases of an organism. This kind of data is currently analyzed by the transcriptome age index (TAI) and its derivatives [9]. In principle, TAI combines the evolutionary and expression data by calculating mean evolutionary age of expressed genes weighed by their expression values. This kind of analysis produces a single profile that connects the evolutionary levels and the developmental phases. The significance of obtained TAI fluctuations over development could then be tested by repeated measures ANOVA [9]. Although very useful for testing general biological hypothesis [9], this approach radically simplifies underlying evolutionary and developmental information.

To find a balance between necessity to collapse such complex datasets and keeping biologically relevant information, we tested here how CA performs on developmental expression data coupled with evolutionary information. We present the preliminary results of CA applied to the data obtained during the development of a microorganism. The obtained results have a similar biological interpretation as the results obtained by calculating the TAI profile, while giving additional information on similarities between evo-devo data points.

II. CORRESPONDENCE ANALYSIS METHOD

In this section, we present the basic concepts of CA adopted from Yelland [10]. A more detailed formal mathematical definition of the CA method can be found in [1]. The typical input data for CA is a contingency table. A contingency table C is an $I \times J$ matrix where x_{ij} values are observations that can be associated with two categorical variables V_1 and V_2. I and J are the number of possible values of the categorical variables V_1 and V_2.

A simple toy example that is often used in explaining CA is a contingency table of employee smoker types in a fictitious organization [1]. In this table, the first categorical variable (V_1) is the staff group and it can obtain values from the set: {senior managers, junior managers, senior employees, junior employees, secretaries}. The second variable (V_2) is the smoking category that can have values from the set {none, light,

medium, heavy}. Every employee from the organization contributes to only one field in the table that corresponds to its staff group and smoking category, i.e., the table contains the count of employees belonging to each combination of the two categories.

The first step in CA is calculating the correspondence matrix *P* from the contingency table. The correspondence matrix is an *I*×*J* matrix of probabilities of a sample belonging to each combination of categories from V_1 and V_2. The p_{ij} element of the matrix *P* is calculated by dividing each element x_{ij} from matrix *C* with its total sum *n* defined with (1).

$$n = \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} \tag{1}$$

The marginal probability of row *i* is annotated with p_{i+} and is defined as the sum of the *i-th* row (2).

$$p_{i+} = \sum_{j=1}^{J} p_{ij} \tag{2}$$

In a symmetric way to (2), the marginal probability of column *j* is annotated with p_{+j} and defined as the sum of the *j-th* column (3). In CA the marginal probabilities or rows and columns are also called masses.

$$p_{+j} = \sum_{i=1}^{I} p_{ij} \tag{3}$$

The chi-square independence test [11] is usually included as the step of CA. The test gives the information on the independence of the observed categorical variables V_1 and V_2 (rows and columns of *C*). V_1 and V_2 are independent if the joint probability of each element in matrix *C* is equal to the product of the corresponding marginal probabilities (4).

$$\forall i, \forall j,\ p_{ij} = p_{i+}p_{+j} \tag{4}$$

If V_1 and V_2 are independent, their product in row *i* and column *j* is called the theoretical probability and its annotated with μ_{ij} (5).

$$\mu_{ij} = p_{i+}p_{+j} \tag{5}$$

The chi-square statistic calculates the variation of observed probabilities p_{ij} from the theoretical probabilities of the variables if they are independent with (6).

$$\chi^2 = n\sum_{i=1}^{I}\sum_{j=1}^{J}\frac{\left(p_{ij}-\mu_{ij}\right)^2}{\mu_{ij}} \tag{6}$$

Under the null hypothesis of having independent variables V_1 and V_2 the χ^2 statistic follows the χ^2 distribution [11] with *(I-1)×(J-1)* degrees of freedom. If the *p-value* is sufficiently low the null hypothesis can be rejected, meaning V_1 and V_2 are not independent. The chi-square statistic gives us the strength of the deviation of observed and theoretical probabilities but it does not give us the information on how the probabilities of samples differ from each other (row-row or column-column). To obtain this information the χ^2 distances can be calculated. The χ^2 distance d_{ik} between row *i* and *k* are given with (7).

$$d_{ik} = \sqrt{\sum_{j=1}^{J}\frac{\left(p_{ij}/p_{i+} - p_{kj}/p_{k+}\right)^2}{p_{+j}}} \tag{7}$$

To see that the χ^2 distance is related to the χ^2 statistics we can examine the χ^2 distance or row *i* to the centroid (also known as barycenter in CA) of rows. The row centroid *z* is a row containing column marginal probabilities p_{+j} from *j=1 to j=J*. We can insert the centroid row and row *i* in (7). If we use (5) and the fact that the sum of the centroid row is 1 with a few math operations we get (8).

$$d_{iz}^2 = \frac{1}{p_{i+}}\sum_{j=1}^{J}\frac{\left(p_{ij}-\mu_{ij}\right)^2}{\mu_{ij}} \tag{8}$$

In CA the product of the marginal probability (mass) p_{i+} with the χ^2 distance to the centroid d_{iz}^2 is called the inertia. If we compare (8) with the chi-square statistic (6) we can see that the total inertia of all rows is equal to the χ^2 statistics divided by *n* (9), the term is annotated with ϕ^2 and is called the Pearson's mean-square contingency.

$$\phi^2 = \sum_{i=1}^{I} p_{i+}d_{iz}^2 = \frac{\chi^2}{n} \tag{9}$$

The equations (7), (8), (9) are made for rows, in a symmetric way the equations can be derived for columns. The goal of CA is to reduce the table of χ^2 distances in a lower dimension so that the points can be visualized while approximating the χ^2 distances in the original table. The method uses the singular value decomposition (SVD) method [12]. The SVD is performed on the matrix of standardized residuals Ω (10).

$$\Omega = \left[\frac{p_{ij}-\mu_{ij}}{\sqrt{\mu_{ij}}}\right] \tag{10}$$

SVD decomposes the original matrix Ω to two orthogonal matrices *V* and *W* and one diagonal matrix Λ (11).

$$\begin{aligned}\Omega &= U\Sigma V^T \\ UU^T &= VV^T = 1\end{aligned} \tag{11}$$

Matrix W_r is a diagonal matrix where the diagonal element *i* is the square roots of the reciprocal values of the marginal probabilities of the corresponding row *i* (12).

$$W_r = diag\left\{\frac{1}{\sqrt{p_{i+}}}\right\} \tag{12}$$

The final row scores are calculated with the expression (13).

$$R = W_r U\Sigma \tag{10}$$

The Euclidean distances between rows in the matrix *R* are equal to the χ^2 distance of the original corresponding rows. To make a 2D plot of rows, we can use only two components of the matrix *R*, so we plot only the first two components in each row that contain the most

information. The total inertia can be used to calculate the quality of the representation. We can observe the percentage of inertia in the representation of the total inertia.

The columns plot can be produced symmetrically to the rows plot. The matrix W_c is a is a diagonal matrix where the diagonal element j is the square roots of the reciprocal values of the marginal probabilities of the corresponding column j (13).

$$W_c = diag\left\{\frac{1}{\sqrt{p_{+j}}}\right\} \tag{13}$$

The final column scores C are calculated with the expression (14).

$$C = WV\Sigma \tag{14}$$

Before plotting the columns to the same graph as the rows their values have to be scaled so they occupy roughly the same region of the plot. Due to this scaling the row-column distances are not a representation of the χ^2 distances. The interpretation of the row-column correlation is not as straightforward as the row-row or column-column correlation. The interpretation of the results is discussed further in the next section.

For data preprocessing, we have developed scripts in the programming language Python. The chi-square test and CA was done in the programming language R with the package FactoMineR [13].

III. Results and Discussion

In this section, we present the preliminary results of CA applied to linking evolutionary age and the developmental phases of a model microorganism. Gene expressions are measured over 11 developmental phases annotated *T1-T11* using the RNA-sequencing (RNA-Seq) method [14]. The evolutionary gene age is obtained by phylostratigraphic approach [15]. Each gene is assigned to an evolutionary step, i.e. to a categorical variable that can take one of the predefined values (called phylostrata [16]). Higher step values indicate evolutionary younger genes. We placed the data in a matrix (contingency table), where rows (V_1) are evolutionary steps (*G1-G3*) and columns (V_2) are developmental phases (*T1-T11*) and applied the CA method.

To test if the values in the matrix deviate significantly from the matrix where the rows and columns are independent, we have performed a chi-square test of independence [17]. The obtained chi-square statistic has a p-value less than 1e-100, indicating that the rows and columns are not independent.

The CA plot of evolutionary step groups (blue circles) and developmental phases (red triangles) is shown in Figure 1. The total inertia of the raw profiles is captured in the plot, i.e., the first two dimensions encounter for 100% of the total inertia.

In CA, the Euclidean distances of the projected points when comparing rows to rows or columns to columns represent the chi-square distances of the original profiles [10].

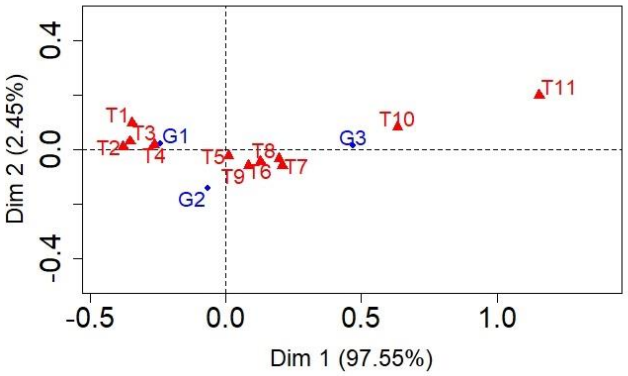

Figure 1. CA of evolutionary steps *G1-G3* (blue circles) and developmental phases *T1-T11* (red triangles).

First, we can analyze row and column profiles separately. From the plot we can see that row profiles (evolutionary age) *G1* and *G3* are well separated in the first dimension. *G2* is near the origin in dimension one, but is separated from *G1* and *G3* in the second dimension.

From the plot we can distinguish three groups of column profiles (developmental phases). The first group contains points (*T1-T4*), second (*T5-T9)*, and third (*T10-T11)*. In CA the points near to the origin have profiles that are similar to the mean profile [10]. The points from the second group are near to the origin and those of the first and third group are separated in the first dimension.

Comparing the rows to columns is not so straightforward as comparing only rows or only columns. For this comparison we used a method adopted from Yelland [10]. We can connect the row and column points to the origin with a straight line and compare the angles between them. If the angle is acute, then the correspondence of the evolutionary step and development phase is greater than on average. In contrast, if the angle is obtuse, the correspondence is lower than on average. For example, we can see in Figure 1 that the group *G1* corresponds to development phases *T1-T4.*

The first dimension encounters for 97% of the total inertia. If we examine the meaning of the dimensions, we can see that the development phases are ordered in the first dimension from *T1* to *T11*. This gives us an interesting interpretation of the first dimension as the timeline of the development process. We have compared the CA results to the results of the TAI profile and we have seen that they give a similar biological interpretation of the process. Additionally, CA gives a way to visualize the evolutionary steps and development phases on the same graph. From CA we can get insight into the grouping of developmental phases and their correspondence to evolutionary age groups.

IV. Conclusion

In this paper, we have presented the application of correspondence analysis to evo-devo data. The biological interpretation of the results agrees well with the

interpretation obtained by the standard TAI analysis. Compared to the TAI method, CA gives a way to visualize and examine the correspondence of evolutionary steps and development phases on one plot. This indicates that the CA method could be a useful tool for exploring and visualizing evo-devo data.

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Calculation of topological molecular descriptors based on degrees of vertices

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***Abstract* - Topological molecular descriptor is calculated by a mathematical procedure from the structure of chemical compounds represented by a molecular graph, containing information about their structural characteristics [1]. There are many defined topological descriptors in literature which transform specific chemical information into useful numerical values that have been used for correlation of structure-descriptors with various physico-chemical properties [2]. Among the first topological descriptors that accelerate further development of the field are M1 and M2 indices introduced by Gutman and Trinajstić in 1972 [3] (later named Zagreb indices). Vertices of a molecular graph represent atoms and edges connecting vertices of a graph represent carbon-carbon (or non-hydrogen) chemical bonds. The total number of edges connecting one vertex with its (first) neighbour carbon vertices corresponds to valence of that atom with other carbons within a molecule. One of the largest classes of topological descriptors is the one based on the analysis of vertex degrees of a molecular graph [4]. Starting from electronic version of chemical structures we will develop and optimize an application for calculation of different vertex-degree-based topological descriptors, which is made available for free use to the research community at http://meteo2.irb.hr/indexer.**

***Keywords* - topological molecular descriptor, vertex-degree, molecular graph, structural information, Zagreb indices, modified indices, M1, M2, web server**

I. INTRODUCTION

The development of the area of modeling the relationship between the chemical structure (encoded in electronic form) and their chemical and molecular properties or activities is directly related to the development of new molecular descriptors. Molecular descriptors are numerical parameters that quantify the structural characteristics of chemical compounds (molecules). Today, thousands of molecular descriptors can be calculated for medium-sized chemical compounds used in the field of drug research (design) [1]. Most of these descriptors are based, solely or in part, on a simplified representation of the structure of the molecule in the form of a partially connected graph. In that graph-scheme, atoms are shown in the graph as vertices, and chemical bonds (which actually exist between atoms) are represented by edges [2]. Topological indices M1 and M2 (the first and the second Zagreb index) introduced by Gutman and Trinajstić [3] are later influenced a more intensive development of topological descriptors, one of the most frequently used sub-class of molecular descriptors named also degree-based topological descriptors [4]. Zagreb index M1 is calculated as the sum of square of valences of each non-hydrogen atom in the molecule, and Zagreb index M2 is the sum (over all bonds within molecule, when they are treated as single bonds) of products of valences of bonded atoms (*i.e.* atoms forming chemical bond). The advantages of topological descriptors are reflected in their rapid computation comparing to other descriptors that require long-term optimization of structures at either lower or higher levels of optimization. At present, this advantage is especially remarkable when modeling is performed on large data sets of molecular structures. Today, data sets that have tens of thousands of structures are very common in modeling. After introduction of Zagreb indices several modified forms of indices are proposed and intensively used in structure-property modeling of different chemical and biological problems. A recent highly cited overview and comparative study related to degree-based indices was published by Gutman [4]. However, to our best knowledge, there are no available web-based free applications by which one can compute all introduced forms of Zagreb indices. That is why we decided to develop a web server for computation of original and different modified forms of Zagreb indices, to be used in comparative studies or in further development of degree-based topological descriptors.

II. MATERIALS AND METHODS

Developed application starts from input file containing structures of chemical compounds recorded in the MOL format and inserted into one file in SDF (Structure Data File) format [5]. Single SDF file contains one or more

molecular structures each recorded/given in the MOL structure format. The MOL/SDF file is strictly formatted file which contains data about position of each atom in a molecular structure, and also metadata molecule like chemical formulae, molecular ID or software usage information. We used MOL/SDF format although there are many other structure formats, and also there are computer programs for conversion of one form of chemical structures into different other formats [5].

TABLE I. MAVEN DEPENDENCES USED IN THE PROJECT

	Maven dependency details		
	Group id	***Artifact id***	***version***
1	org.openscience.cdk	cdk-group cdk-data cdk-atomtype cdk-isomorphism cdk-core cdk-io cdk-interfaces	1.5.3
2	junit	junit	4.11
3	jgrapht	jgrapht	0.7.3, 0.5.3
4	org.jgrapht	jgrapht-core jgrapht-ext	1.3.0
5	com.google.code.gson	gson	2.2.4
6	net.objecthunter	exp4j	0.4.8

SDF/MOL format can also contain (simplified) SMILES structure form [5]. SMILES line is at the end of metadata written below lines <UNIQUE_SMILES> or <USER_SUPPLIED_SMILES>. SMILES format usually skips hydrogen in its representation, although hydrogen can be also shown. In this case "CC" means that two carbon atoms are connected by single covalent bond. These two C atoms are symmetric and three H atoms are bonded to the rest three free valence places of each carbon (there are six hydrogens in ethane molecule).

```
C2H6
APtclcactv10201006432D 0   0.00000     0.00000     1

  8  7  0  0  0  0  0  0  0  0999 V2000
    2.0000    0.0000    0.0000 C   0  0  0  0  0  0  0  0  0  0  0  0
    3.0000    0.0000    0.0000 C   0  0  0  0  0  0  0  0  0  0  0  0
    2.0000    0.6200    0.0000 H   0  0  0  0  0  0  0  0  0  0  0  0
    1.3800    0.0000    0.0000 H   0  0  0  0  0  0  0  0  0  0  0  0
    2.0000   -0.6200    0.0000 H   0  0  0  0  0  0  0  0  0  0  0  0
    3.0000   -0.6200    0.0000 H   0  0  0  0  0  0  0  0  0  0  0  0
    3.6200   -0.0000    0.0000 H   0  0  0  0  0  0  0  0  0  0  0  0
    3.0000    0.6200    0.0000 H   0  0  0  0  0  0  0  0  0  0  0  0
  1  2  1  0  0  0  0
  1  3  1  0  0  0  0
  1  4  1  0  0  0  0
  1  5  1  0  0  0  0
  2  6  1  0  0  0  0
  2  7  1  0  0  0  0
  2  8  1  0  0  0  0
M  END
> <UNIQUE_SMILES>
CC

> <USER_SUPPLIED_SMILES>
CC

$$$$
```

Figure 1. Example of structure of ethane (C_2H_6) in MOL/SDF format

In Figure 1, an example of structure of ethane is shown. Ethane is composed of two carbons (C) and six hydrogen (H) atoms. In chemistry, the valence of H atom is one, and that of C atom is four, meaning that each carbon is connected to four other adjacent atoms (the first neighbors). For the purpose of this work, only lines between 5 and 19 will be briefly described. In lines 5 to 12 the first three columns contain 3D coordinates of atoms (in Angstroms). Symbol of atoms can be found in the fourth column.

Lines 13 to 19 represent atom connectivity where the first two columns represent serial number of atom which is a serial number of line in atom section of the MOL file listed above. In the third column, information about covalent bond strength are given (1 = single, 2 = double, 3 = triple bond).

For development of algorithm and web server, the following programming technologies are used: PHP, Java, JavaScript, bootstrap CSS framework [6], and handlebars.js [8].

Together with parameters for skipping hydrogens, treating multiple bonds as single, JAR (Java ARchive) format binary application is called from PHP script. Framework used inside of java application is Apache Maven (the list of dependences are given in Table I) [9], and it loads different libraries for each purpose. For reading SDF file, org.openscience.cdk version 1.5.3. is used [10]. Due to unavailability of old packages, external Apache Maven repositories servers were used during development of java application (Ebi [11] and Nexus [12]).

III. RESULTS

The main aim of this study is to develop a free web server for calculation of a representative list of degree-based topological descriptors (Table II) according to their review given by Gutman [4]. Another goal is to enable calculation and development of novel topological descriptors of this type based on user preferences and selected functional form relating valences of atoms forming chemical bond.

To find connections between atoms (*i.e.* degrees of vertices), a Java library of graph theory data structures and algorithms "JGraphT" is used [16], which represents molecule as a graph made of vertices (atoms) and edges (bonds), and helps to detect nearest neighbors when needed. When connection degrees are calculated, expression evaluator exp4j [14] was applied to calculate values of each descriptor from the pre-defined list of degree-based topological descriptors given in Table II. Analogously, values of descriptor defined by the built-in formulae given by the user (as input) are also calculated.

To use custom formulae option, these functions are supported: ln, log(log10), cos, sin, abs, exp, power. The user has an option to give as input a novel function into the web form and the application calculates and give in the output file numerical values of descriptor defined by the user as well as all descriptors from Table II.

For calculation of descriptors from Table II all connections (bonds) have to be found, and according to user settings, it is possible to select an option to include or exclude double and triple bonds (otherwise, these bonds are treated as single bonds). Also, it is possible to include or skip hydrogens in calculation. The degree of the first atom in a bond is represented as X, and the second one is represented as Y in formulae (Table I). In case that the first atom has higher degree (valence) than the second one, then positions of these numbers (X and Y) are replaced (it is assumed that X is always smaller or equal to Y). This rule is introduced in the algorithm to avoid possibility of getting ambiguous results.

TABLE II. DESCRIPTORS IMPLEMENTED IN WEB APPLICATION*

Descriptors and formulas	
Descriptor	***Formula***
F1	$[x + y]$
F2	$x \cdot y$
F3	$[x \cdot y]^{(-0.5)}$
F4	$[x + y]^{(-0.5)}$
F5	$[(x + y - 2)/(x \cdot y)]^{0.5}$
F6	$[(x \cdot y)/(x + y - 2)]^{3}$
F7	$2 \cdot (x \cdot y)^{0.5}/(x + y - 2)$
F8	$2/(x + y)$
F9	$2 \cdot \{[\ln(x)/y] + [\ln(y)/x]\}$
F10	$\ln(x + y)$
F11	$[\ln(x) + \ln(y)]$
F12	$[(x/y) + (y/x)]$
F13	$[1 - \lvert x - y\rvert]$
F14	$\lvert\lvert\log(x) - \log(y)\rvert^{0.5}\rvert$
F15	$\lvert(x^{0.25}) - (y^{0.25})\rvert$
F16	$[(x \cdot y)/(x + y)]$
F17	$[x]^{(-0.5)}$

*Only functional form related to different degree-based indices are given in this table. However, the final value of each index is obtained as the sum over all bonds in the molecule (i.e. sum over all bonds must be added in each functional form. Only in case of index F17, the summation goes over all degrees (atoms).

When all bond aggregations are done, exp4j library is used with built-in formulae (F1 – F17), as well as with the user custom formulae (which are entered by the user as input given prior to starting computation). After that, exp4j method parses formulae and takes parameters (degrees) X, Y and N (the number of connections, *i.e*. chemical bonds).

For testing functions inside application, JUnit 4.11 [15] was used. The web-based application named *Zagreb indices and their modifications* can be accessed and used at address: http://meteo2.irb.hr/indexer.

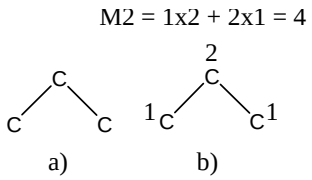

Figure 2. Example of calculation of Zagreb indices M1 and M2 for structure of propane (C_3H_8) shown without hydrogens.

In order to make application more user friendly, a bootstrap CSS framework [6] is used. For frontend development, two JavaScript libraries were used: jQuery for easier HTML document traversal and manipulation [7], and handlebars.js templating library [8] for representing JSON (JavaScript Object Notation format) output [9] in HTML form.

User has to upload a SDF file containing molecular structures and to set parameters (*e.g*. treating multiple bonds as single, or include/exclude H atoms). As an additional option, user can enter a novel functional form relating X and Y into the front-end form (*i.e*. formulae of a novel degree-based index).

Input data are transferred to server which loads a PHP script and executes a Java binary file via shell execution, giving JSON output which is generated by google gson [13] and displayed in the front-end.

Descriptors listed in Table II together with the numbers of bonds of particular type (*i.e*. numbers of bonds of type (1,2), (2,2), (2,3), … (4,4) used in computation of all descriptors) are given as output information in the output file that can be downloaded by the user.

IV. CONCLUSION

In this paper we have described the development and functionality of the web server for the calculation of the Zagreb indices and their modifications recently reviewed [4]. These topological indices are calculated from the degrees of atoms that form chemical bond in a molecule. Many topological indices introduced after 1972 [3] were inspired by topology indices M1 and M2, and they found extensive application in molecular modeling of properties and activities of molecules. Developed web server allows computation and later comparison of the most important descriptors based on valences of atoms, and allows the definition of other (novel) functional forms that is calculated based on the valence of atoms participating in formation of chemical bonds. Also, it is also possible to compute by the developed web server the number of particular types of bonds in a set of chemical compounds (that are used in calculation of degree-based indices).

The developed server (*Zagreb indices and their modifications*) will facilitate comparison of the performances and qualities of various degrees-based topological indices in the field of modeling of properties and activities of chemical compounds, as well as the development of novel degree-based indices.

ACKNOWLEDGMENT

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BIOMEDICAL ENGINEERING

Detection of Human Bodypart Abnormalities by Microwaves – A New Approach

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***Abstract*—We present modified antenna-like devices – applicators – for direct detection of internal inhomogeneities such as breast tumours and brain haemorrhages, at a frequency about 1 GHz. This direct detection provides the possibility of using a simple microwave generator and simple rectification and position registration of the received signals. Direct readouts are thus possible, without any massive computing resources as with tomographic imaging. The transmitting applicator is non-contacting and in free air close to the object. It generates an essentially quasistatic axial magnetic field which induces a circular electric field in the tissue. The receiving 3D contacting applicator contains a high-permittivity ceramic and is resonant. Its mode field provides the desired polarisation sensitivity and filters out the main electric field. The overall system sensitivity for detection of internal inhomogeneities is accomplished by optimised use of the orthogonality of the primary magnetic, induced electric, and diffracted electric fields. When developments are completed, the system will replace or complement existing commercial technologies at a low cost.**

***Keywords*—microwaves; applicators; diffraction; bolus liquid; medical; detection.**

I. INTRODUCTION

Microwaves offer possibilities of non-invasive detection of abnormalities such as brain haemorrhages and breast tumours [1–4]. Microwave imaging was introduced in the early 80's; the object was submerged in a microwave-absorbing liquid – bolus – for avoiding interferences as well as reducing direct coupling between antennas [5]. While X-rays provides contrast by the atomic behaviours and thus an optical-like see-through capability, and ultrasound provides elasticity reflections back to the transmitter from different tissue interfaces, microwaves behave very differently: direct see-trough and reflections do not work. Instead, diffraction phenomena appear at and around objects with different dielectric properties and are mainly determined by the water and ionic content and the object size. Since the contrast mechanisms of the three principles are very different and often quite weak, making the quality of examinations quite operator-dependent, the methods are often complementary if the equipments are not very expensive, as is the case with the almost perfect magnetic resonance tomography method.

We are using the very general term diffraction in the meaning by the German physicist Sommerfeld from more than 100 years ago: *"Diffraction phenomena result in deviations from the rectilinear wave propagation paths associated with reflection and refraction and include all the wave phenomena inside and outside the object or obstacle."* Nearfields are thus included in diffraction, and an important example for our work is given in [6].

There are several problems with the microwave detection: properly adapted antenna applicators are not at all related to communication antenna technologies, the signal attenuation is typically quite large so that the instrumentation becomes complex, and disturbing surface waves occur at the outer boundary of the head and breast [7], [8].

A way of eliminating the surface waves is to immerse the bodypart in a bolus liquid with similar dielectric properties to the body tissues, but that causes discomfort and handling problems, as well as a much stronger signal attenuation than with directly contacting antenna applicators. Our group at Mälardalen University is therefore focusing on new kinds of antenna applicators and studies of how the diffraction phenomena can be utilised maximally towards direct detection of the inhomogeneities. Our R&D work can be said to be in three technically independent areas: transmitting applicators in free air not needing direct contact to the bodypart and not emitting surfaces waves, movable receiving applicators, and signal handling methods for assisting the operator in the search for and position determination of any internal abnormalities. Our goal is to provide a rather low-cost equipment that will be very easy to use and not cause any risks as with X-rays, so it can be used for initial examinations and be complemented with e.g. X-ray mammography for achieving a very low overall rate of false positives/negatives.

II. NON-MICROWAVE DETECTION METHODS

A. X-ray Mammography

This is the golden standard for mass screening of breasts. However, it is also characterised by the following disadvantages:

- Uncomfortable and painful breast compression – abnormalities in the breast periphery and near the muscle are not discovered.
- Ionizing radiation – fear and possible damages.
- Low contrast between glandular/fibro-connective and tumour tissues – no large difference between healthy and abnormal tissue,so the method depends much on the radiologist experience.
- Often requires additional examinations such as invasive breast biopsy.

B. Ultrasound

Ultrasound is not used as a standard for breast screening. However, the technology is improving, non-invasive and not painful. It is since some years used as a complement to X-ray mammography. Disadvantages are:

- Requires operator skill – movements are registered clearly but static soft tissues typically not.
- Typically, low contrast to tumor tissue – contrast is by compressibility. Invasive contrast agents are increasingly used.
- In the breast case: strong reflection from the ribs – which deteriorates the imaging.

C. Magnetic Resonance Imaging (MRI)

This is the overall imaging state-of-the-art, and has a very high resolution, which in general results in an excellent tissue differentiation. However:

- The specificity is low for tumours – non-harmful deviations may be taken for tumours.
- Very high cost – not an alternative for mass screening.
- Uncomfortable for individuals with claustrophobic tendencies.

III. BRIEF OVERVIEW OF MICROWAVE METHODS

A. General

These non-invasively visualise complex dielectric properties differences of the various elements of the bodypart under investigation. There is a fairly high contrast relation between different tissues. As a first example, the property differences are significant between tumourous and healthy breast tissue. A second example is brain haemorrhages, due to the higher water content in blood than in white and grey matter. Furthermore, the microwaves penetrate the skull, which is not the case with ultrasound. The microwaves are non-ionizing and the power levels used are very low and in parity with those of mobile phones. The methods are suitable for imaging and discerning of abnormalities in protruding bodyparts such as head, breast and extremities. As a result, efforts are made towards design of equipment for fast brain scanning. However, there are not yet any clinical-ready system for hospital or ambulance usage. Some systems are described in the sections below. There is also a recent popularly scientific overview [4].

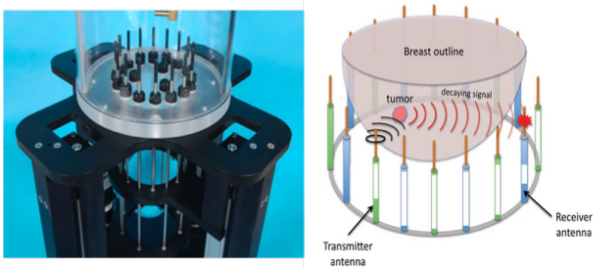

Fig. 1: A bolus liquid container with 16 immersed monopole antennas (Meaney 2015).

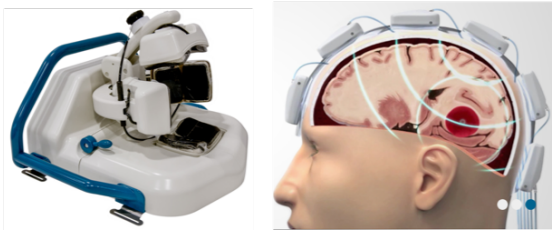

Fig. 2: Medfield Diagnostics microwave-assisted diagnostic equipment illustration and equipment.

B. Microwave-Assisted Diagnostics Equipment under Development by Commercial Companies

An analysis of the developments in academia and companies over the last several years indicates three different focus areas with regard to the transmitting and receiving devices.

1. Multiple, quite simple antennas at a distance from the object under test (OUT), which is submerged in a large microwave-absorbing bolus tank [3]. – Works for breasts but not skulls. Images from the Meaney *et al.* group (US) are shown in Fig. 1. – Advantages are proven functionality, quite simple monopole antennas creating fields that are easy to use for computations and result in relatively uncomplicated algorithms for reconstructing the dielectric permittivity profile, and no creation of surface waves due to the dielectric similarity of the liquid and tissue. – Disadvantages are practical complications with handling and tempering of the bolus liquid, other logistic issues, and additional weakening of microwave signals in the bolus liquid between antennas and the OUT requiring expensive microwave instrumentation.
2. Multiple, modified communication antennas imbedded in objects contacting the head. Only intended for statistical classification of strokes and haemorrhages. Images from the Medfield Diagnostics company are shown in Fig. 2 and in [9]. – Advantages are a relatively inexpensive and easy-to-use design. – A major disadvantage is the need for very comprehensive statistical data for obtaining a sufficient functionality, in view of the necessary access to patients in a life-threatening state. It is not clear to what extent the overall design reduces the unwanted creation

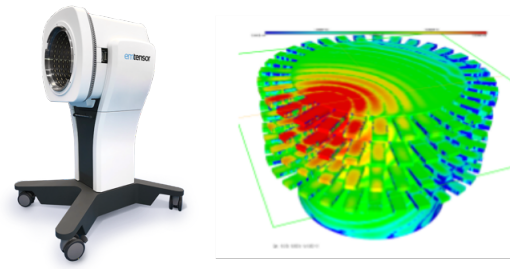

Fig. 3: EMTensor microwave-assisted diagnostic equipment illustration and equipment.

of surface waves between transmitting and receiving antennas. These surface waves are much less attenuated than the useful signals propagating through the head and may reduce the system functionality.

3. A large number of special high permittivity ceramic waveguide antennas in rather close contact to the head via a bolus liquid layer. Designed for microwave 3D tomographic imaging of the brain parts of the head. Illustrations of work related to the EMTensor company are shown in Fig. 3 and [10], [11]. – Advantages are proven clinical functionality for heads, and the design and the large number of antennas making it possible to construct 3D images. The thin and continuous bolus layer provides reduced signal attenuation and reduces the surface waves effects. – Disadvantages are an expensive system with the algorithms requiring comprehensive post-processing computation resources.

C. Our Microwave-Assisted Diagnostics Equipment with Direct use of Diffraction Phenomena

A primary necessity is that the use of bolus liquids should be limited as much as possible, for obtaining sufficiently strong direct signals between a transmitting device and some few fixed or movable receiving devices, and for handling reasons. An ideal transmitting device should function with neither direct contact to the OUT nor require any bolus liquid layer, while not creating any surface waves. Our results clearly show that large steps towards fulfillments of this requirements have been successfully taken. The transmitting design solution basically functions as a ”magnetic monopole” emitting only an axial magnetic field from a slotted current-fed loop based on our invention [12] and improved by additional devices. This induces an orthogonal circular electric field which then propagates inside the OUT due to its high permittivity. No significant surface waves are excited. However, and due to the axial magnetic field not resulting in any diffraction effects along its axis, the transmitting device needs to be repositioned

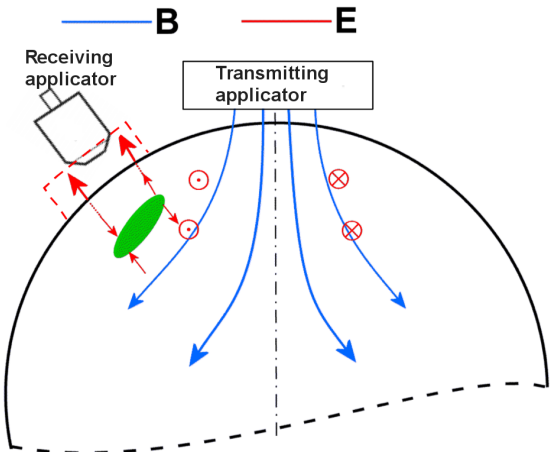

Fig. 4: Primary and diffracted fields, with transmitting and receiving applicators.

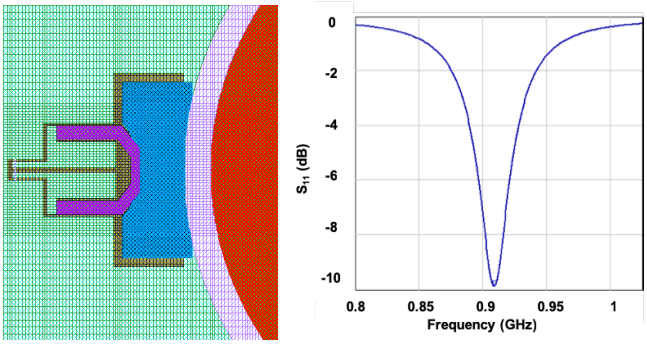

Fig. 5: Meshing of the receiving applicator inserted in a small bolus gel holder, left image. Green = air, light magenta = skull bone, red = white matter, blue = bolus, dark magenta = high permittivity ceramic. The right figure shows the S_{11} of the receiving applicator as a transmitter into the bolus liquid.

in practical use, and then together with one or several receiving devices.

The particular properties of the diffracted field should be utilised for maximising the reception of the particular polarised fields in the OUT surface region. This means that the overall dominating propagating electric field must be filtered out. For achieving these highly specialised requirements, the receiving applicator employs a very high permittivity ceramic for creating a cylindrical axial TM-type mode field. This special design enhances the sensitivity to an axial electrical field and reduces it for radially directed such fields, with the applicator axis as reference. Fig. 4 shows an outline of the fields involved in the detection principles of the inhomogeneities. As seen in the figure, the primary magnetic field, the primary induced electric field, and the diffracted electric field are approximately orthogonal. In addition, the magnetic wall effect occurs in the high permittivity region at the boundary to free space. This results in a dominance of the surface-parallel electrical field just inside the boundary. Since the diffracted field to be received is essentially perpendicular to the boundary, the receiving device must be sensitive to this boundary-normal field and the sensitive part of the receiving device must then be surrounded by a high permittivity material. We have therefore chosen to introduce a small bolus container (diameter 30 to 40 mm) into which our special antenna applicator is inserted see Fig. 5 and [12]. The properties of the applicator set (i.e. the applicator partially submerged in a open-ended metal can containing bolus liquid) is shown in the left Fig. 5. The resonant frequency is about 906 MHz and the loaded Q-value about 16. The frequency choice is a tradeoff between the field attenuation in the tissue and the resolution of the inhomogeneity. The resonant properties of the receiving applicator are important for elimination of extraneous interferences, since the transmitting applicator is inherently non-resonant. The dimensions of the transmitting ring must be practical and such that only a quasistatic magnetic field is generated, which typically reduces its applicability to frequencies from around

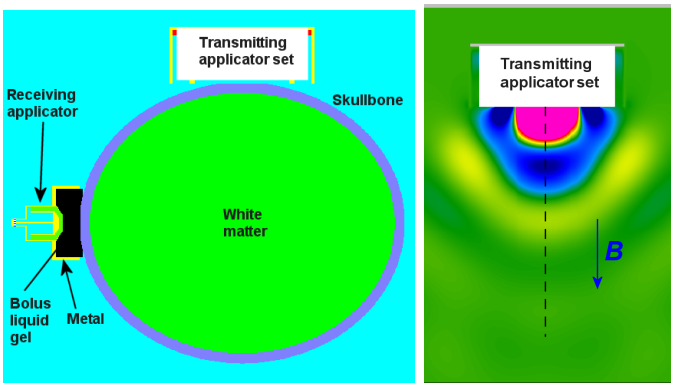

Fig. 6: The overall scenario, left image. Dimensions: see text. The right image is showing the momentaneous axially directed *B* field emanating from the transmitting applicator. Linear scale: magenta = positive maximum, dark blue = negative maximum, and green = 0.

0.7 GHz to 1.5 GHz. The resonant properties of the receiving applicator are of course also necessary for providing the field polarisation sensitivity.

IV. NUMERICAL MODELING OF OUR SYSTEM

The scenario consists of an ellipsoidal skullbone in free air ($\varepsilon' = 17$, $\sigma = 0.26$ S/m) with horizontal major axis 220 mm, horizontal minor axis 156 mm, and height diameter 166 mm. The skullbone thickness is 6 mm and there is simulated white matter ($\varepsilon' = 45$, $\sigma = 0.8$ S/m) inside. The overall scenario has about 11 million voxels with sizes varying from about 0.5 mm cubes to maximum voxel dimensions of 1.6 mm. Typically run-time for achieving stationary conditions on a 3 GHz processor is approximately 3 h. The Quickwave FDTD software is used throughout [13]. We have substantial experience with this since many years and thorough checks using analytically solvable scenarios are made now and then. One has of course to observe possible instabilities by e.g. huge dynamic ranges of fields which occur in the transmitting antenna parts. The main details are shown in Fig. 6. The transmitting applicator is not touching the OUT; the distance in free air being 3 to 4 mm. Its main transmitting property is shown in the right Fig. 6, which shows the axial momentaneous *B* field in linear scale. The overall diameter of the transmitting applicator set is about 80 mm.

Fig. 7 shows the x-directed momentaneous *E* field in logarithmic scale, with red = maximum, and darkest blue = 70 dB down from the red. In spite of the symmetry with the exception of the blood ($\varepsilon' = 61$, $\sigma = 1.6$ S/m) inhomogeneity (and only partly by the receiving applicator and bolus; ($\varepsilon' = 44$, $\sigma = 1.11$ S/m) one clearly sees the diffraction effect by the blood inhomogeneity. Furthermore, the lighter green colour in the skullbone part indicates that the x-directed field propagates to the receiving applicator. Please note that the *E* field inside the applicator is polarised in the $\pm$z direction and therefore zero in the applicator.

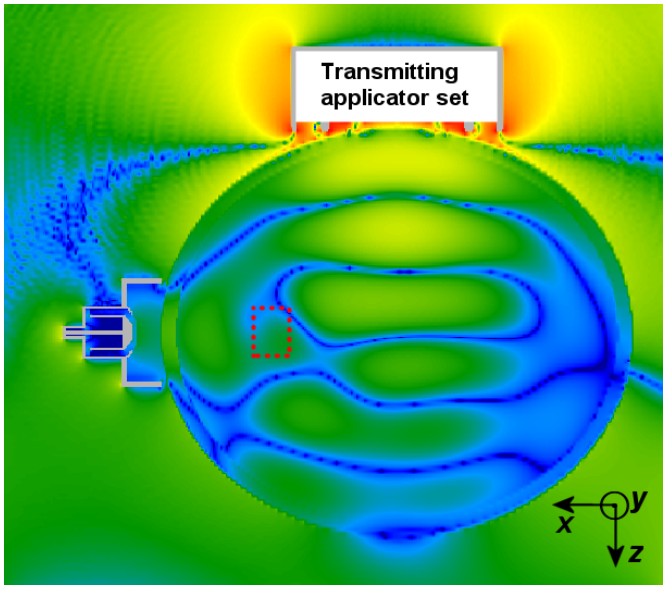

Fig. 7: The x-directed momentaneous *E* field in logarithmic scale. See text for details. The size of the blood clot is 15 mm $\times$ 15 mm $\times$ 18 mm. It is situated with its centre 44 mm from the skull exterior and off-centre by 26 mm in the y direction.

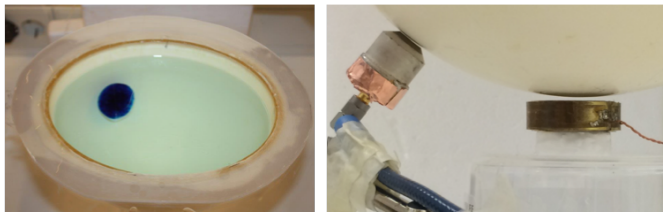

Fig. 8: Left photo: the experimental skull with simulated brain substance and a blood clot. Right photo: transmitting and receiving applicators in an earlier setup.

It should also be noted that the Fig. 7 shows only the x-directed *E* field and that there is a dominant y-directed *E* field. This is however, very significantly, by 30 dB or more, filtered out by the design of the receiving applicator set. As a result, the signal amplitude sensed by the applicator has a difference of 4 dB with and without the inhomogeneity. This significant difference is the result of the intentional design of the transmitting and receiving applicator sets and their polarisations. Furthermore, the position of the inhomogeneity was chosen for fulfilling the orthogonality conditions for maximum sensitivity. Of course these properties allow determination of the position of the inhomogeneity when the applicator is moved or if several applicators are used.

V. EXPERIMENTAL WORK

This is an ongoing project and we have not yet completed the experimental setups in accordance with the modeling scenario presented here. The performance of the older experimental system shown in Fig. 8 indicated about 0.5 dB difference

when the blood clot was moved around, see left photo in the Fig. 8. Present improvements are in the proprietary transmitter set and the use of a bolus part with the receiving applicator.

The right Fig. 8 shows an earlier setup with the same general outline as in the left Fig 6. The pictures are partially from previous work [6], [14]. We have improved the transmitting applicator by some field filtering and absorption means resulting in a much more pure output signal. As to the receiving applicator set we realised a need for having a metallic boundary i.e. providing an electric wall at the applicator, for best reception of the axially directed E field. All experimental details are not yet finished, including cables and shielding, so full details can not yet be provided.

VI. CONCLUSION

The system under development by us has some unique properties: direct readouts requiring neither a large number of antennas nor sophisticated reconstruction algorithms, and optimised use of polarisation effects by the diffracted fields emanating from the internal inhomogeneities. The combination of a special transmitting device and a resonant receiving device requires only amplitude measurements, which significantly reduces system complexity, cost and some calibration issues, while achieving good sensitivity. We therefore expect our overall system approach to become a viable and cost-effective class of equipment for detection of human bodypart abnormalities – by a different technique allowing a better diagnostic reliability, alone or in combination with other non-microwave technologies.

ACKNOWLEDGMENT

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Comparison of publicly available beat detection algorithms performances on the ECGs obtained by a patch ECG device

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***Abstract* – Eight ECG beat detection algorithms, from the PhysioNet's WFDB and Cardiovascular Signal toolboxes, were tested on twenty measurements, obtained by the Savvy patch ECG device, for their accuracy in beat detection. On each subject, one measurement is obtained while sitting and one while running. Each measurement lasted from thirty seconds to one minute. The measurements obtained while running were more challenging for all the algorithms, as most of them almost perfectly detected all the beats on the measurements obtained in sitting position. However, when applied on the measurements obtained while running, all the algorithms have performed with decreased accuracy. Considering overall percentage of the faulty detected peaks, the four best algorithms were *jqrs*, from the Cardiovascular Signal Toolbox, and *ecgpuwave*, *gqrs*, and *wqrs*, from the WFDB Toolbox, with percentages of faulty detected beats 1.7, 2.3, 2.9, and 3, respectively.**

Keywords - Patch ECG, R-peaks, beat detection, heart rate, telemonitoring, remote health monitoring

I. INTRODUCTION

Electrocardiogram (ECG) signals obtained from patch ECG sensors, in normal daily activities, are more challenging from the signal processing perspective, since they are more contaminated with noise and artifacts, compared to the ECGs obtained in clinical settings. This makes detection of prominent signal features, like for instance R-peaks, and the calculation of the heart rate, much more challenging compared to the standard clinical settings, in which subjects are supposed to be lying down and be relaxed, not to cause skeletal muscle electrical activity, which may be picked up with the same electrodes measuring the ECG.

Beat detection is an initial and fundamental step for ECG analysis, segmentation, clustering [1] and classification. Accurately determined R-peaks are necessary also for validation of R-R [2] or Q-T [3] variability, and detailed analysis of P-waves [4]. Specialized beat detectors are needed for the extraction of fetal ECG [5]. Finally, reliable and robust beat detectors are essential in the monitoring and diagnostics of irregular rhythm and arrhythmias [6].

There are a lot of different approaches to beat detection published in literature [7], some of which are specifically targeting mobile ECG devices [8]. These algorithms have not yet been tested on measurements obtained directly with patch ECG devices, which are becoming more popular by the day, since they are easy to use and wireless [9]. The leads obtained with patch ECG devices are usually called the differential leads [10]–[12].

We have tested functions for beat detection from the "WFDB Toolbox for MATLAB and Octave" [13], [14] and the "Cardiovascular Signal Toolbox" [15], both from the PhysioNet [16], which is a free collections of recorded physiologic signals and related open-source software. We have also applied a simple wavelet-based beat detection algorithm, to have one algorithm outside of PhysioNet to compare with. Since for calculating the heart rate, the number of detected beats is the most relevant, not the precision in time domain of the prominent ECG feature detected, our purpose was only to examine if the algorithms detect the correct number of beats, not if the ECG features are detected at exact time moments.

II. METHODS

A. Data acquisition

We have recorded two ECGs from each of ten study participants (age range 25-63 years, 9 males, 1 female): one ECG in a sitting position and one while running on a treadmill. Each measurement lasted from 30 s to 1 min. While in the sitting position, the subjects were asked to be completely relaxed.

The measurements were obtained with the Savvy patch ECG [5], [6], [9], [17], which was positioned according to Fig. 1. The subjects were asked to put one of the electrodes at the end of the sternum bone, and the other horizontally to the right as much as it goes, and to press the self-adhesive electrodes to the skin to achieve a proper contact. The subjects did not shave and did not apply and special cleaning to the skin before usage. The sampling frequency was 128 Hz.

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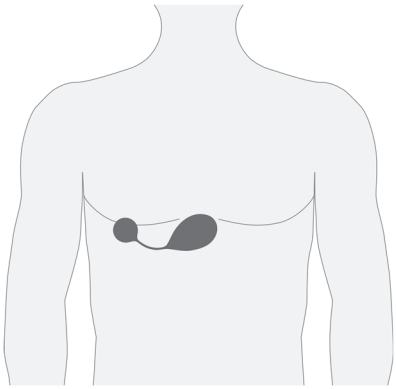

Figure 1. Positioning of the Savvy patch ECG

B. *Beat detection algorithms examined*

The PhysioNet Cardiovascular Signal Toolbox is an open-source modular program implemented in MATLAB, mainly for the purpose to calculate heart rate variability. We have used the following functions: *jqrs*, *run_sqrs* and *wqrsm*. The *jqrs* [18], [19] is an implementation of the Pan Tompkins (P&T) [20] algorithm that finds R-peaks, whereas *run_sqrs* and *wqrsm* (detect Q-waves) are re-programmed original *sqrs* and *wqrs* functions from the Physionet WFDB library.

The WFDB Toolbox for MATLAB and Octave is a set of wrapper functions for the PhysioNet's WFDB Software Package and other PhysioToolkit applications. We have tested the following functions: *ecgpuwave*, *gqrs*, *sqrs*, and *wqrs* [21]. The *ecgpuwave* is based on the P&T algorithm and returns a number of fiducial points on the ECG (we used only R-peaks). The other three functions return the locations of the Q-wave. All four functions are wrappers for the WFDB library functions with the same names.

The wavelet algorithm was adopted from the MALTAB documentation [22] and is presented here:

```
1 %meas is the variable containing ECG
measurement
2 %sampling frequency:
3 Fs=128
4 %tmeas contains time points:
5 Tmeas=0:(1/Fs):(((length(meas)-1)/Fs);
6 wt = modwt(meas,5);
7 wtrec = zeros(size(wt));
8 wtrec(4:5,:) = wt(4:5,:);
9 y = imodwt(wtrec,'sym4');
10 y = abs(y).^2;
11 [qrspeaks,locs]=findpeaks(y,tmeas,
'MinPeakHeight',0.03,'MinPeakDistance',0.150);
12 %locs contains the positions of the QRS peaks
detected
```

The ECG signal (line 6) is decomposed to level 5 using the default "*sym4*" wavelet. In lines 8 and 9, the ECG waveform was reconstructed using only the wavelet coefficients at scales 4 and 5, which correspond to the $[11.25, 22.5)$ Hz and $[5.625, 11.25)$ Hz frequency bands, respectively. The two intervals cover the passband shown to maximize QRS energy. Then the MATLAB's peak finding algorithm from the Signal Processing Toolbox is applied (line 11) on the squared signal built from the wavelet coefficients (line 10).

C. *Data processing*

The data was imported in MATLAB and processed with the beat detection functions. We did not filter the data before applying the functions, since the required filtering is implemented within the functions.

All raw measurements were examined by two independent observers who identified the correct locations of R-peaks. Each measurement was than plotted with correct R-peaks and the QRS location information obtained from each of the beat detection algorithms (see Fig. 2.). The observers independently marked the beats that were not recognized (false negatives - FN) and the falsely identified beats (false positives - FP).

Even if the prominent ECG feature detected with the algorithm was only approximately correctly detected in time (e.g. perhaps R-peak detected was few ms left or right to the correct R-peak), it was still considered by the observers as a correct detection. A plot showing two ECG segments with correct R-peaks and those identified by the *sqrs* algorithm is shown on Fig. 2.

The star before the third beat is an example of a fiducial point (in this case Q-wave) detected at a wrong location. We have however considered this and similar situations as correct beat identification, because the time shift in the

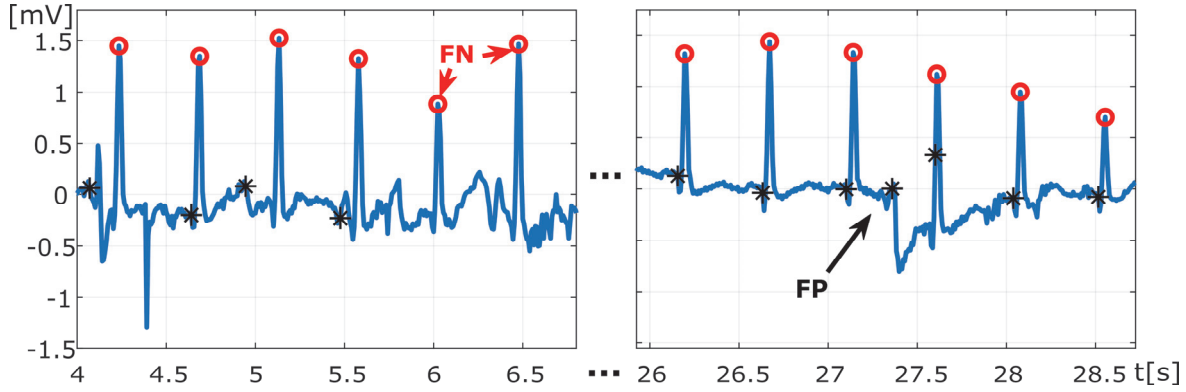

Figure 2. Two excerpts from a treadmill measurement containing two FNs (left figure), and one FP (right figure). Red circles are the correct locations of the R-peaks, whereas the black stars are the Q-wave locations determined by the *sqrs* function from the Cardiovascular Signal Toolbox.

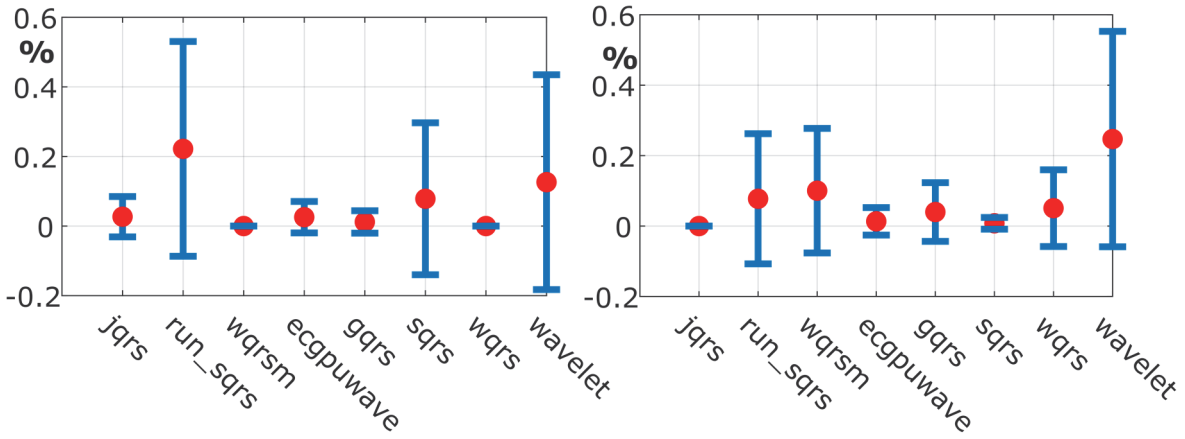

Figure 3. Left: Mean and standard deviation of the relative number of FNs. Right: Mean and standard deviation of the relative number of FPs. The relative number of FNs and FPs was calculated by dividing the number of missed beats and falsely identified beats (respectively) with the total number of beats in each measurement.

detection of a particular fiducial point does not significantly affect the heart rate calculation.

We have calculated the relative numbers of FPs and FNs by dividing them with the total number of correct R-peaks in each measurement, to accommodate for the different measurement lengths and different heart rates between subjects.

III. Results and Discussion

The agreement between the two observers was perfect. The obtained relative numbers of FPs and FNs is shown on Fig. 3. Table 1 shows the percentage of FN and FP beat detections for each beat detection method and for two different settings: sitting and running.

From Fig.3 it is obvious that the *ecgpuwave* and the *gqrs* methods from the WFDB toolbox, as well as the *jqrs* from the Cardiovascular Signal Toolbox, have very low relative numbers of FNs and FPs, but most of the functions showed very high performance in detecting heart beats. The only exceptions are *run_sqrs* and *sqrs*, which had problems in finding beats on very noisy measurements, and the wavelet approach, which had a lot of both FPs and FNs.

This is visible in more detail in Table 1. All the algorithms, except wavelet, performed very well for the measurements obtained in sitting position. Only *ecgpuwave* and *run_sqrs* showed notable errors: FN=1.6% and FP=5.7% respectively.

While running, again *run_sqrs* and the wavelet approach had by far lowest performance with FN=46.3% and FP=40.1%, respectively. The *wqrsm* showed high FP=21%, whereas *sqrs* had high FN=14.3%.

The *run_sqrs*, *sqrs* and the wavelet approach failed mostly on two noisy measurement obtained while running that were so much noisy that it was even hard to determine visually the R-peaks correctly. The other methods performed surprisingly well even on those very noisy signals.

TABLE 1. Percentage of FP and FN beats for each method while sitting, while running, and in total (FN and FP together)

Method	Sitting		Running		Total
	FN	FP	FN	FP	
jqrs	0.9	0	5.1	0	**1.7**
run_sqrs	0.5	**5.7**	**46.3**	7.6	17.1
wqrsm	0	0	0	**21**	6.2
ecgpuwave	**1.6**	0	4.0	2.7	**2.3**
gqrs	0.7	0	1.3	8.1	**2.9**
sqrs	0.7	0	**14.3**	1.6	4.8
wqrs	0.0	0	0	10.3	**3**
wavelet	13.4	8.6	5.6	**40.1**	18.0

Considering the overall percentage of the faulty detected peaks, the four best-performing algorithms were *jqrs*, *ecgpuwave*, *gqrs*, and *wqrs* (see Table 1.).

IV. Conclusion

On twenty measurements obtained from ten people in two different setting, we have shown that most of the examined beat detection algorithm perform very well, even though the signals obtained were not filtered before processing and were quite noisy, which is expected from the ECGs obtained during running by using patch ECG devices with two electrodes.

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Wireless Body Sensor for Electrocardiographic Monitoring in Equine Medicine

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***Abstract* – Wireless body sensor, connected via Bluetooth technology to a smart device, was used to obtain ECG data in seven horses while they were standing, walking and trotting. Different positions of electrodes were tested. Measurements with the electrode distance of 8 cm, as proposed in the wireless sensor, gave reliable results only in standing horses, because the voltage of the recorded waves was low and easily superseded by motion artifacts. To increase the voltage of the recorded waves, additional extension wires had to be used. To avoid movement artifacts, the most appropriate placement of electrodes was determined. The positive electrode was placed on the left chest side near the caudal cardiac border and the negative electrode was placed on the left side of the withers. In these recordings, QRS complexes could be followed during trotting, while P waves were buried in the irregular baseline caused by the motion. Wireless ECG data were compared to simultaneously recorded standard ECG in all seven horses, and equivalent results were obtained for heart rate, cardiac rhythm and duration of different waves.**

Keywords - horse ECG; wireless body sensor; veterinary medicine; equine medicine

I. INTRODUCTION

In equine patients, cardiac arrhythmias are common as a cause of poor athletic performance or as a complication of various pathologies; therefore, a long-term electrocardiogram (ECG) in real environment is of utmost importance. Wireless body sensor, connected via Bluetooth technology to a smart device, have proven to be accurate and reliable for monitoring of the cardiac rhythm in humans, dogs and cats [1-9]; while in equine medicine, a wireless body sensor coupled with a smart device was not previously used to obtain ECG data.

In horses and cows [10-12], as well as in dogs and cats [13-18], hand-held smartphone-based electrocardiograms have been compared to standard ECGs, to evaluate these ECG devices. However, handheld wireless ECG monitors cannot be used for long-term monitoring of cardiac rhythm, which is essential in hospital settings. In horses, an ECG during exercise is also a very important part of a cardiac diagnostic work-up. Horses have a higher incidence of clinically insignificant bradyarrhythmias at rest due to high vagal tone. These physiological arrhythmias, such as sinoatrial block, second degree atrioventricular block, wandering pacemaker and sinus bradycardia, usually disappear during exercise and/or excitement, when the vagal tone decreases and the sympathetic tone increases. Furthermore, the absence of arrhythmias during rest does not rule out rhythm abnormalities during strenuous exercise, when tachyarrhythmias such as atrial fibrillation, atrial escape complexes, supraventricular tachycardia, ventricular escape complexes and ventricular tachycardia significantly affect animal's performance [19-21]. The most common equine cardiac abnormalities are mitral regurgitation, atrial fibrillation, aortic insufficiency and tricuspid regurgitation [22]. In 1153 middle-aged and older horses, the prevalence of mitral regurgitation was around 3% [23].

In this article, we report the findings of the ECG data obtained by wireless body sensor in seven horses. Our research question was: How does the Savvy sensor (Savvy®, http://www.savvy.si/en/), which was designed for use in humans, perform in horses? Although the use of wireless ECG sensor coupled via Bluetooth to a smart device has not been previously reported in equine medicine, Audiocor recordings have been obtained in 116 horses [24]. Audiocor is a battery-driven device combining phonocardiography and ECG and hence allowing noninvasive, continuous assessment of variables representing systolic and diastolic cardiac function [24].

The rest of the paper is organized as follows. Section II presents the materials and methods: the wireless ECG body sensor, its placement and the measurement procedure; Section III presents the results; in Section IV, the results are summarized and discussed; and finally, Section IV concludes the paper.

II. MATERIAL AND METHODS

The wireless ECG sensor used in this study has been previously described [1, 25] and is readily available today. The sensor consists of two precordial electrodes with a distance of 8 cm attached to an electronic module with battery, which enables up to 7-day continuous measurement. The sensor records one bipolar (single channel) lead, but it cannot store the obtained recordings. Low-power Bluetooth coupling to an Android smart device with MobECG application is required for the display and continuous storage of the real-time ECG data (Fig. 1). In our study, we used Samsung Galaxy J3 smartphone with an advanced experimental version of MobECG application, which enabled more detailed sampling. The gathered data were analyzed with the

publicly available VisECG software (http://e6-mobile-ecg.ijs.si).

Initially, the electrode patches were attached to wet hair, but the electrode attachment was inadequate; the voltage of the ECG waves was low and there were numerous detachment artifacts. Hence, the hair was clipped and the skin dry-cleaned before the attachment of the electrode patches. Different positions of the electrodes were tested – the wireless body sensor was placed over the region of the heart on the left and right side of the chest. Both positions gave satisfactory recordings, however, the voltage of the recorded waves was larger when placed on the left chest side. Measurements with the electrode distance of 8 cm, as proposed in the wireless sensor, gave acceptable results only in inactive horses, because the voltage of the recorded waves was relatively low (Fig. 2) and therefore easily superseded by motion artifacts. To increase the voltage of the recorded waves, extension wires had to be used (Fig. 3, Fig. 5).

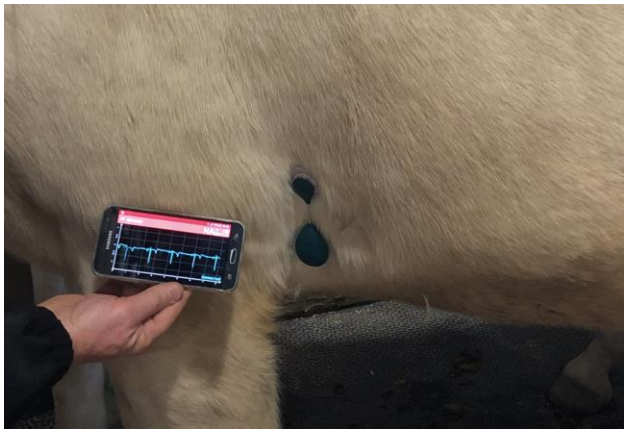

Figure 1. Savvy sensor placed over the region of the heart on the left side of the chest, Bluetooth coupled to the smartphone, and real-time display of the ECG with MobECG application

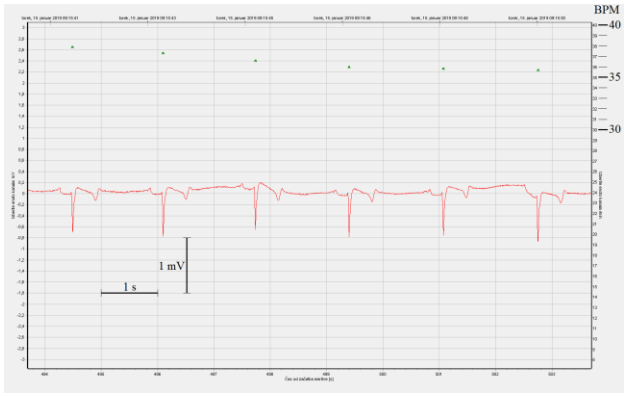

Figure 2. VisECG display of the recording with the wireless sensor placed over the heart region on the left chest. ECG waves can clearly be seen, but the voltage of the recorded waves is relatively low (0.8 mV)

ECG data were obtained from seven horses (Table I) while standing, walking and trotting. Wireless ECG data were compared to simultaneously recorded standard base-apex ECG (Fig. 4), which was recorded by a Schiller Cardiovit 2015 ECG machine, at 25 mm/sec speed and 10 mm/mV sensitivity.

During walking and trotting of the horses, the sensor was bandaged to the thorax to prevent detachment of the electrodes (Fig. 6). In one horse, the wireless ECG sensor was also used for monitoring during anesthesia.

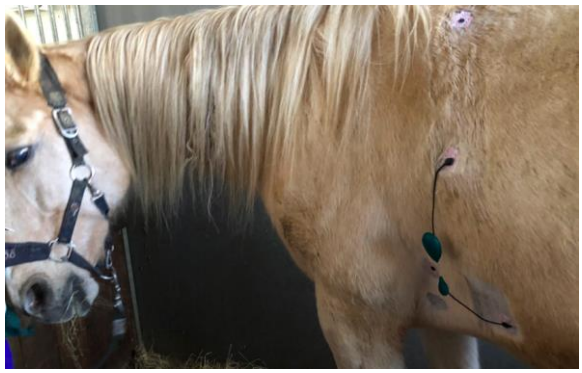

Figure 3. Extension wires to increase the voltage of the recorded waves (Hungarian warm-blooded)



Figure 4. Simultaneous recording of wireless and standard base-apex ECG (Thoroughbred)

TABLE I. BREED, AGE, SEX, NEUTERING STATUS AND DIAGNOSES OF THE SEVEN HORSES

	Breed	Age (years)	Sex and neutering status	Diagnoses
1	Arab/Lipizzaner	17	male, neutered	podotrochlosis
2	Hungarian Warm-blooded	16	female, intact	IAD
3	Thoroughbred	1	male, intact	VSD, MR
4	Westphalian	23	male, neutered	MR
5	Icelandic horse	6	male, neutered	dermatomycosis
6	Lipizzaner	18	female, intact	retrobulbar abscess
7	Hanoverian	15	male, neutered	rectal diverticulum

Legend: VSD–ventricular septal defect, MR–mitral regurgitation, IAD–Inflammatory Airway Disease



Figure 5. Positive electrode near the heart on the left chest wall and the negative electrode on the left side of the withers (Westphalian). To avoid motion artifacts due to leg movements, the positive electrode was positioned further caudal (arrow)



Figure 6. The sensor was bandaged to the thorax to prevent electrode detachment during exercise (Arrab/Lipizanner)

III. RESULTS

An example of an entire 20-minute long measurement, while horse (Lipizzaner) was standing and moving freely in the box, can be seen in Fig. 7. There are no large variations in ECG amplitudes and no large heart rate deviations, therefore no arrhythmias are present. Global overview of a whole measurement gives useful initial information about the heart rhythm. An example of a shorter section can be seen in Fig. 8. The voltage of different ECG waves changed with the position and distance between electrodes (Table II), as was previously shown in humans [26], and dogs and cats [1]. Better contact with skin resulted in larger amplitudes, even at 8 cm distance. The larger distance between electrodes resulted in larger amplitudes of the waves, and the factors of enlargement (Table II) differ among the waves (for example, when we increase distance from 28 to 50, T wave enlarges less than P and QRS).

TABLE II. VOLTAGE OF DIFFERENT WAVES AT VARIOUS POSITIONS OF THE ELECTRODES

Position of ECG sensor		Distance between electro-des (cm)	Amplitude (mV)		
			P wave	QRS com-plex	T wave
1	ECG sensor over the region of the heart on left chest side, hair unclipped (as in Fig.1)	8	0.06	0.5	0.2
2	ECG sensor on left chest side, hair clipped (Fig. 1)	8	0.14	1	0.27
3	ECG sensor with wire extensions, one electrode at caudal cardiac border, one electrode in middle of left chest (Fig. 3)	23	0.14	1.7	0.60
4	ECG sensor with wire extensions, one electrode at caudal cardiac border, one electrode on left withers (Fig. 5)	50	0.30	3	0.80

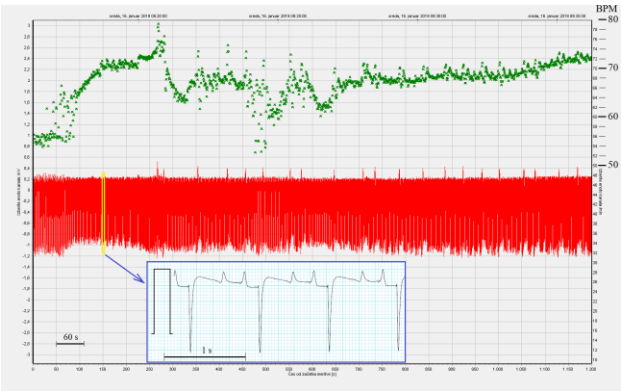

Figure 7. VisECG display of a 20-minute ECG interval (red), horse standing and moving freely in the box. Each heartbeat is presented with one green x showing the instantaneous heart rate, computed from two successive heartbeats. Inserted picture shows ECG signal in detail

For the smallest noise and best ECG signal, appropriate choice of light-weighed electrodes, connectors and wires, and firm attachment were of crucial importance. The most appropriate placement of electrodes was determined to avoid motion artifacts as much as possible. For most useful ECG recordings during walk and trot, to avoid artifacts due to the front leg movement, the positive electrode was placed more caudally on the left chest side near the caudal cardiac border and to minimize the motion of the negative electrode, it was placed on the left side of the withers (Fig. 5). Myopotentials of contracting muscle influence ECG signal and therefore the withers was a good choice for the electrode. The distance between electrodes was 40 to 60 cm, depending on the size of the horse. In these recordings, QRS complexes could clearly be followed during trotting, while P waves were buried in the irregular baseline caused by the motion (Fig. 9).

Wireless ECG data were compared to simultaneously recorded standard ECG in all seven horses, and equivalent results were obtained for heart rate, cardiac rhythm and

duration of different waves. In the ECG recordings of the seven horses, no arrhythmias were identified.

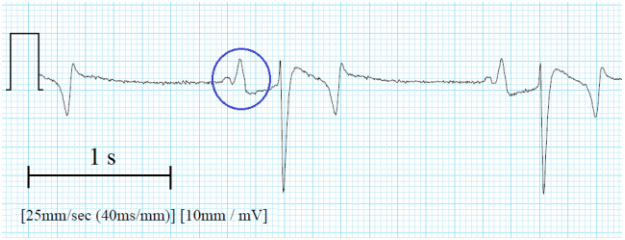

Figure 8. VisECG presentation of the ECG in PDF format. The measurement was made by extension wires, horse standing. The voltage of the QRS complexes increased to 2.3 mV. At slow heart rate, P waves are often bifid/biphasic (circle)

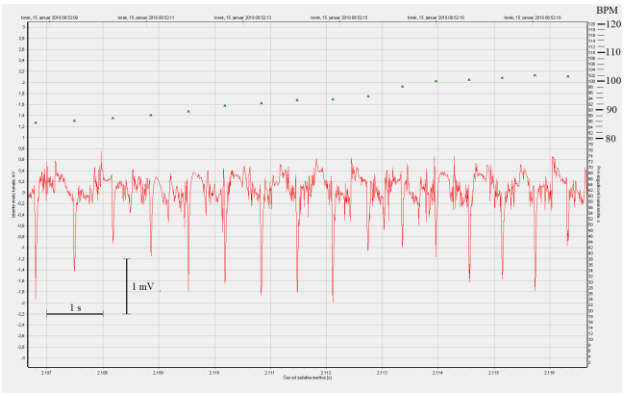

Figure 9. VisECG display of ECG during trotting where heart rate was 85-102 beats/min. Note that QRS complexes can clearly be seen, while P waves are buried in the irregular baseline

IV. DISCUSSION

Wireless ECG data were compared to simultaneously recorded standard base-apex ECG in seven horses, and equivalent results were obtained for heart rate, cardiac rhythm and duration of different waves. This is an expected finding; in accordance to previous experience and literature data [1-9]. Wireless sensor is accurate and comfortable to wear, therefore it can be used for a longer time, while the horse is moving freely in a box or during exercise. It can as well be used for ECG monitoring during anesthesia. Standard ECG can only be used in standing horses – the numerous wires connected to the machine make the measurement challenging. In standard equine base-apex ECG, the exact position of the electrodes is not that important, as long as the leads are constructed along the mean electrical axis, i.e. along the long axis of the heart. Limb leads are not suitable for clinical use in horses [19, 27, 28].

In our study, the most appropriate placement of the electrodes was determined. Best ECG signal was obtained if electrode was placed above left ventricle. However, to avoid artifacts due to the front leg movement, the positive electrode was placed more caudally on the left chest side near the caudal cardiac border. To minimize the motion of the negative electrode, it was placed on the left side of the withers. This position provided ECG recordings obtained during trotting, where QRS complexes could clearly be followed, while P waves were buried in the irregular baseline caused by the motion. In horses, it is of crucial importance to make a reliable ECG recording during exercise, because cardiac arrhythmias are one of the possible causes of poor performance [21, 29]. Over-interpreting the relevance of exercising rhythm variations harms the opportunity to perform at full potential, while underestimating an arrhythmia can be devastating. Arrhythmias during or immediately after exercise are a potential cause of sudden cardiac death. Limited data suggest that the risk for sudden death during racing may be higher than that reported in human athletes [30-32]. The risk for sudden death in racehorses is reported to be as high as 0.29 per 1000 starts [32]. In more than 40% of horses with poor performance, an arrhythmia was diagnosed during or immediately after exercise. In 50% of these animals, arrhythmia was believed to be clinically important [33]. However, in poor performing racehorses, solitary premature contractions are common during standardized incremental treadmill exercise, but their clinical relevance remains unknown [34].

The interpretation of the wireless ECG recordings can be challenging, especially interpretation of exercise ECG due to multitude of motion artifacts. Even in standard ECG recordings, overinterpretation of artifacts from a poor-quality recording is a common mistake. Multiple lead systems have the advantage of being more sensitive and specific, and always have one or more “backup” leads in case of electrode detachment [19, 20].

It is noteworthy that this wireless sensor can be used in heart rate variability studies to assess vago-sympathetic balance. ECG monitors are superior to heart rate monitors for assessment of heart rate variability, because manual correction for abnormal beats and artifacts is only possible in ECG measurements [35-39]. Besides monitoring of equine cardiac patients, this wireless ECG sensor could be useful for long-term monitoring of horses with systemic diseases also. Furthermore, the wireless ECG sensor could be valuable for monitoring during anesthesia, as tested in one horse of this study.

Interestingly, compared to human heart, equine heart and electrocardiogram have several unique features. Resting heart rate in horses can be as low as 20 beats per minute, while maximum heart rate is 240 beats/min. The heart rate increases rapidly during walk-to-trot or trot-to-canter transitions. The spread of the depolarization from the sinus node through atria can be observed in the P wave. When the heart rate changes, the P wave often changes. Even successive P waves are commonly not identical. The conduction of the impulse through the AV node is slow and profoundly affected by the vagal tone. Since the muscle of the equine heart is large, the conduction system is abundant to enable rapid and synchronized depolarization of the ventricular myocardium, which can be observed as a large QRS complex. Depolarization is followed by repolarization, represented by the T wave, which is very variable in size and orientation, and dependent on the heart rate. T waves are not useful in diagnosis of cardiac disease, but may be helpful to differentiate between a normal and abnormal ventricular beat, and between artifacts [19, 20].

V. CONCLUSIONS

Wireless ECG sensor can be used for long-term ECG measurements in ambulatory and hospitalized horses and for monitoring during anesthesia. During movement, the

wireless ECG sensor is less useful due to multitude of artifacts, however, this needs further validation.

ACKNOWLEDGMENT

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Interactive home healthcare system with integrated voice assistant

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***Abstract*—Voice assistants are making their way in home healthcare, improving patient care by increasing efficiency and presenting a new experience by offering a wide range of tools and capabilities. Patients can access medical information, monitor and analyze health issues and communicate with ease with the help of useful applications and services. This is especially beneficial for the elderly patients. This paper showcases the patient-focused voice and web services developed for Amazons Alexa and Google Assistant and pinpoint the benefits of this technology in healthcare in the comfort of the patients home.**

***Index Terms*—Voice assistant, voice application, healthcare, medical services, heart monitoring system**

I. Introduction

Technology is disrupting industries wide across the whole spectre and these advancements are happening at such a pace, which makes it hard for the humans to adapt to it. The healthcare is no exception to this, now spreading into the homes of the patients. For example, with heart sensors that allow 24/7 monitoring of the heart condition. But technology is an obstacle, as well as a helping hand, to the elderly people, which are most in need of heart related treatments. They are unable to use the web and mobile applications and furthermore, with their deteriorating memory and lack of medical knowledge, they are led to isolation, in this aspect. This is where voice applications, come offering a well known interface.

Voice is gaining on popularity with the adults in the U.S, in fact according to a statistical research [1], 46% of U.S. adults are already using voice assistants at home and the number is only expected to increase in the coming years. In a survey conducted by Google [2], 41% of people, who own a voice-activated speaker say it feels like talking to another person. Aside from convenience, voice assistants offer a number of advantages in healthcare, for an example its hands-free interaction, 55% of surveyed users [1] stated that one of the major reasons they use these applications is to interact with their devices without using their hands, also there are projections that 50% of all searches will be voice made, by 2020 [3]. This is especially beneficial for people with disabilities who may have difficulty typing on a smartphone or a keyboard. Voice assistants have the potential to remove barriers and give these patients more control over their health, adding value to patient engagement. Whether by optimizing communication or providing critical new features, voice assistants are becoming an essential part of the healthcare industry shift towards patient-centricity. This paper is a proof-of-concept for voice enabled healthcare system, that contributes informing the patients heart conditions.

The paper is organized as follows. Related work of similar applications and enabling technologies voice operated healthcare are described in great detail in Section II. Section III describes the architecture of the voice enabled healthcare system. Section IV describes the healthcare services implemented in our voice applications. A voice assisted heart healthcare use case is described in Section V. The conclusion is presented in Section VI. In Section VII the authors discuss the results. Future work is presented in Section VIII. The conclusions are presented in Section IX.

II. Related work and Enabling technology

A. Related work

Up to the point of writing the paper, the authors found two startups operating in the home healthcare field by integrating voice enabled platforms. CardioCube [4] is a voice enabled artificial intelligence application that runs on an Amazon Alexa enabled device. Its main feature is to communicate with the patient about their hearth failure decease in the comfort of their home, asking questions that any cardiologist would. With the retrieved information, CardioCube updates the patients EHRs hosted on the hospitals server for better and faster decisions. This solution is in the same field, covering voice enabled home healthcare, but it differs in that it represents a cardiac therapist.

Pillo [5] is a voice enabled home health device that manages and personalizes the patients healthcare regimen. It stores, dispenses and orders refills for the patients medication. Due to its voice enabled features, patients can interact with it and Pillo will provide answers to health-related questions. Voice and facial recognition help Pillo ensure the right person gets the scheduled medication. Also it can send alerts of an medication issue to the patients caretaker. This products covers the voice

enabled home healthcare segment, but it differs in that is only a medication organiser.

B. Medical cloud

Tasic et al. [6] propose a solution to deal with the challenges of building a medical cloud. Its functionality goes beyond storing data, namely elasticity and scalability, quality of service, security and privacy, availability and disaster recoverability being the strong points of the medical cloud. The medical cloud collects streaming raw data, extracts important features by processing it and stores it neatly in the patients EHRs.

EHRs provide invaluable data to clinical researchers, who advance medical knowledge and the development of new treatments for common health problems. Making EHRs available through applications makes patients more and more engaged in their healthcare, giving the ability to manage their conditions. By helping the patient take control of their disease management, it is creating a greater sense of patient empowerment.

C. Wearable Sensors - Savvy

Wearables in recent years are gaining a momentum in healthcare. In the past, wearable technology has been too bulky or unwieldy to be useful, but the proliferation of smaller, more compact, more powerful devices and the resulting improvements in computational power have made wearables more convenient. It is giving new opportunities for both patients and clinicians to monitor chronic conditions in ways that were once impossible. This new tech could help transform the focus of healthcare from reactive chronic-disease treatment to one that proactively treats these conditions and helps prevent such exacerbations. Analysts view wearable computing as an industry primed for explosive growth in the near future. For instance, Tractica reports [7] that worldwide medical wearables shipments constituted 2.5 million units in 2016.

Savvy ECG [8] is a wearable medical sensor that constantly measures ECG signals. Savvy placed its emphasis on elegance and simplicity of design, both in its outward appearance and its underlying technology. It is fixed on two standard ECG electrodes and can be easy attached/detached to the body of the patient. Its lightweight, has a long-lasting battery and is IP54 certificated, which means it has limited protection from dust and water spray from any direction. Savvy uses Bluetooth to communicate with a mobile device streaming data in 30 second intervals, further on communicating via Wi-Fi or 3G/4G mobile operator network with the medical cloud, where the data is analyzed and processed. As an alternative to the mobile device, Savvy can communicate to the local computer by connecting it with the appropriate cable [9].

D. Voice assistants

Amazon and Google are leading the voice search trend with their branded hardware. With the progression of Artificial Intelligence, innovative decision makers are beginning to explore new opportunities to leverage voice technology beyond commonplace routine. Being part of the Internet of things, which is taking popularity in every household and is integrated in people's everyday life. For example, Ilievski et al. [10] in their paper demonstrated how a voice assistant can be integrated with a home Air Quality Index measuring station.

Alexa is the voice controlled assistant developed by Amazon, which serves users via an Echo device, which has internet access. Amazon hosts a natural language processing system on the cloud to understand users requests and integrated very sensitive microphones that let the Alexa assistant to listen and give back a quick response through the speaker. But, the device streams you voice only when you ask it to do something. The default wake up word is Alexa. Once you have its attention, the microphone streams everything you say to Amazons cloud for further analysis. Alexa uses skills [11], voice application, to enable new abilities. They can be stock Amazon or developed by a third party developers. Each skill has a special invocation name that makes it unique from other skills. It is composed of actions that fulfill a users request, called intents and each intent can be activated by likely spoken phrases called utterances.

Parallel to the Alexa Skills, in the Google environment we have the Google Actions [12]. Using these the developers extend the functionality of the Google Assistant enabled devices, which include Google Home devices and Android smartphones with versions of 5.1.1 and up. The Google Actions consist of three important components. The first one is the intent. This describes the need or aim that the user wants to achieve by using the Google Assistant. Each intent, has its own unique identifier and it is recognized by Speech-to-text translation of the voice command of the user. Then comes the Action, that can serve several specific intents of the user. There are two types of Actions, Smart home Actions, which can be used to control your IoT devices in your home, and Conversational Actions that can have a variety of applications such as buying things online. Finally, each Action has its own fulfillment, the code that is used to handle the intent and process the queries from the user. Such Conversational Action and Alexa Skill have been developed, to support the medical services. Each of these medical services are described in full detail in the following section.

III. Architecture

The workflow starts with the wearable ECG sensor (section II, C) registering the ECG scans (Fig. 1). The mobile application [9] communicates with the wearable ECG sensor via Bluetooth worn on the patients body, monitors the scans and stores them on local storage and on the medical cloud. The ECG data sent to the cloud is analyzed and stored on the server. Patients can monitor and access the data sent from the sensor and receive alerts for abnormal heart functionality. The web application [9] enables registered doctors to monitor patients heart condition and retrieve data files of ECG scans. The medical cloud [6] has a crucial role in providing more personalized healthcare and information-based services. It collects the raw data from the sensors, processes the data to reveal relevant information, stores the information in EHRs which are easily accessible for all authorized applications and users.

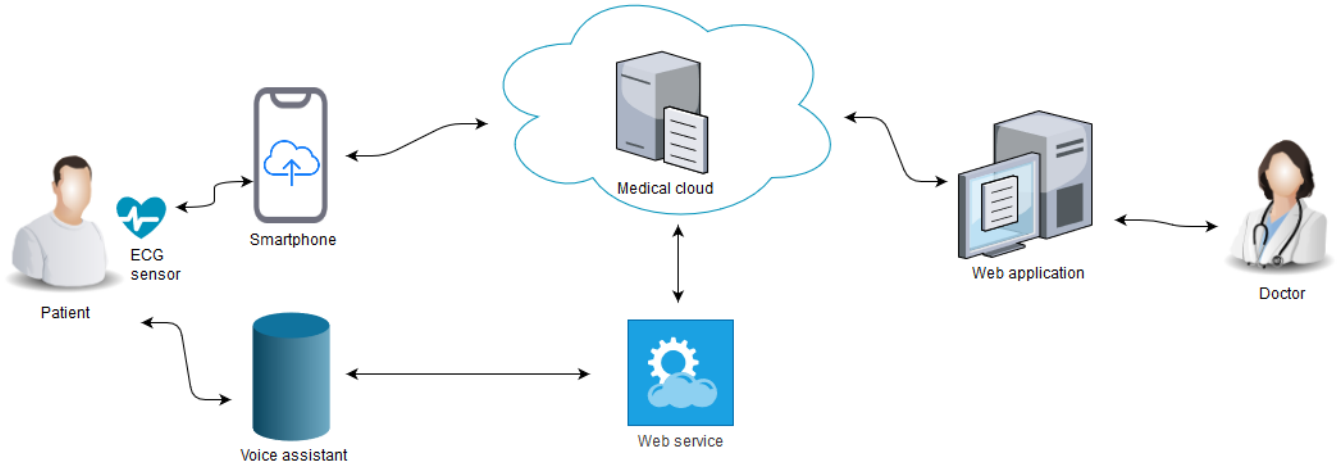

Fig. 1. Workflow of the voice assistant integrate healthcare system

The voice application takes the systems functionality one step further. It receives voice commands and information from the patient, which then communicates with the developed web service for the requested service or information. The featured voice enabled services are: heart condition checker, sending a report of the patients heart condition, scheduling appointments and a therapy reminder. The voice application is developed for the Google assistant devices and Amazon Alexa enabled devices. More about these services in the next section.

As an addition to the architecture, the authors developed a special web service that serves incoming request from the voice applications. When the voice application requests heart condition, the web service sends back processed heart condition information from the patients EHRs stored in the medical cloud. If there is something noted in the reading, the patient can forward a file of the reading through the web service to the doctor. As part of this web service, the authors developed a custom voice management system that schedules appointments through a voice interaction with the patient. Also the web service keeps in order the patients schedule of his therapy, by sending notifications through the voice application.

IV. Medical Background

A heart attack is a serious medical emergency within the cardiovascular diseases. Statistics provided by the World Health Organization on heart diseases [13], have revealed that different types of a heart attack are the cause of nearly one-third of deaths in the World. However, a timely medical attention may save the patient of premature death, and drastically reduce the risk of serious damage to the heart [14]. Interestingly, studies show that a heart attack may be predicted a couple of hours before its onset by detecting changes in the Electrocardiogram (ECG) of the patient [15].

In this project the authors aim at detecting three types of arrhythmia's: Ventricular fibrillation, infrequent Atrial fibrillation and frequent Atrial fibrillation. Each type of arrhythmia is mapped to a severity level value. Depending of the type of the irregular heartbeat, the web service by request of the voice application retrieves the types of occurred arrhythmia's and returns a value of severity. The vale of severity then is used to respond with a message to the patient. Ventricular fibrillation is severity level 1, which means that the patients heart condition is fine and no further actions are needed. Atrial fibrillation on the other hand, if this type of arrhythmia occurs infrequently, the voice applications suggest the patient to see that doctor in the next week or so. If Atrial fibrillation is frequent, then the voice application suggest the patient to see a doctor and continues on scheduling an appointment.

V. Voice Assisted Medical Services

The future of voice assisted healthcare, and the system presented in this paper as a proof-of-concept (for heart care) first, need to provide the user with time-efficiency in taking care of their health, by encompassing different services and functionalities into one single application. The voice applications developed for this paper, both for the Google Assistant and Alexa Devices, have been made with this aim. As mentioned previously they are communicating with our Web Service, that acts as a layer communicating with the medical cloud and other needed services.

The authors have developed 4 different functionalities for the Voice applications (skills), implemented as a proof-of-concept. First, it is enabled for the user to easily and instantaneously get advice about the readings made by the previously mentioned Savvy sensor. When prompted, the assistants tell information about the readings since the last time such question has been asked. Depending on the results, there are three types of replies, no action to be taken, recommendation of an appointment to be scheduled in a couple of weeks time and immediate appointment scheduling. In order to make it more convenient for the doctor, a pdf of the readings can be sent to the doctor in advance of the appointment.

This brings us to the second functionality, that is appointment scheduling (Fig. 3). Through the web service the user can schedule the nearest appointment or one on a specific date, by talking to the Voice assistants. A typical use case is as follows, first the user makes the query I want to schedule an appointment., the assistant asks for what time and day, and after the user answers the question, a final confirmation is requested, after which the appointment is scheduled.

After the appointment, the user may have received a certain therapy to follow and again the responsibility for the therapy schedule can be handed over to the voice assistant skills developed by the authors. That is, for each user apart from the readings and EHR information on the web service, a therapy information is stored that the user can save. The user can input several medications and their specific schedules, one medicine at a time. After prompting the assistant to insert new therapy, the user can insert the new medicine according to the pattern: ”Medicine, X times a day, starting at hour.” This can be repeated for all needed medicines. The therapy service flowchart is show in Fig. 4. The assistants, in addition, remind the users about their therapy and appointments, by notifying them if they use the assistants within 30 minutes of some of the two types of events.

VI. Voice Assisted Heart Healthcare Use Case

In this section we will go through a use case where the user checks his heart condition (Fig. 2). The functionality loop starts with the patient asking the voice assistant, at any moment, to check the readings from the sensor, example phrases: *”How are the ECG scans?”*; *”Is everything alright with the readings?”*. This will return the readings since last time the patient checked the condition of his heart. Depending on the severity of the readings, the voice assistant will respond with different sentences, some requiring further actions. If everything is alright, the voice assistant would notify the patient by saying: *”Everything seems fine”*. If the readings show a slight appearance of abnormal heart activity, the voice assistant will notify the patient by saying: *”I suggest seeing a doctor in one or two weeks time?”*. If the medical cloud detects abnormal heart activity, it will notify the patient with the sentence: *”Detected severe arrhythmia, I am appointing you to the doctor on ¡date¿”*. In the last example, the communication continues with arranging an appointment with the patients doctor by suggesting a date by checking previously with the appointment management system. The patient can accept the appointment or suggest another an optimal date.

VII. Results

For these proof-of-concept voice skills, 4 functionalities have been developed for the future of home care voice assistants. The ECG readings check, appointment scheduling, therapy record and sending a pdf to the doctor’s email. All necessary functions that encompass a complete home care solution. A demo video of these can be seen on the following link: https://bit.ly/2V2iFg7. The demo has been done using the Amazon Alexa Echo dot.

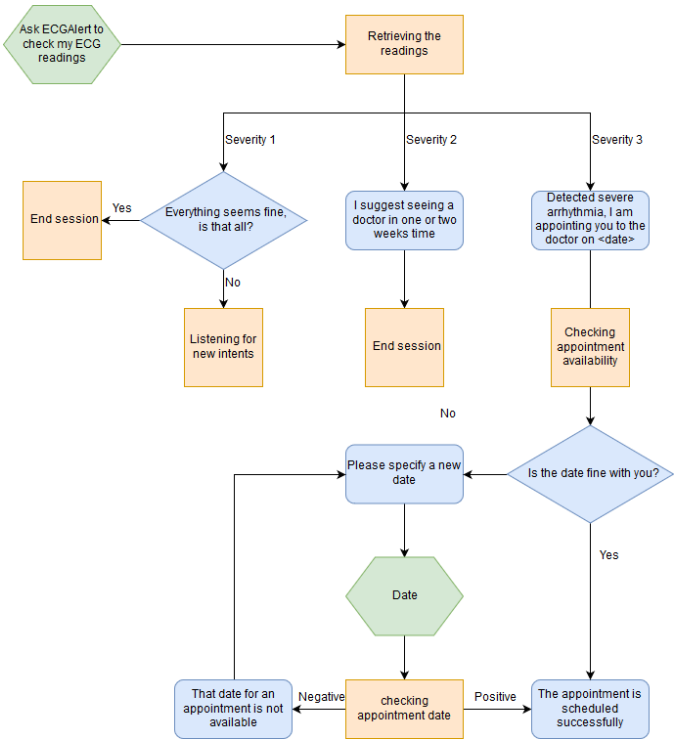

Fig. 2. Heart condition decision flowchart

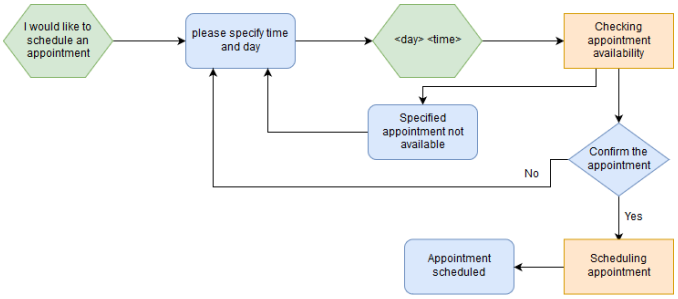

Fig. 3. Scheduling appointment decision flowchart

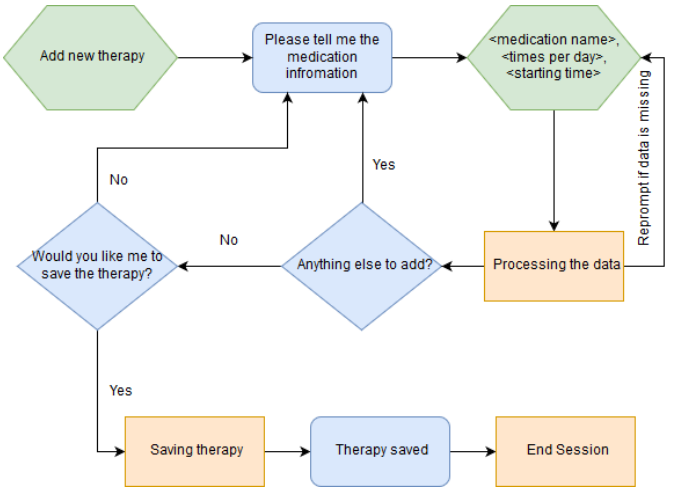

Fig. 4. Adding new therapy decision flowchart

VIII. Future work

This paper presents Alexa and Google Assistant applications, with the intention to serve the patient and help him with the monitoring of his vital signs in the comfort of his own home. Furthermore, giving the patient options to schedule a doctors appointment, save his therapy and medications guidelines so that the assistant can notify him and remind him when an action is needed and finally. Further functionalities might be a first aid help in emergency situations. The Assistant could look for the optimal hospital, depending on the traffic and frequency of visitors information and book a taxi ride or simply call a First-Aid ambulance, depending on the severity of the symptoms. In addition, voice assistants can advance its helpfulness by having the functionality of a symptom checker. The user at home lists the symptoms to the assistant, and the assistant based on probability could inform him of the most probable issue. Furthermore, it can find its use in first-aid ambulances, where a quick important medical information is needed, such as patients health record, blood type, allergies and so on.

IX. Conclusion

This paper focuses on solving the obstacles patients face when using wearable health sensors in their home environment. Such as lack of convenient tracking of readings, as well as misunderstanding of sensor readings, by handling the responsibility to the Amazon and Google voice assistants. Furthermore, the voice assistants can make suggestions and even schedule a doctors appointment, make reminders of the actions needed in the prescribed therapy and before appointments. Such use case of home health monitoring is the Savvy ECG sensor with voice assistant interaction, which is briefly described and it presents an easier way to understand and act on the readings. The authors hope that this paper will convey the benefits of voice interaction in the domain of home healthcare.

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New Approach of Dysgraphic Handwriting Analysis Based on the Tunable Q-Factor Wavelet Transform

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***Abstract*—Developmental dysgraphia is a neurodevelopmental disorder present in up to 30 % of elementary school pupils. Since it is associated with handwriting difficulties (HD), it has detrimental impact on children's academic progress, emotional well-being, attitude and behaviour. Nowadays, researchers proposed a new approach of HD assessment utilizing digitizing tablets. I.e. that handwriting of children is quantified by a set of conventional parameters, such as velocity, duration of handwriting, tilt, etc. The aim of this study is to explore a potential of newly designed online handwriting features based on the tunable Q-factor wavelet transform (TQWT) in terms of computerized HD identification. Using a digitizing tablet, we recorded a written paragraph of 97 children who were also assessed by the Handwriting Proficiency Screening Questionnaire for Children (HPSQ–C). We evaluated discrimination power (binary classification) of all parameters using random forest and support vector machine classifiers in combination with sequential floating forward feature selection. Based on the experimental results we observed that the newly designed features outperformed the conventional ones (accuracy = 79.16 %, sensitivity = 86.22 %, specificity = 73.32 %). When considering the combination of all parameters (including the conventional ones) we reached 84.66 % classification accuracy (sensitivity = 88.70 %, specificity = 82.53 %). The most discriminative parameters were based on vertical movement and pressure, which suggests that children with HD were not able to maintain stable force on pen tip and that their vertical movement is less fluent. The new features we introduced go beyond the state-of-the-art and improve discrimination power of the conventional parameters by approximately 20.0 %.**

***Index Terms*—Handwriting difficulties, developmental dysgraphia; online handwriting; digitizing tablet; tunable Q-factor wavelet transform; machine learning**

I. Introduction

Despite the rapid technological evolution in society, handwriting is still one of the most important life skills that children have to manage in the first years of their school attendance. Fluent and legible handwriting is important for expressing, communicating and recording their ideas [1], [2]. There are many underlying component skills that may interfere with handwriting performance, such as fine motor control, motor planning, in-hand manipulation, visual perception, sustained attention, etc. [3], [4]. It is estimated that 10–30 % of school-aged children suffer from a neurodevelopmental disorder called developmental dysgrafia, which is associated with difficulties mastering handwriting [5]. Handwriting difficulties (HD) can negatively impact academic success, self esteem, emotional well-being, behavior, and attitude [6], [7]. For a benefitial and effective therapy, it is necessary to have an objective methodology that would enable HD identification and complex assessment [8].

For identification and rating of the gravity of possible HD, Rosenblum et al. [9] developed the Handwriting Proficiency Screening Questionnaire for Children (HPSQ–C). The questionnaire apprehends the most significant indicators of dysgraphic handwriting [10], such as legibility, performance time, and physical and emotional well-being. It was already used in several studies considering different language groups [11]–[13]. Although Rosenblum et al. also developed a questionnaire, where the assessment is done by teachers (HPSQ – Handwriting Proficiency Screening Questionnaire for Children) [14], in this study we have decided to focus on HPSQ–C, because children are able to evaluate their handwriting skills better than anyone else. We proved this fact in our recent paper, where we compared results of HPSQ and HPSQ-C scales [15].

Current methods for identification of HD in children are outdated in comparison with methods dealing with reading disorders [16]. Today's trend in clinical assessment of children's handwriting tends to point toward examination of global legibility or specific letter's criteria, such as shape, spacing, position, number of errors, etc. Even though these criteria provide valuable information about handwriting, it's assessment together with administration and pattern searching is time consuming, expensive, and subjective. Moreover, they are usually limited to handwriting product, while the process of handwriting itself is less analysed.

Recent ongoing advancement in biomedical and IT technology enabled a new approach of handwriting analysis based on digitizing tablets (sometimes called digitizers). The digitizers record various signals during handwriting (see Fig. 1): x and y position of a pen when it touches paper's surface (on-surface movement), same coordinates of the pen when it is up to 1.5 cm above the

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surface (in-air movement), pressure, azimuth and altitude (tilt). We are used to call this kind of handwriting as online, because samples of these signals carry information about time [17].

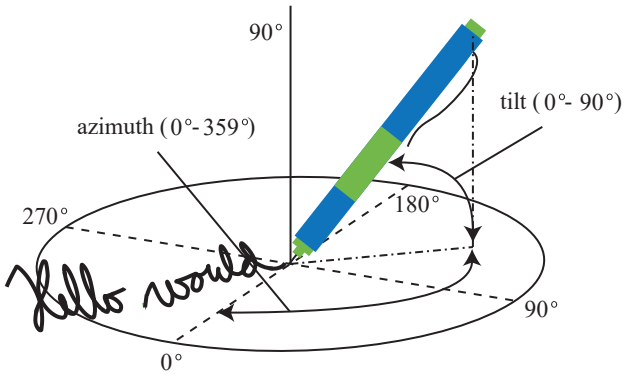

Fig. 1. Online handwriting signals: position (on-surface/in-air), pressure, azimuth, altitude(tilt).

Quantitative analysis of online handwriting is cost-effective, non-invasive, and recently proven diagnostic tool [5], [12], [18]–[23]. For instance, Asselborn et al. [24] reported 96.6 % sensitivity and 92.2 % specificity when diagnosing dysgraphia in a cohort of 298 pupils using BHK test in combination with random forest classifier [24]. Zhiming et al. reached 85.7 % HD identification accuracy employing modified support vector machine classifier in a database of 300 Chinese pupils assessed by HPSQ [11]. Next, in our recent study we were able to estimate total scores of HPSQ–C with approximately 14.77 % error using gradient boosted tree classifier in combination with only 6 specific in-air features (tested on a database of 97 Czech pupils) [15].

Almost all up-to-date scientific works are based on rather basic handwriting features. The advantage of this approach is, that the features could be easily clinically interpretable, which means that they can be linked with specific manifestations of HD. Nevertheless, since the developmental dysgraphia is associated with deficient fine motor skills, poor dexterity, poor muscle tone, or unspecified motor clumsiness, which generally manifests in higher complexity of handwriting, we assume that the conventional features are not able to sufficiently quantify these complexities. This led us to research of new parameterisation methods, that could significantly improve accuracy of computerized HD assessment. We hypothesize, that features based on the tunable Q-factor wavelet transform (TQWT) [25] could better quantify the hidden complexities in dysgraphic handwriting by residual of the decomposition, which should exhibit higher energy for dysgraphic (i.e. more irregular/complex) handwriting. Therefore, the specific aims of this study are:

- to introduce new TQWT based features quantifying handwriting complexity,
- to compare these features to the conventional ones (considered as a baseline) in terms of HD identification accuracy.

Further organization of the paper is as follows. Section II describes dataset and its acquisition process. In addition, it introduces the new TQWT based features and defines a baseline. Finally, this section provides information about employed statistical analysis. The results we achieved are presented in Section III. Discussion of the results and conclusions are given in Section IV and V, respectively.

II. Study & Methods

A. Dataset

For the purpose of this study we enrolled 65 pupils, who were attending 3rd and 4th grade of an elementary school. Almost all of them were right handed (only 2 kids were left handed). Children were asked to fill in the HPSQ–C questionnaire, which consists of 10 questions. Consequently, they were separated into two groups on the basis of a cut-off value derived from the HPSQ–C total score. The experimental group consists of children with higher values of HPSQ–C (i.e. children with HD). Children without HD are considered in the comparative group. Demographic information of children in both groups can be found in Table I. All children used the cursive handwriting and in all cases their parents signed an informed consent form. Thorough the whole study we followed the Ethical Principles of Psychologists and Code of Conduct released by the American Psychological Association (see https://www.apa.org/ethics/code/).

TABLE I
Dataset structure

Gender	N	Age [y]	Mark [-]	HPSQ–C [-]
Experimental group				
girls	16	9.19 ± 0.75	1.61 ± 0.47	20.88 ± 2.16
boys	17	9.18 ± 0.73	1.46 ± 0.38	22.82 ± 4.29
Comparative group				
girls	14	9.21 ± 0.70	1.11 ± 0.21	6.57 ± 2.38
boys	18	9.06 ± 0.73	1.01 ± 0.06	7.83 ± 2.28

N – number; y – years; HPSQ–C – HPSQ–C total score, Mark – mean mark of four major schools subjects (Czech language, Mathematics, English language, Fundamentals of civics and natural science)

B. Data Acquisition

The enrolled children were asked to copy a short paragraph (63 words, 371 characters including spaces), which was selected from a book for 3rd grade. During the acquisition, they were writing on a lined A4 paper, that was laid down and fixed to a digitizing tablet. For this purpose we used Wacom Intuos Pro L (PHT-80) digitizer with Wacom Inking pen. This pen is providing a valuable visual feedback during handwriting, which is entirely similar to the response of a regular inking pen. All signals of online handwriting were sampled with frequency f_s = 150 Hz. An example of the paragraph copy task performed by a pupil with and without HD can be found in Fig. 2.

C. Baseline Handwriting Features

Online handwriting signals were parameterized on a global level (i.e. the whole handwriting), as well as on the stroke one. We extracted the following set of

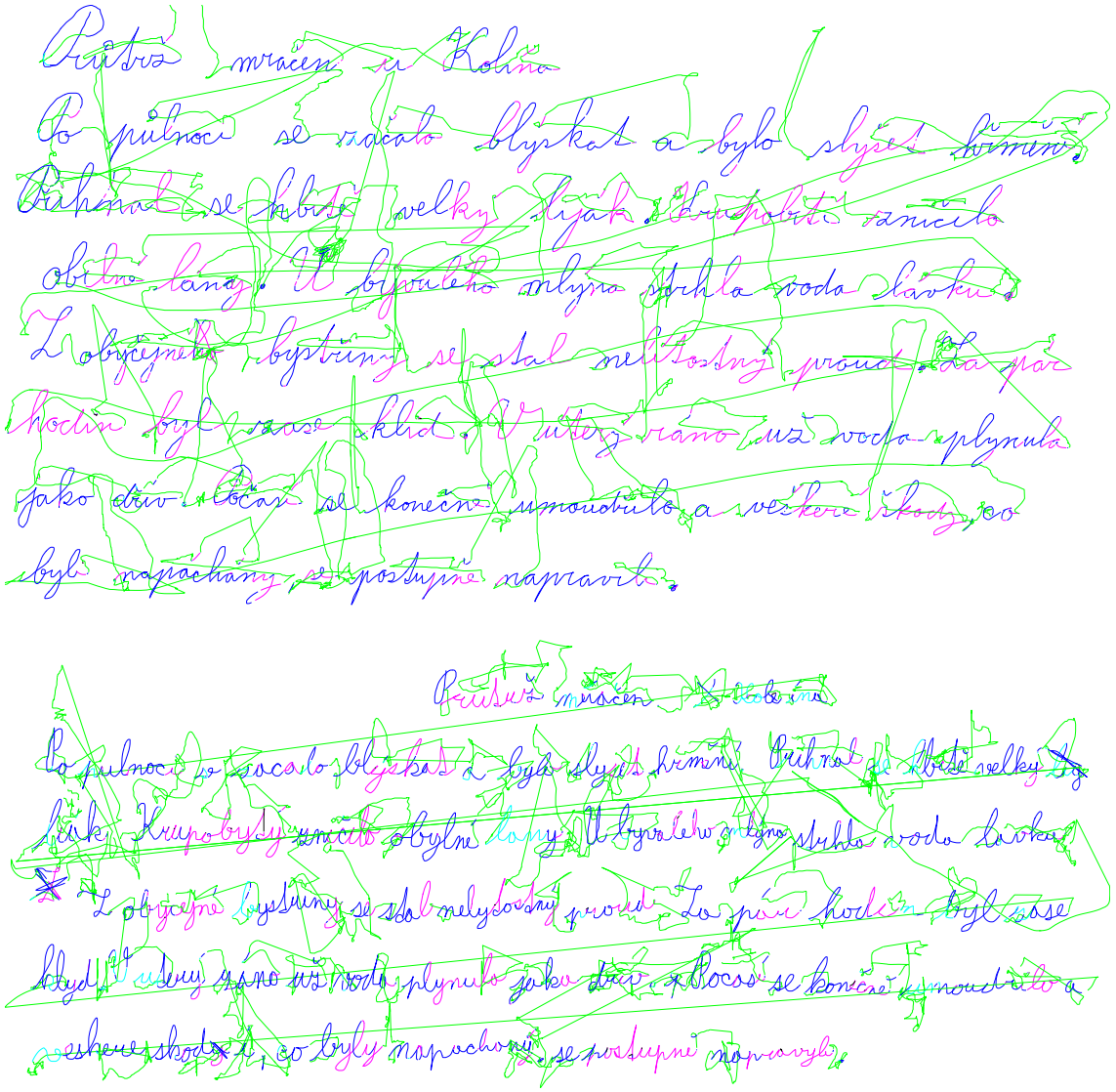

Fig. 2. The paragraph written by a child without HD (HPSQ-C = 3, upper part of the picture) and with HD (HPSQ-C = 35, lower part of the picture). The color of letters is given by the tip pressure of the pen (cyan: 0 – 25 %, blue: 25 – 50 %, purple: 50 – 75 %, black: 75 – 100 %). Green strokes around letters represent the in-air trajectories.

baseline parameters: kinematic (velocity, acceleration, jerk), temporal (duration), spatial (width, height, length of stroke), and dynamic (pressure). Kinematic, temporal and spatial features we calculated from both on-line and in-air movements. We also considered their horizontal and vertical projection. Features represented by a vector were consequently transformed into a scalar value using statistics such as mean, standard deviation, median, relative standard deviation, etc. For more information see [12], [18], [26].

D. Tunable Q-factor Wavelet Transform

The TQWT is a flexible fully-discrete wavelet transform, that can decompose a signal into two components, which represent its oscillatory behavior. With fine tuning we can decompose any signal into a high q-factor component $x_{\mathrm{HQ}}[n]$ and a low q-factor component $x_{\mathrm{LQ}}[n]$ [25]. If we consider the online handwriting signal as $x[n]$, then its TQWT residual part $x_{\mathrm{RES}}[n]$ can be calculated as:

$$x_{\mathrm{RES}}[n] = x[n] - x_{\mathrm{HQ}}[n] - x_{\mathrm{LQ}}[n]. \tag{1}$$

As already mentioned in the introduction, we assume that $x_{\mathrm{RES}}[n]$ contains information, that is linked with deficient fine motor skills, poor dexterity, poor muscle tone, or unspecified motor clumsiness [12]. Therefore, a signal-to-noise ratio (SNR) measure based on $x_{\mathrm{RES}}[n]$ could hypothetically differentiate handwriting associated with or without difficulties.

A clear part of $x[n]$, i.e. without the strong effect of HD, can be calculated using the following formula:

$$x_{\mathrm{CL}}[n] = x[n] - x_{\mathrm{RES}}[n]. \tag{2}$$

Next, we calculated SNR based on the three approaches published at [27]: SNR based on the Teager-Kaiser Energy Operator ($\mathrm{SNR}_{\mathrm{TEO}}$), SNR based on the Conventional

Energy Operator E (SNR_{CON}), and SNR as the energy ratio of $x_{\text{RES}}[n]$ and $x_{\text{CL}}[n]$, i.e.:

$$\text{SNR}_{\text{E}} = 10 \cdot \log_{10} \left(\frac{E(x_{\text{CL}}[n])}{E(x_{\text{RES}}[n])} \right) [\text{dB}]. \quad (3)$$

We applied the TQWT on all raw online handwriting signals (see Fig. 1) and also on velocity, acceleration, and jerk profiles.

Extracting around eight hundred features from each pupil was computationally highly demanding, so we designed our program to work on various computers at the same time. Each computer can be set to extract features only for selected pupils and save its results to a remote server.

E. Statistical Analysis

We considered three scenarios in our study:

1) Baseline: experiments based on the baseline handwriting features (81 in total).
2) Scenario 1: based on the TQWT features (665 in total).
3) Scenario 2: combination of the baseline and TQWT features (774 in total).

Firstly, we performed an exploratory analysis using Pearson's and Spearman's correlation between handwriting features and HPSQ–C total score. In addition, we employed univariate classification analysis, where we tested discrimination power of individual features using support vector machine (SVM with linear kernel) [28] and random forest (RF including 40 trees) [29] classifiers. We considered 10-fold cross-validation with 100 repetitions. The discrimination power was evaluated by accuracy (ACC), sensitiviy (SEN), specificity (SPE), and the Matthew correlation coefficient (MCC).

In the second step, we performed multivariate classification analysis, using a combination of the sequential floating forward selection (SFFS) algorithm [30] and SVM/RF classifiers. We followed the same cross-validation settings and evaluation measures. Due to large computational demands of SFFS, especially in Scenario 2, where a feature space has big dimension, we additionally included minimum redundancy maximum relevance feature selection (mRMR) [31] into the machine learning pipeline (i.e. feature pre-selection). After this pre-selection each model was trained in approximately 1.5 day on a computer with CPU Intel i5 6500 3.2 GHz and 16 GB 1600 MHz DDR3 RAM.

III. Results

Results of the Baseline scenario are shown in Table II. Strongest relationship with the HSPQ–C total score exhibited mean velocity (in-air) with $\rho = -0.38, p = 0.0016$. The best discrimination power had standard deviation of altitude, that was modelled by RF (MCC $= 0.35$, ACC $= 67\,\%$, SEN $= 70\,\%$, SPE $= 65\,\%$). In the multivariate classification analysis we reached 73 % accuracy (MCC $= 0.49$, SEN $= 80\,\%$, SPE $= 68\,\%$) using 3 features modelled by SVM.

TABLE II
Baseline scenario

COR / feature name		Spearman's r		Pearson's ρ	
M of velocity††		-0.36^{**}		-0.38^{**}	
M of height of stroke‡‡		0.37^{**}		0.34^{**}	
Duration of writing††		0.31^{*}		0.28^{*}	
C	UCA / feature name	ACC [%]	SEN [%]	SPE [%]	MCC [-]
S	M of velocity††	64.1±17.4	70.6±25.7	59.3±28.9	0.3±0.4
S	M of height of stroke‡‡	63.5±18.2	65.0±28.1	63.7±28.2	0.3±0.4
S	M of jerk††	61.6±17.2	84.3±20.9	40.7±28.5	0.3±0.4
R	Std of altitude	66.7±17.6	69.6±27.4	65.0±28.1	0.3±0.4
R	Length of writing‡‡	65.2±18.5	59.8±28.5	71.7±27.7	0.3±0.4
R	M of vertical jerk‡‡	63.8±18.0	59.0±28.7	70.5±28.1	0.3±0.4
	MCA / feature name	ACC [%]	SEN [%]	SPE [%]	MCC [-]
S	SHOS	66.7±17.4	75.6±26.0	58.1±29.3	0.3±0.4
S	M of velocity††	66.6±18.9	76.1±26.4	59.1±29.8	0.3±.4
S	M of duration of stroke‡‡	73.5±17.1	80.8±23.5	68.8±27.4	0.5±0.3
R	Std of altitude	66.7±17.9	69.1±27.3	65.4±29.0	0.3±0.4
R	SVnJ††	65.6±18.4	69.2±27.7	64.3±29.3	0.3±0.4
R	Std of length of stroke‡‡	69.5±17.7	71.8±27.2	68.3±27.9	0.4±0.4

COR – Correlation analysis, C – Classificator, UCA – Univariate Classification Analysis, MCA – Multivariate Classification Analysis, †† – In-air, ‡‡ – On-surface, R – Random Forest Classifier, S – Support Vector Machine, M – Mean, Std – Standart deviation, SHOS – Std of height of the stroke ‡‡, SVnJ – Std the of vertical normalized jerk, $^{*} - p < 0.05$, $^{**} - p < 0,01$, $^{***} - p < 0.001$.

Table III reports results of Scenario 1. In correlation analysis SNR_{E} of vertical normalized jerk (in-air) achieved the highest value of $\rho = 0.37$ ($p = 0.0022$). The highest discrimination power was observed in 4th moment of SNR_{CON} extracted from pressure profile and modelled by RF, where ACC $= 68\,\%$ (MCC $= 0.38$, SEN $= 68\,\%$, SPE $= 71\,\%$). Regarding the multivariate analysis, we reached ACC $= 79\,\%$ using 6 TQWT features, that were modelled by SVM (MCC $= 0.58$, SEN $= 86\,\%$, SPE $= 73\,\%$).

Finally, results of Scenario 2 can be found in Table IV. In this case the classification accuracy was further improved to ACC $= 85\,\%$ (MCC $= 0.70$, SEN $= 89\,\%$, SPE $= 83\,\%$), where a feature space containing 9 parameters was modelled by SVM.

IV. Discussion

On the basis of our correlation analysis, we can confirm, that HD manifest in higher energies of TQWT residual signals of online handwriting. This finding is supported, for example, by the positive correlation ($\rho = 0.37, p = 0.002$) between SNR_{E} of vertical normalized jerk (in-air) and the HPSQ–C total score. Moreover, the vertical movement during handwriting involves activation of more muscles than in the horizontal case. Therefore, this movement is more complex, requires better handwriting proficiency, and better differentiates children with and without HD. Another finding based on the correlation analysis is, that children with lower values of mean velocity (in-air) exhibit higher HPSQ–C scores. This probably means that children with HD have slower transitions between strokes, which could be linked with cognitive functions.

Since MCC $= 0.49$ in the Baseline scenario was lower than MCC $= 0.58$ in Scenario 1, we can conclude that the TQWT based parameters outperformed the conventional ones. Nevertheless, a combination of both feature sets brought even better results (MCC $= 0.70$), which suggests

TABLE III
SCENARIO 1

COR / feature name	Spearman's r	Pearson's ρ
SNR_E of VNJ	0.36^{**}	0.37^{**}
SNR_{TEO} of RIRP	-0.31^{*}	-0.31^{*}
SNR_{CON} of 95PXP	-0.26^{*}	-0.30^{*}

C	UCA / feature name	ACC [%]	SEN [%]	SPE [%]	MCC [-]
S	SNR_{TEO} of STY	65.3±17.7	71.4±25.7	63.3±28.9	0.3±0.4
S	SNR_{CON} of SEY	65.3±17.9	67.7±28.4	66.2±27.5	0.3±0.4
S	SNR_E of HS	65.3±17.6	71.6±26.1	60.4±29.5	0.3±0.4
R	SNR_{CON} of 4MP	68.1±18.1	68.0±27.8	70.6±27.5	0.4±0.4
R	SNR_E of 1OEX	67.9±17.5	69.0±27.7	68.6±27.6	0.4±0.4
R	SNR_E of IRY	68.3±16.9	66.7±26.9	70.7±27.2	0.4±0.4
	MCA / feature name	ACC [%]	SEN [%]	SPE [%]	MCC [-]
S	SNR_E of IRX	69.2±18.0	75.4±25.3	64.2±29.0	0.4±0.4
S	SNR_E of RIXA	76.9±16.2	81.0±23.6	73.9±26.1	0.5±0.3
S	SNR_E of 95XO	77.0±16.4	82.0±23.1	74.3±26.1	0.5±0.3
S	SNR_E of 90XO	78.5±15.7	84.3±22.1	73.4±25.8	0.6±0.3
S	SNR_{CON} of RRY	78.6±16.1	85.2±20.8	73.0±26.2	0.6±0.3
S	SNR_{CON} of RIRYP	79.2±15.6	86.2±20.2	73.3±26.2	0.6±0.3
R	SNR_E of IRXS	66.3±17.8	66.3±28.1	67.3±27.9	0.3±0.4
R	SNR_{CON} of 1OEYP	74.0±17.0	73.0±26.7	75.8±26.7	0.5±0.4
R	SNR_{CON} of RINTQ	74.8±17.3	76.3±25.9	74.5±26.2	0.5±0.4
R	SNR_E of 90PXP	75.1±16.8	77.3±25.0	74.0±26.8	0.5±0.4
R	SNR_{TEO} of 1OEYP	76.5±16.2	78.5±23.7	76.9±24.8	0.5±0.3

COR – Correlation analysis, C – Classificator, UCA – Univariate Classification Analysis, MCA – Multivariate Classification Analysis, $\dagger\dagger$ – In-air, $\ddagger\ddagger$ – On-surface, R – Random Forest Classifier, S – Support Vector Machine, M – Mean, Std – Standart deviation, VNJ – vertical normalized jerk $\dagger\dagger$, STY – Shannon entropy of TEO of y position $\ddagger\ddagger$, RIRP – relative interdecile range of pressure p, 95PXP – 95th percentile of x position $\dagger\dagger$, SEY – Shannon entropy of y position $\ddagger\ddagger$, HS – height of stroke $\ddagger\ddagger$, 4MP – 4th moment of pressure p, 1OEX – 1st order entropy of x position $\dagger\dagger$, IRY – interdecile range of y position $\ddagger\ddagger$, IRX – interdecile range of x position $\ddagger\ddagger$, RIXA – relative interpercentile range of x position $\dagger\dagger$, 95XO – 95th percentile of x position $\ddagger\ddagger$, 90XO – 90th percentile of x position $\ddagger\ddagger$, RRY – relative interdecile range of y position $\dagger\dagger$, RIRYP – relative interdecile range of y position $\ddagger\ddagger$, 1OEYP – 1st order entropy of y position $\ddagger\ddagger$, IRXS – interdecile range of x position $\ddagger\ddagger$, RINTQ – relative interquartile range of y position $\ddagger\ddagger$, 90PXP – 90th percentile of x position $\ddagger\ddagger$, * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$.

TABLE IV
SCENARIO 2

	MCA / feature name	ACC [%]	SEN [%]	SPE [%]	MCC [-]
S	SNR_E of 90XO	69.5±17.8	76.9±25.7	65.5±27.7	0.4±0.4
S	M of velocity $\dagger\dagger$	77.8±15.5	80.6±22.6	76.1±24.9	0.6±0.3
S	Std of jerk $\ddagger\ddagger$	82.7±15.0	84.7±22.1	82.2±21.8	0.7±0.3
S	SNR_{CON} of 90XO	84.6±14.3	87.7±20.5	82.0±22.5	0.7±0.3
S	SNR_{CON} of MADX	84.6±14.1	88.5±18.1	82.1±22.7	0.7±0.3
S	SNR_{TEO} of FCY	84.6±14.4	89.0±18.5	82.1±21.7	0.7±0.3
S	SNR_{TEO} of FCX	84.5±14.4	89.0±18.0	82.0±22.7	0.7±0.3
S	SNR_{CON} of FCX	84.2±14.6	88.7±17.9	82.5±22.3	0.7±0.3
S	SNR_{CON} of FCY	84.7±14.3	88.7±18.7	82.5±22.4	0.7±0.3
R	SNR_E of IRX	66.0±17.1	66.5±27.4	67.5±27.1	0.3±0.4
R	MOSW	75.3±16.1	74.0±26.4	77.7±24.7	0.5±0.3
R	SNR_{TEO} of PXY	77.3±16.6	74.3±26.5	80.9±23.8	0.5±0.4
R	SNR_E of 90XO	78.4±15.7	76.9±24.8	81.2±22.8	0.6±0.3
R	SHS	79.6±15.7	79.1±23.7	81.0±24.9	0.6±0.3
R	SNR_E RINTERP	79.7±15.1	79.2±23.6	81.9±23.6	0.6±0.3
R	SNR_E of 95XO	80.3±15.1	79.4±24.4	81.9±23.5	0.6±0.3

COR – Correlation analysis, C – Classificator, UCA – Univariate Classification Analysis, MCA – Multivariate Classification Analysis, $\dagger\dagger$ – In-air, $\ddagger\ddagger$ – On-surface, R – Random Forest Classifier, S – Support Vector Machine, M – Mean, Std – Standart deviation, 90XO – 90th percentile of x position $\ddagger\ddagger$, MADX – mean absolute deviation of x position $\dagger\dagger$, FCY – first correlation coefficient of y position $\dagger\dagger$, FCX – first correlation coefficient of x position $\dagger\dagger$, IRX – interdecile range of x position $\ddagger\ddagger$, PXY – position of max. of y position $\dagger\dagger$, RINTERP – relative interpercentile range of y position $\dagger\dagger$, 95XO – 95th percentile of x position $\ddagger\ddagger$, MOSW – Mean of speed of writing $\dagger\dagger$, SHS – Std of height of stroke $\dagger\dagger$, * – $p < 0.05$, ** – $p < 0,01$, *** – $p < 0.001$.

that the conventional parameters still play their significant role in HD analysis.

Regarding the computerized identification of HD, Asselborn et al. [24] reported SEN $= 96.6\,\%$ and SPE $= 99.2\,\%$ using 53 features. Zhimming et al. [11] reported SEN $= 77\,\%$ and SPE $= 77\,\%$ based on 7 features. Finally, in our recent article we reached SEN $= 96\,\%$ and SPE $= 97\,\%$ based on 7 features [12]. We received SEN $= 89\,\%$ and SPE $= 83\,\%$ in this study, which is lower than in the recent ones. Nevertheless, since each team used a different set of parameters, tasks and different cohorts, the results are hardly comparable.

Finally, we can observe that the most discriminative TQWT features (see Table III and Table IV) are extracted mainly from the on-surface/in-air x and y trajectories and from the pressure profile. Therefore, we assume that the higher handwriting complexities associated with HD are not that much manifested in tilt and azimuth.

V. CONCLUSION

The general goal of this study is to introduce new TQWT based parameters quantifying handwriting complexity and evaluate these features in terms of HD identification accuracy. The results suggest that the residual signal of TQWT decomposition contains some information about irregularities/complexities linked with HD. More specifically, the major occurrence of these complexities was observed in the x/y trajectories and in the pressure profile. Finally, we found out that the newly introduced parameters (those based on TQWT) improve HD identification accuracy by approximately $20\,\%$ (in comparison to the baseline feature set). Unfortunately, we cannot compare our results with achievements of other research teams, because any experiments based on the considered dataset have not been published yet. Nevertheless, our goal was to compare TQWT based parameters with a conventional baseline features.

This work has a couple of limitations. First of all, the dataset does not have a large number of samples, which means that the results cannot be well generalized, nevertheless, it provides an intuition and some pilot conclusions, that can be further developed and evaluated on larger cohorts. Next, the TQWT decomposition can be tuned using several parameters. In the frame of our experiments we followed the settings recommended in [25], however, some kind of optimization could further increase the discrimination accuracy. The children assessed themselves by HPSQ–C, which means that our trained models are dependent on a subjective rating. Finally, the children were recorded only in one session, therefore we are not able to monitor intra-writer variability, and its effect on models' sensitivity and specificity.

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Analysis of a Differential Noise Detection Filter in ECG Signals

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***Abstract*—Noise detection presents a big challenge in wearable heart monitor technology and beat detection. The distorted signal is hard to interpret and as a consequence, valuable information may be lost. In this paper, we present our research for developing a noise detection filter based on a differential filter. Our analysis offers in-depth evaluation of the optimal values of two critical parameters - window size and Signal-to-Noise threshold. Our final goal is to minimize errors in QRS detection and beat classification caused by noise-distorted data.**

***Index Terms*—Noise Detection, ECG, Telemedicine**

I. Introduction

Wearable health monitors are quickly becoming ubiquitous and as a result there is a rapidly growing amount of data that is digitally processed and analyzed. The integrity of this data is of utmost importance, especially when dealing with highly sensitive information such as health data.

ECGalert [1] is an instance of a wearable heart monitor that transfers health data to the cloud for further processing. A wearable sensor samples the heart activity, while the data is collected by the user's mobile phone over Bluetooth. Once the user connects to the Internet and the recording has been completed, it is automatically uploaded to the cloud where the data is subject to detailed analysis. The ECGalert system can correctly classify several types of beats, such as

- Normal (N),
- Ventricular (V),
- Supraventricular (S), and
- Fusion of Ventricular and normal beats (F);

as well as the following types of rhythm episodes:

- Bigeminy,
- Trigeminy,
- Ventricular ectopies,
- Supraventricular (atrial) ectopies,
- Atrial fibrillation and flutter,
- Ventricular tachycardia and fibrillation.

ECGalert uses an improved version of the Hamilton QRS detection algorithm [2] for its analysis. We have found that correct detection and classification depend on the quality of the recording. Noise may cause valuable information (contained within the signal) to be lost. This may result in false identification of a QRS complex, or even missing a QRS complex detection, which ultimately leads to false diagnosis. Therefore, noise detection and identification of uninterpretable segments is the first step to eliminating errors caused by noise.

Unreadable, or uninterpretable, in this sense, means that the noise level is so high that efficient filtering techniques used in QRS detection algorithm can not perform well and reveal sufficiently good results, where the sensitivity and positive predictivity of QRS detection is higher than 99.8%.

Noise is usually classified as:

- *high frequency noise*, usually caused by the environment and nearby electro-magnetic field, and
- *low frequency noise*, usually caused by muscles and body movement.

Elimination of very low frequency noise can be efficiently realized by a high pass filter with cut-off frequency of 0.5 or 1 Hz. This will eliminate the baseline drift that usually occurs in the signal.

Elimination of high frequency noise that occurs due to the electricity and other electro-magnetic fields can be efficiently realized by a low pass filter with cut-off frequency of 30 Hz or above.

The spectrum of an ECG signal, where the QRS complexes are usually lays between 3-15 Hz [3] and a deeper analysis shows which filters can be used for noise elimination [4]. The best results are obtained by implementing wavelet filtering methods [5]

The real problem can be identified by analyzing the typical power spectra of an ECG signal, as presented in [3]. Eliminating the very low and very high frequencies by a bandpass filter [4] will still reveal a signal where the noise corrupts the original ECG signal. In fact almost all QRS detection algorithms work on detecting the high slope of a QRS complex [6], [7], which is always corrupted by noise which appears between 3-10 Hz.

Therefore, the real problem is to identify if the noise level is high enough that it will prevent the correct detection of QRS complexes. A differential filter is proposed in this research to analyze the level of noise in the signal. The problem is that we do not know if the signal contains QRS complexes, and we do not know their position. The detection method uses analysis of a given signal segment and the energy of signal level within the signal segment. The QRS complex itself generates a high level of energy, and we have to conclude if there is noise or

not. If the analyzed segment is small enough, then we face the problem that there are none, one or two QRS complexes. To solve this, the segment should be large enough to contain several QRS complexes. Analyzing a segment that is too large will lose the efficiency to detect the interval where noise exists.

Accuracy and reliability are determining factors in the usability of a health-monitoring product and this proves to be our motivation. In this paper, we present our findings regarding the implementation of a differential filter, as well as a thorough analysis of the optimal values for window size and Signal-to-Noise threshold, that will give a clear indication that the signal can be efficiently processed.

The structure of this paper is as follows. Related work is presented in Section II and our methodology is explained in Section III. Section IV presents the results. Finally, a discussion is given in Section V.

II. Related work

Velayudhan et al. [8] present a comprehensive summary of the various noise-detection and denoising techniques that can be applied to an ECG signal. They find that the adaptive filtering technique outperforms the other approaches when the signal has a low SNR, however the filtered residue technique is superior when working with moderate SNR.

Jekova et al. [9] analyze the performance of five different SR/VF detection algorithms to determine the ones that perform best with noisy data. They concluded that TCIs, VF filter and spectral analysis were the most appropriate algorithms. Based on the presented data it can be concluded that the VF algorithm had the best results in terms of performance stability.

Sameni et al. [10] propose a novel framework for achieving high-resolution ECG by implementing the Bayesian approach. In this framework they review the performance of conventional filtering approaches where they conclude that Unscented Kalman Filter basend on the Unscented Transform is the most robust approach to severe nonlinearities of the input time series.

Jekova et al. [11] present a thorough analysis of the most common noise types present in ECG recordings, as well as a novel approach to evaluating the level of noise corruption in ECG data. Their proposed solution incorporates six parallel noise tests which aim to assess the corruption level of specific noises. This approach uses 13 parameters to determine the presence of noise.

Lee et al. [12] propose a real-time approach for the detection of artifacts caused by motion and noise (MN). Their algorithm works in two stages. Firstly, empirical mode decomposition of the signal is performed, and then they attempt to identify noisy segments in the resulting high-pass-filtered signal by evaluating the randomness of the calculated values. The result is a threshold for the separation between clean and MN-corrupted data.

Determining the level of SNR in an analyzed ECG signal presents another challenge in the interpretation of ECG recordings.

III. Methodology

Our work is based on the differential filter, and our goal is to identify the optimal values for which the algorithm performs best.

A. Algorithm

The algorithm we propose is a first-difference operator. We calculate the difference between two adjacent samples with

$$y[i] = x[i] - x[i-1], \tag{1}$$

where **y** is the resulting vector which contains the difference between all adjacent samples in the original vector **x**. Once all the values in vector **y** are calculated the following summation of values is performed

$$sum = \sum_{i=0}^{n} |y[i]| \tag{2}$$

This sum is continuously recalculated after the sliding window has shifted **z** amount of times, i.e. **z** new samples have been inserted into the filter.

Experimental analysis allowed us to determine the optimal threshold which differentiates the original, clean signal from the noisy signal.

B. Data

The data we used to conduct this research was obtained from the MIT-BIH Noise Stress Test Database which is freely available on the PhysioNet [13] website. Originally, the data was digitized at 360 samples per second per channel with 11-bit resolution, however we have resampled it to 125Hz and 16-bit resolution.

These records were obtained in such a way that two records found within the MIT-BIH arrhythmia ECG database, 118 and 119, were used as a basis where noise of the types typically observed in ECG recordings were added to the files, generating variations of the files with different SNRs. The name of the record means how much noise is added, by identifying the signal to noise ratio measured in dB. There are 6 records within this database for 118 and 119 labeled by e24, e18, e12, e06, e00 and e_6, correspondingly to SNR levels of $24dB$, $18dB$, $12dB$, $06dB$, $0dB$, and $-6dB$.

SNR level of $24dB$ means dominant signal, level of $0dB$ means equal level of noise and signal and level of $-6dB$ means that noise is dominant in relation to the signal. Although the original signal was sampled using an 11-bit resolution (values within range 0 to 2047 and zero at 1023), due to high level of noise, every file was resampled to 16-bit resolution (values between 0 and 16383, and zero at 8191).

Noise was not added to the whole signal but in segments. The first segment starts at the fifth minute, lasts two minutes, then in alternate segments of 2 minutes without and with noise.

C. Evaluation indicators

The following statistical parameters are used to evaluate the performance of the algorithm: sensitivity, positive predictive value and 1/F score.

A careful definition of true positives (TP), false positives (FP), false negatives (FN) and true negatives (TN) is needed to calculate these statistical parameters. In this paper, we define two evaluation measures, the first one concerns the ability to detect:

- QRS complex,
- a high noise level that prevents QRS detection algorithm to perform satisfactorily.

The majority of authors use only the first evaluation measure to detect a QRS complex, defining TP to be an identified QRS complex within 150ms from the true QRS complex, FP to be a detected QRS that does not exist, FN to be inability to detect a QRS complex, and TN correctly identifying the non-existence of a QRS complex. According to the standard 60601-2-47 [14], a QRS is correctly detected if it is within $150ms$ of the real location of the QRS complex.

Sensitivity (SEN), also known as hit rate or true positive rate (TPR), measures the proportion of correctly identified positive cases TP in regards to the actual number of positive cases (altogether those correctly and incorrectly detected QRS complexes), calculated by (3).

$$SEN = \frac{TP}{TP+FN} \tag{3}$$

Positive Predictive Value (PPV), also known as precision, is the proportion of positive results that are true positives in regards to the total number of detected QRS complexes, that is positive results (both true and false positives) acquired with the detection method, calculated by (4).

$$PPV = \frac{TP}{TP+FP} \tag{4}$$

Sensitivity refers to the ability of the algorithm to detect all existing events, while positive predictive rate means how much of the detected events are correct.

Presenting just one of these statistical measures may mislead real performance. High sensitivity means that the algorithm will reveal all existing events (detecting all relevant QRS complexes) but at the same time it may also reveal a lot of misses (detecting false positives, QRS complexes that do not exist). This is why the $Fscore$ as a harmonic mean of both these values will reveal a more comprehensive and accurate statistical measure to evaluate the performance. (5) presents the way it is calculated.

$$\frac{1}{F\ score} = \frac{1}{SEN} + \frac{1}{PPV} \tag{5}$$

In this research we use an improved version of the Hamilton's QRS detector [7], which performs better than most of the existing QRS detectors [15] achieving QRS detection sensitivity of 99.1% and positive predictive value of 99.9%. This algorithm has shown the following performance in regards to the MIT-BIH noise stress testing database, and including original records from MIT-BIH arrhythmia database, as presented in Table I.

TABLE I
PERFORMANCE OF THE IMPROVED QRS DETECTION ALGORITHM TESTED ON THE MIT-BIH NOISE STRESS TESTING DATABASE

Record	SEN	PPV	1/F score
118	100.00%	99.91%	99.95%
118e24	100.00%	99.87%	99.93%
118e18	99.47%	97.42%	98.43%
118e12	98.02%	91.40%	94.59%
118e06	95.87%	82.85%	88.89%
118e00	87.18%	76.47%	81.47%
118e_6	84.55%	69.88%	76.25%
119	100.00%	99.95%	99.97%
119e24	99.90%	99.90%	99.90%
119e18	99.80%	96.59%	98.17%
119e12	99.30%	87.92%	93.26%
119e06	96.48%	79.21%	87.00%
119e00	89.58%	71.72%	79.66%
119e_6	83.34%	66.08%	73.71%

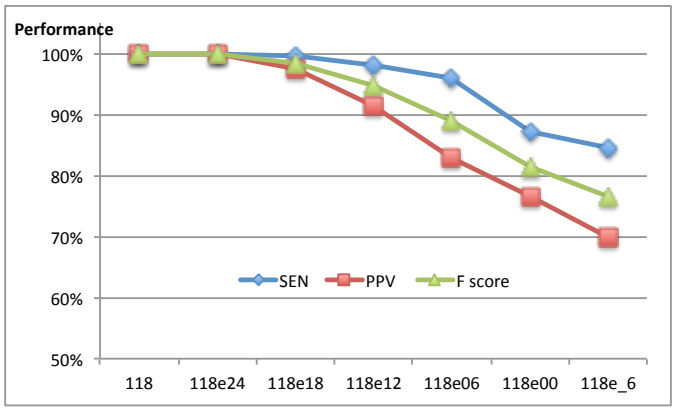

Fig. 1. Performance of the QRS detection algorithm evaluated on record 118 MIT-BIH noise stress testing database (SNR level indicated after the record name)

Analyzing the QRS detection algorithm presented in Fig. 1 and 2, we conclude that if the level of noise is lower than SNR of $12dB$ then the achieved QRS detection performance is higher than 98%, which is the performance achieved by state-of-the-art QRS detection algorithms.

Therefore, the new evaluation measure we introduce is the ability to detect if the noise level is low enough, such that the signal to noise ration (SNR) is higher than $12dB$ and QRS detection performs well.

In this sense, we calculate the sensitivity, positive predictive rate and 1/F score to detect if the SNR is higher than $12dB$ in order to enable quality detection of QRS complexes in the ECG signal. This will be achieved by calculating:

- TP (true positive) for a segment that the tested algorithm correctly detects a high level of noise,
- FP (false positive for a segment for which the tested algorithm wrongly detects a high level of noise for a signal with a small level of noise,

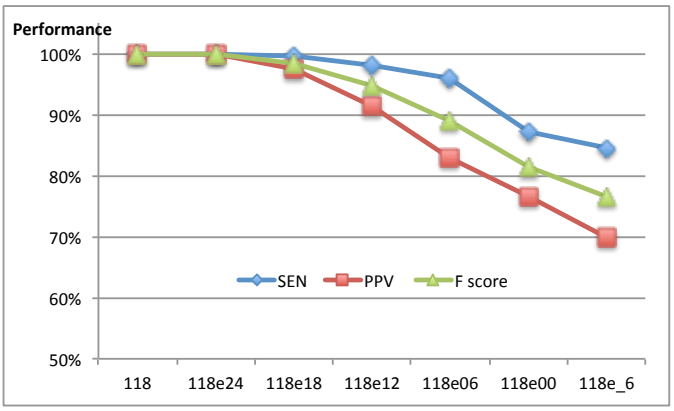

Fig. 2. Performance of the QRS detection algorithm evaluated on record 119 MIT-BIH noise stress testing database (SNR level indicated after the record name)

- FN (false negative) for a segment for which the tested algorithm does not detect a signal with a high level of noise,
- TN (true negative) for a segment that the tested algorithm does not detect since the signal does not have a high level of noise.

The corresponding statistical measures SEN, PPV and 1/F score are calculated by the same equations (3), (4) and (5) correspondingly.

The results will be evaluated according to the calculation of the number of episodes and duration of segments with high levels of noise. The number of segments with high level of noise in the existing signal is 7 and total duration of noise is 13 minutes and 5 seconds per record.

IV. Results

Our research aims to identify the optimal values for window size and Signal-to-Noise threshold. We assumed that a dependency between these two parameters and the accuracy of the algorithm exists. The first parameter that we reviewed is window size, i.e. the amount of samples the filter can hold at any given time. The values we experimented with were 250, 625 and 1025, which correspond to 2, 5 and 10 second intervals sampled at 125Hz.

Our analysis concludes that a filter length of 625 is most optimal when working with files sampled at 125Hz. We have also experimented with values for **z**, which as we previously mentioned is the number of samples that will be inserted into the filter before another calculation of sum is conducted. Our research shows that from three analyzed values: 25, 50 and 100 - 50 and 100 prove to perform better than 25. Figures 3 and 4 visualize the data on which we based our conclusions for filter length and z. The data is presented so that the x-axis visualizes the number of noisy episodes detected by our algorithm, while the y-axis presents the file and filter length which has been used in format file_name-filter_length.

The correct number of noisy episodes that are present in the noise-corrupted files is 7. As it was previously mentioned,

TABLE II
Achieved results for performance to detect high level of noise in the ECG signal.

Record	Threshold	SEN	PPV	1/Fscore
118e_6	20000	0.99	0.96	0.95
119e_6	20000	0.98	0.97	0.96
118e00	20000	0.97	0.97	0.93
119e00	20000	0.90	0.98	0.88
118e06	45000	0.99	0.72	0.70
119e06	45000	0.98	0.96	0.95
118e12	45000	0.95	0.71	0.68
119e12	45000	0.79	0.97	0.76
118e18	70000	0.99	0.47	0.46
119e18	70000	0.97	0.54	0.51
118e24	70000	0.94	0.46	0.42
119e24	70000	0.83	0.50	0.41

noise was not added to the whole signal but in segments. The first segment starts at the fifth minute, lasts two minutes, then in alternate segments of 2 minutes without and with noise. So the total number of noisy episodes for each file is 7.

The second parameter is Signal-to-Noise threshold for which we have experimentally determined the optimal value. Fig. 5 visualizes the effect of noise on the value of sum. We have experimentally concluded that 20000 is an appropriate threshold for differentiating between clean and noisy signal when SNR is between -6 and 0. The threshold for the remaining files has also been experimentally deduced. This experimental determination of the value of threshold was realized by testing the performance of the system to different values, and determining which value proved to be an appropriate differentiating line between the clean and noisy signal.

Table II contains the results from all of the conducted experiments.

V. Discussion

Our research shows that a filter length of 625 is optimal when working with data sampled at 125Hz. Conducted experiments also prove that 50 samples is an optimal value for the recalculation interval. For the sake of readability, the data presented in Table II has only been processed once with a filter length of size 625 and **z**=50.

Experimental data showed that a threshold of 20000 will result with satisfactory performance of the algorithm in terms of SEN, PPV and 1/F score if the data has an SNR between -6 and 0. This was further confirmed with the results presented in Table II. As the SNR increases, it is evident that it becomes harder to differentiate between the clean and noisy signal, hence the poor performance of the algorithm as SNR approaches 24.

Our analysis presents a new tool for determining the SNR in an ECG recording. As 1/F score decreases below 0.70, the SNR increases - which means that the effect of noise on the original signal is minimal. This allows us to approximate the value of SNR in an ECG recording and use this measure as a tool for validating the diagnosis given by ECGalert. For example, if our system detects multiple episodes in one

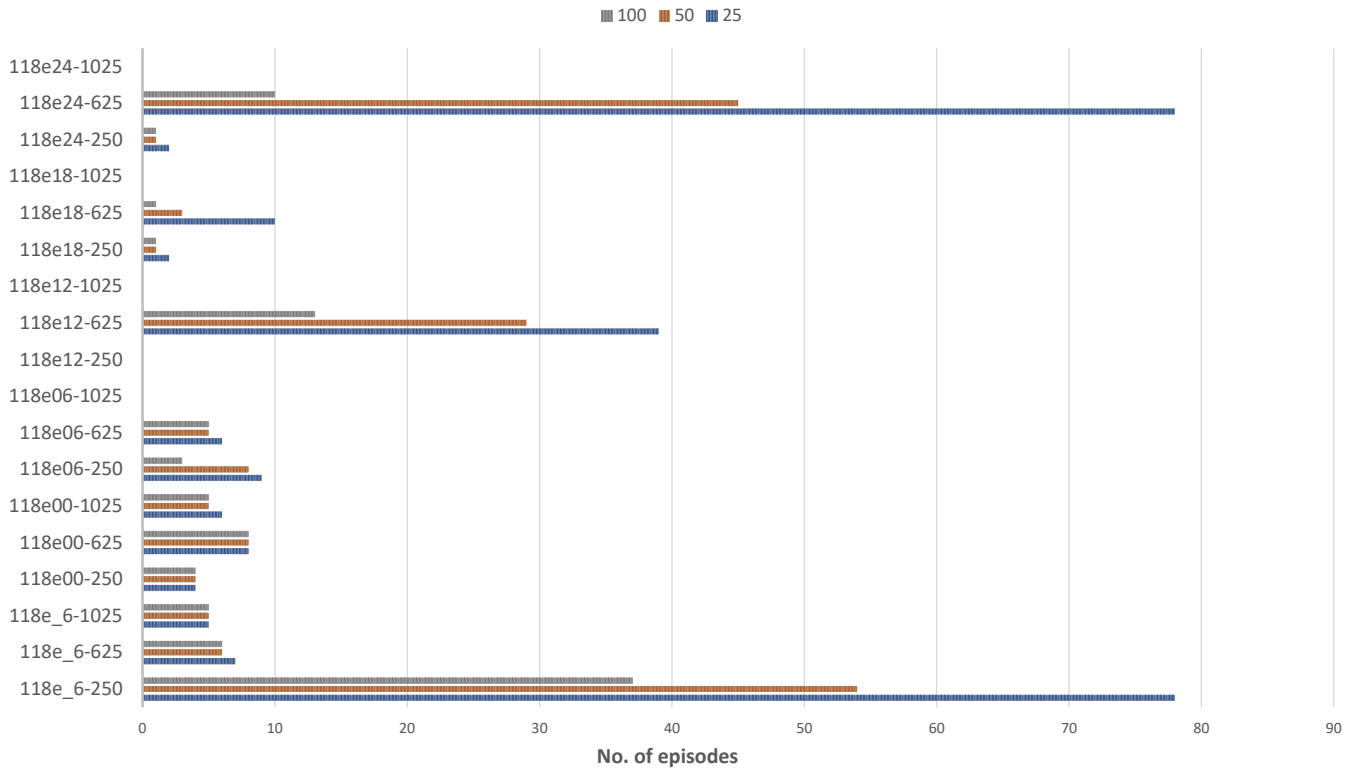

Fig. 3. Visualization of the effect of window size and recalculation interval on the number of detected noise episodes in 118

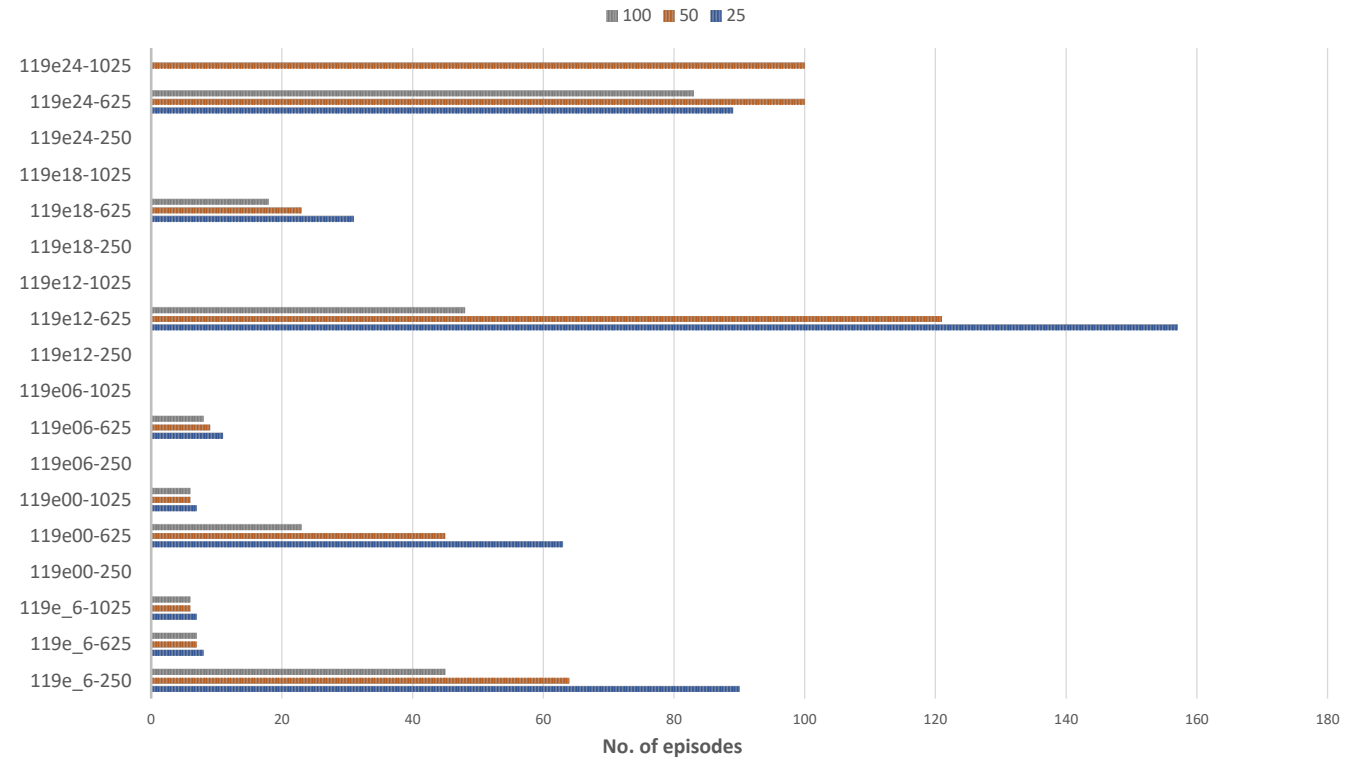

Fig. 4. Visualization of the effect of window size and recalculation interval on the number of detected noise episodes in 119

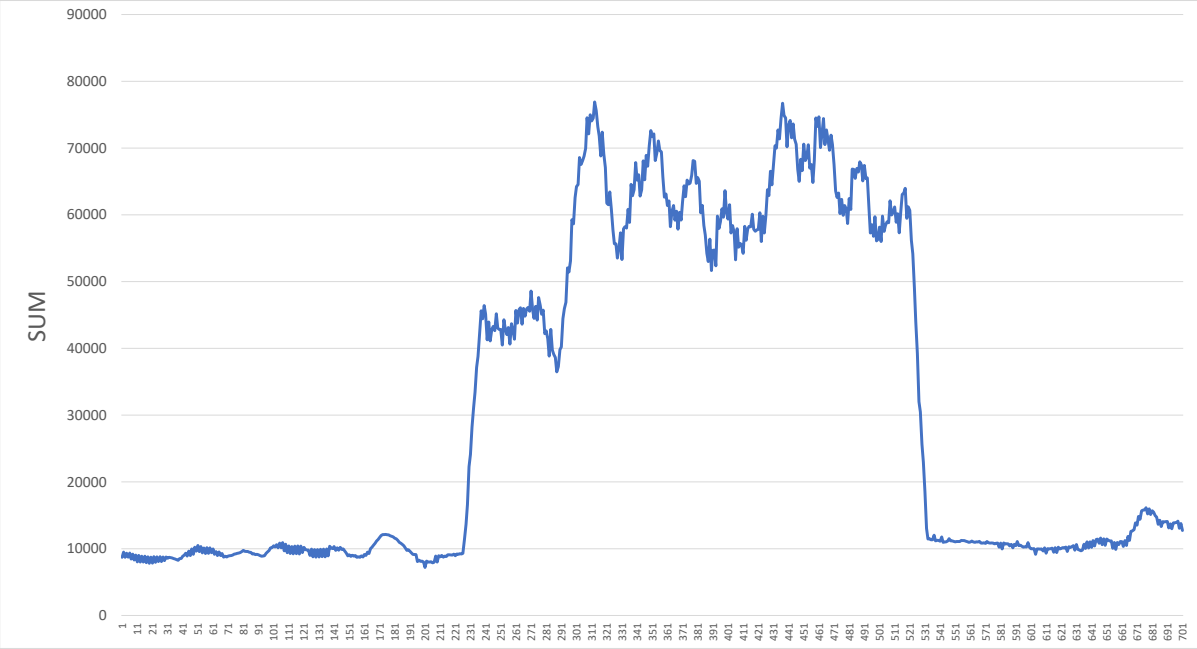

Fig. 5. Visualization of the effect of noise on the value of sum

recording, we may want to confirm that the SNR is high enough so that noise does not get wrongly classified as a QRS complex. By using 1/F score as a measure of recording quality, we add an automated layer of diagnosis verification to our system.

VI. Conclusions

In this paper we have presented a differential noise detection filter, and we have provided in-depth analysis on the effects of window size and Signal-to-Noise threshold on the sensitivity, positive predictive value and F value of the algorithm. Our research proves that when using optimal parameters, the algorithm performs well in different environments with variable amounts of noise.

This approach provides us with the tools to verify that the processed ECG recordings are of good quality and can be correctly processed by our system.

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Detection and Treatment of Atrial Irregular Rhythm with Body Gadgets and 35-channel ECG

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Abstract – The atrial irregular rhythm, often reflected in atrial fibrillation, undulation or flutter, is recognized as one of the major causes of brain stroke and entails an increased risk of thromboembolic events because it increases the likelihood of blood clots formation. Its early detection is becoming an increasingly important preventive measure. The paper presents a simple methodology for the detection of atrial irregular rhythm by ECG body gadget that can perform long-term measurements, e.g. several weeks or more. Multi-channel ECG, on the body surface, gives a more detailed insight into the atrial activity in comparison to standard 12-lead ECG. The information from MECG is compared with single-channel patch ECG. The obtained results suggest that the proposed methodology could be useful in treatments of atrial irregular rhythm. One can obtain a reliable information about the time and duration of fibrillation events, or determine arrhythmic focuses and conductive pathways in heart atria, or study the effects of antiarrhythmic drugs on existing arrhythmias and on an eventual development of new types of arrhythmias.

Keywords – ECG body sensor; gadget; atrial rhythm; body surface potential map; patch ECG;

I. INTRODUCTION

The irregular atrial rhythm (IAR), often reflected in atrial fibrillation (AF), undulation (AU) or atrial flutter (AFL) is a cardiac arrhythmia with various symptoms, e.g. fatigue, palpitations, syncope, heart failure, etc. but can also exists with no symptoms [1]. There are no reliable data about the prevalence of IAR, but the estimated prevalence is 0.5% of the population [2]. The proportion of people with IAR increases with age with 0.1% under 50 years, 4% between 60 and 70 years, and 14% over 80 years old, resulting in a prevalence of around 3% in adults, which is expected to increase in the future with an ageing of population [3]. The IAR is associated with more frequent hospitalizations because of stroke, transient ischemia, heart failure, and pulmonary embolism [4]. It is treated with some success with cardiac rhythm conversion, antiarrhythmic drugs or with atrial catheter ablation, which seems to be most promising, but unfortunately not as successful as one would like. Atrial catheter ablation is a procedure with its own risks that does not completely eliminate possibility for recurrence arrhythmias and has not been shown to reduce the risk for a stroke [5].

The IAR can be classified by frequency and duration of its episodes as: paroxysmal, persistent, or long-standing persistent. It has been demonstrated that the consequences of IAR have been correlated with episodes' duration and with the total amount of IAR time, which is termed often as IAR burden [6]. The IAR burden is therefore one of the most important clinical indicators for the selection and outcome of therapeutic approaches.

The atrial fibrillatory waves, also called the f-waves, are often computed from the V1 lead when using the standard 12-lead ECG recording [7]. The V1 lead is close to the right atrium, which makes the f-waves relatively larger compared to the other leads. Also, other lead configurations, especially designed to record atrial activity, have been proposed [8].

Different methods for atrial activity extraction have been presented [9], and the importance of signal quality assessment of ECG signals is well recognized [10], e.g. a signal quality index (SQI) for f-waves has been proposed recently, which is a promising aid for accurate detection of atrial fibrillation [11].

It was demonstrated [12] that the resolution of the body surface ECG measurements, projected on the hearth surface, could be about ± 10 mm, which is not enough for exact spatial detection of atrial depolarization initiation, or for identifying detailed conduction paths, but could be sufficient for obtaining basic information about the reasons and type of arrhythmias and about approximate locations of depolarization events. Such initial knowledge, obtained by non-invasive methodology, could follow

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to improved preliminary diagnoses and to accelerate further treatment of the cardiac rhythm.

It is known that body surface potential maps (BSPM) reflect intracardiac dominant frequencies of nearest atrial tissue and are able to capture regional differences in atrial activation rates. Since high-frequency sites in the atria maintain AF [13], this indicates that the multichannel ECG (MECG) and BSPM can be used to support a guidance of ablation, or at least to identify the existence of IAR sources.

In order to verify the ability and efficiency of non-invasive BSPM for a preliminary analysis of IAR, the following two hypotheses have been tested:

H1: For repetitive and satisfactory results, the minimal number of body surface electrodes should be about 16, placed on the chest above heart atria, in a grid with electrode distance of about 10 cm.

H2: Non-invasive analysis of IAR, with body gadget and MECG could be of practical use in the diagnostic and treatment processes.

In the rest of the paper a novel approach is presented which is based on a detailed analysis of the PQ interval in time domain. The method is supported by: (a) ECG body gadget for IAR confirmation with subsequent (b) MECG measurements for the analysis of IAR based on BSPM.

II. Equipment and Methods

Patients that experience heart rhythm problems are equipped, in the initial phase, with ECG body gadget. We used a non-obtrusive, medical graded ECG patch, Savvy™ produced by Saving d.o.o. Slovenia [14]. Savvy is a miniature wireless gadget with dimensions of 2 x 9 cm, electrode distance 8 cm, sample rate of 250 samples/s and weight of 21 g. The gadget measures a voltage between two proximal electrodes, termed as differential ECG, which is adequate for the heart rhythm analysis [15]. The gadget has 7-day autonomy while continuously transmitting the measured data in a smartphone via BT4 radio. The gadget supports solutions to every-day problems of the medical personal in hospitals, health clinics, homes for the elderly and health resorts.

In the subsequent phase, when IAR is confirmed, an ambulatory measurement is performed with a 35-chanel MECG [16] previously developed at Jožef Stefan Institute. The first three channels are used for standard limb leads whereas the remaining channels are unipolar leads that measure potential differences between each electrode and standard Wilson Central Terminal [17]. The sample rate is 1000 samples/s.

MECG electrodes are organized in three different grids, shown in Fig. 1. In G10B grid, 28 unipolar electrodes (4-31) are placed on the whole upper part of the body, including back, with approximate electrode

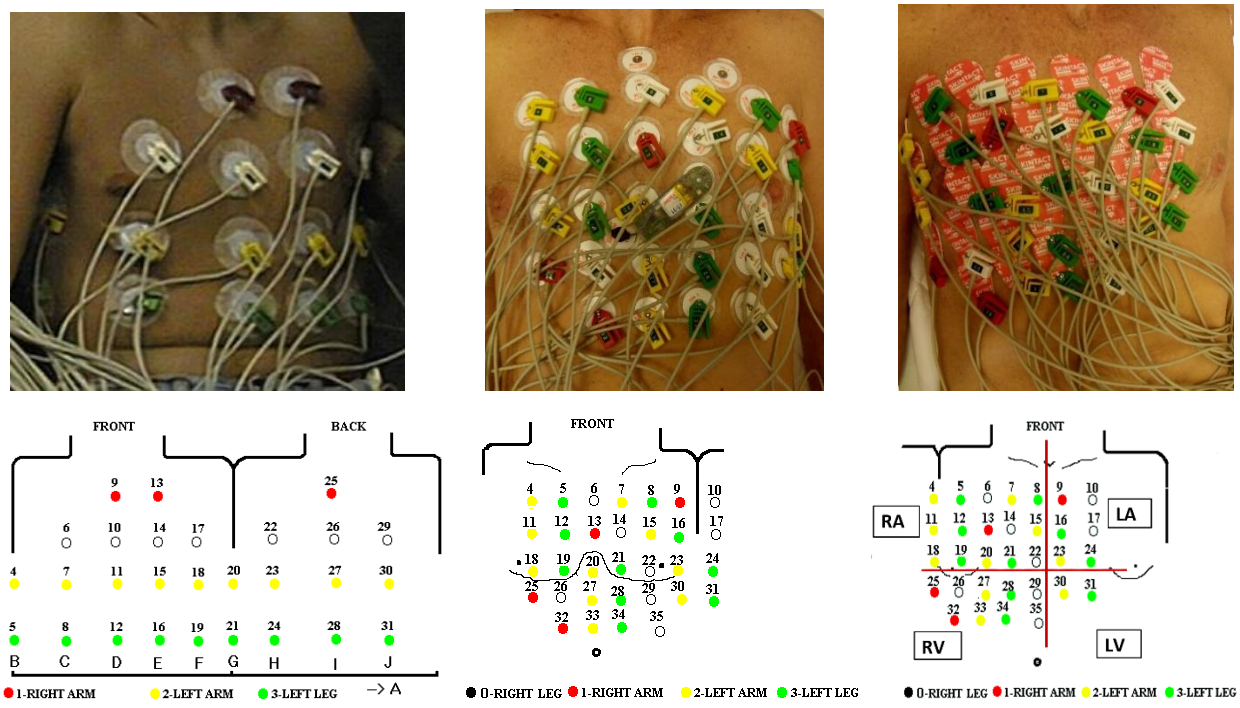

Figure 1. (left) Photograph of MECG with electrodes 4-31 placed on the upper part of body, including back, and beneath it, a schematic presentation of G10B placement. Standard V1 and V2 leads would be in the middle of electrodes 6, 10 and 10, 14, respectively. (center) Photograph and scheme of G5L placement with 32 electrodes. (right) Photograph and scheme of G5R placement.

distance of 10 cm. A photography of G10B with a symbolic scheme is shown in the left column of Fig. 1. The second grid GL5 consists of 32 unipolar electrodes (4-35) with electrode distance of about 5 cm. It is positioned above the left atrium (LA), and shown with a photograph and schematically in the central column of Fig. 1. Finally, the same grid of 32 unipolar electrodes, termed as G5R, is shifted slightly towards the right atrium (RA) for an eventual better assessment of P-waves. A photograph and its schematics are shown in the right column of Fig. 1.

In healthy hearts, the atrial activity is present in the majority of PQ interval, while the rest of the myocardium, e.g. ventricles, is not active during this period. Therefore, PQ interval is appropriate for the analysis of electrical potentials in hearth atria.

Raw MECG measurements have been analyzed by custom developed MATLAB scripts. Filtering, R wave time detection and base-line correction on the RR intervals were done first. Then the PQ intervals were determined. The proposed methodology requires high precision analysis of ECG amplitudes, which serves in generation of BSPM. Therefore, the initial base-line correction of RR intervals should be improved by implementing an additional base-line correction of PQ intervals. This is done by calculating mean ECG amplitudes on 40 ms intervals around boundary points of PQ interval. A subsequent linear interpolation of PQ intervals implements zero potential value on the interval boundaries. For even improved noise removal, a few consecutive beats could be averaged.

The BSPM of PQ intervals are obtained by a 2D cubic interpolation of the MECG measurements on approximately 10 times finer spatial grid than the actual grid of electrodes. We confirmed by preliminary tests that such an approach suffices for a reliable reproduction of body potentials. The calculated BSPM are projected on a plane. In such a simplified approach, it was assumed that the heart is in the center of a cylinder. No customized mapping of potentials from body surface to myocardium is considered. We assume also that an event on a specific body surface point relates to the closest point on the myocardium, which is in accordance with results of previous investigations [13].

In order to reduce the time complexity, the BSPM are analyzed in frames, which are obtained by using, e.g. every fifth set of samples from the whole available time series of the MECG. Note, that ECG is sampled by 1000 Hz, which results in about 40 frames per PQ interval. We have confirmed by preliminary tests that such an "under sampling" cannot deteriorate our results.

The maximum of BSPM was identified for each frame and marked with black diamonds that are connected with arrows, indicating the track of BSPM maxima and their movement directions. Our assumption is that the measured potential maximum on the body surface relates to the depolarization front located in the part of myocardium that is closest to the body surface location where a maximum of potential is registered, which is in accordance with the ECG lead theory [17].

All obtained frames of particular measurements have been packed in "avi" files, which are available in supplementary material for eventual visual inspection (http://www-e6.ijs.si/~roman/files/MIPRO2019/).

III. RESULTS

A. *BSPM of sinus rhythm*

To test our first hypothesis, we acquired MECG measurements from the same person, but with different electrode placements. The heart rhythm was continuously in sinus mode. First measurement was performed with G10B placement followed by G5L. We estimate first the impact of electrodes on the back part of the body. Then we test the accuracy of the BSPM as a function of the electrode density. Because we are interested in atrial arrhythmia, we considered the PQ interval and corresponding P waves only. We average six neighboring beats of the same length for improved noise rejection.

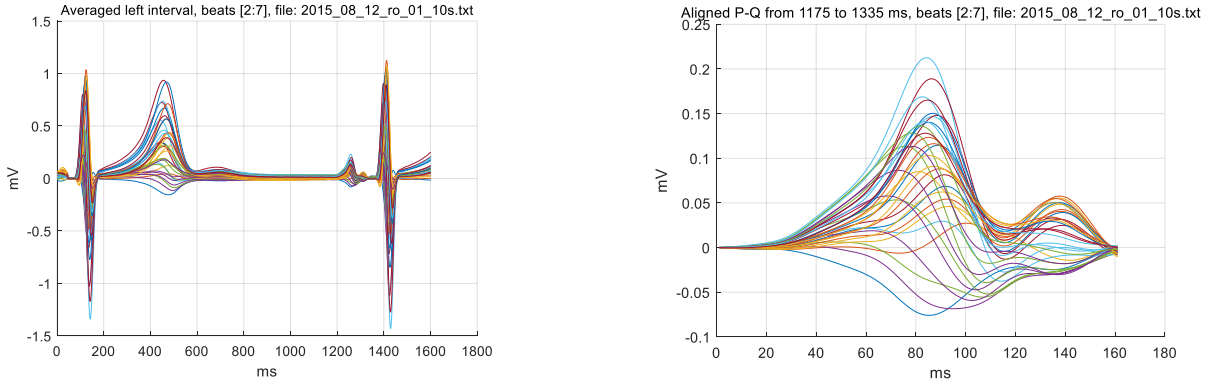

Figure 2. (left) 32 MECG channels from G5L grid of a single sinus beat. (right) Corresponding P wave with aligned start and end point.

In the left part of Fig. 2, all superimposed 32 MECG channels from G5L placement are shown. The extracted P wave, in a magnified view, is shown in the right part of Fig. 2. As explained in the previous section its start and end point are aligned with zero potential.

The whole set of above ECG data has been transformed in a set of BSPM, one for each time-frame, (5 ms in our case). The place of BSPM frame maximum in each time-instance is identified with a diamond. All diamonds are connected with black arrows that represent a track of maxima that is in a relation with atrial depolarization activities.

Fig. 3 shows BSPM frame 29 at 146 ms of PQ interval and its maxima track for a sinus rhythm of a same person and for electrode placements: G10B with 28 electrodes on the upper part of body (above), G5L with 32 electrodes on the chest (left below), and G5L-sparse with 10 electrodes on the chest (right below).

Note, that a set of closer diamonds reflects a smaller velocity of BSPM maximum. Note also, that MECG of G10B was taken a year before G5L measurements. Under the BSPM, corresponding ECG of P waves are shown. Besides, the red line denotes actual time-step and the black curve with circles represents ECG signal that would be measured by a body gadget as placed for IAR detection, i.e. on electrodes 12(- pole) and 20(+ pole) of G5L numbering from Fig. 1. This signal should be very similar to the real ECG gadget measurement, and can be used for validation purposes.

We can see from Fig. 3 that the depolarization of atria starts below lead V1 above the right atrium, which is expected. Then, the BSPM maxima track proceeds towards the left atrium. The impact of electrodes on the back of the body is minimal, because they did not change BSPM considerably, which is in well accordance with theoretical studies [18]. We can also notice that all BPSM maxima tracks are similar, even that the number of sensing electrodes was significantly different.

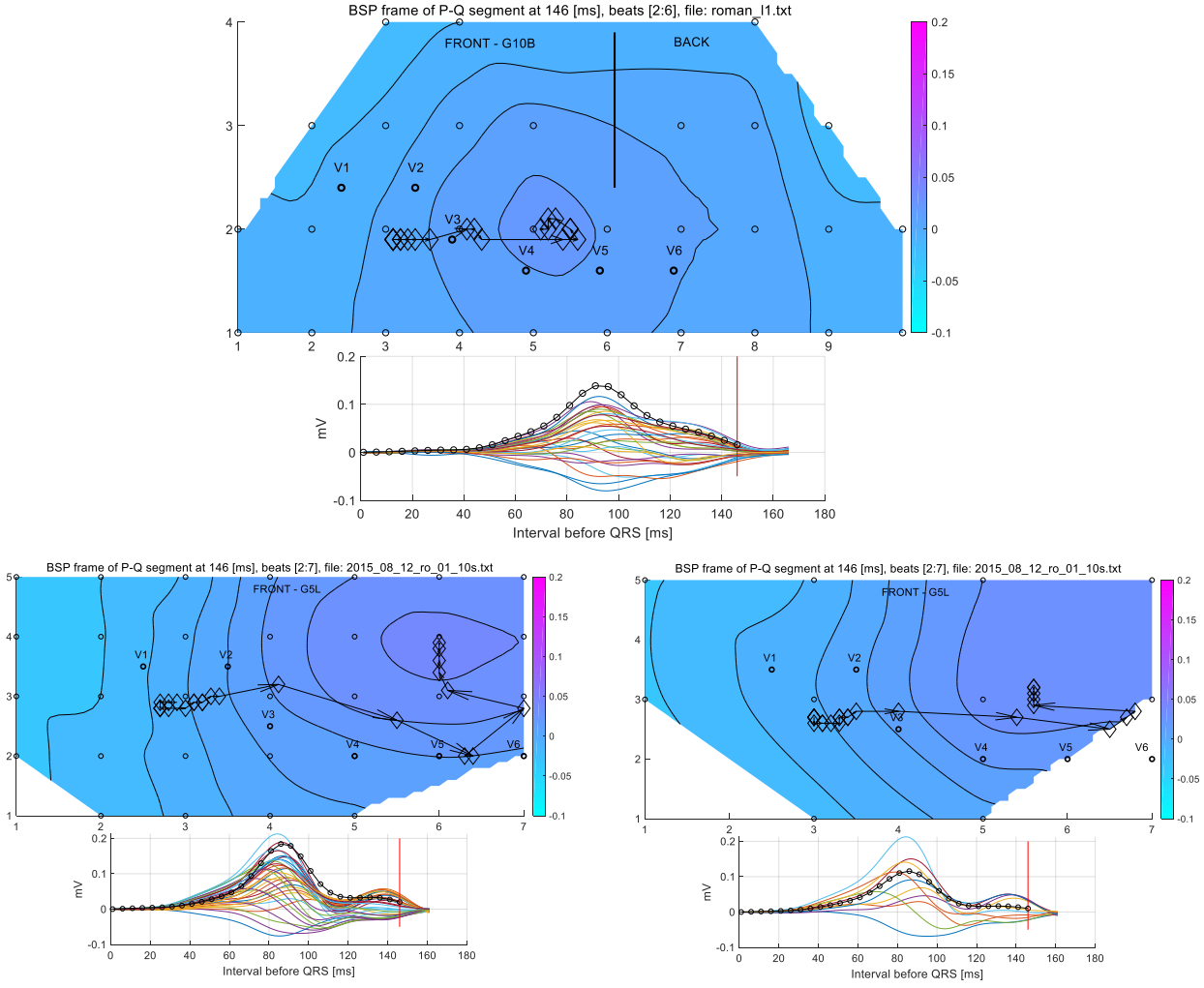

Figure 3. BSPM frame 29 at 146 ms of PQ interval with track of BSPM maxima (connected diamonds) for sinus rhythm obtained from: (above) placement G10B, (left below) placement G5L, and (right below) placement G5L-sparse with only 10 electrodes. X axes have same scales.

Based on the presented results, one can conclude that a set of 16 body surface electrodes with approximate distance of 6 cm, placed on the chest above the atria, is a safe approach that could provide a valuable spatial information about the depolarization source and its propagation.

B. Detection of arrhythmia

A detection of IAR is a trigger for further diagnostic and therapeutic procedures. Besides Holter measurements, which are appropriate at most for up-to 24-hour measurements, an alternative option for long term measurements becomes today an ECG body gadget. Patients that feel irregular rhythm or some other symptomatic sign are advised to wear the body ECG gadget for a week or even more, depending on the frequency of reported heart problems. The measured ECG data are transferred wirelessly to a smartphone, where they are available for further analysis. Alternatively, patient can mark unusual heart events and comment them if necessary. Then, already during the current measurements, they can produce a "pdf" report with the ECG a few minutes before and after the event. The report can be shared with a caregiver or medical expert who will advise how to proceed.

An example of a patch ECG measurement is shown in Fig. 4. Red curve, on the upper panel, represents a measured ECG that shows a transition from IAR to sinus rhythm. Its amplitude is on y-axis and time on x-axis. Blue crosses are positioned on peaks of R-waves. Their values on y axis are actual RR intervals; higher values mean longer RR intervals, i.e. lower heart rate. If RR intervals are highly irregular one can suspect on occurrence of AF (left part of the measurement in Fig. 1), while quite smooth curve of RR intervals usually represents a sinus rhythm (right part of the measurement in Fig. 1).

The lower panel in Fig. 4 shows a typical night rhythm in AFL. We can notice a quite constant ratio of 1:3 for ventricular to atrial contraction with an average RR interval of 880 ms. AFL depolarization waves trigger AV node that conduct the depolarization front to heart ventricles. Note, that even that the heart rhythm is constant an IAR is present. Most of the simplest IAR detection algorithm would fail in this case, so improved algorithms are needed with more sophisticated approaches, based on the analysis of the ECG after T-wave (TP interval) and PQ interval including the P-wave.

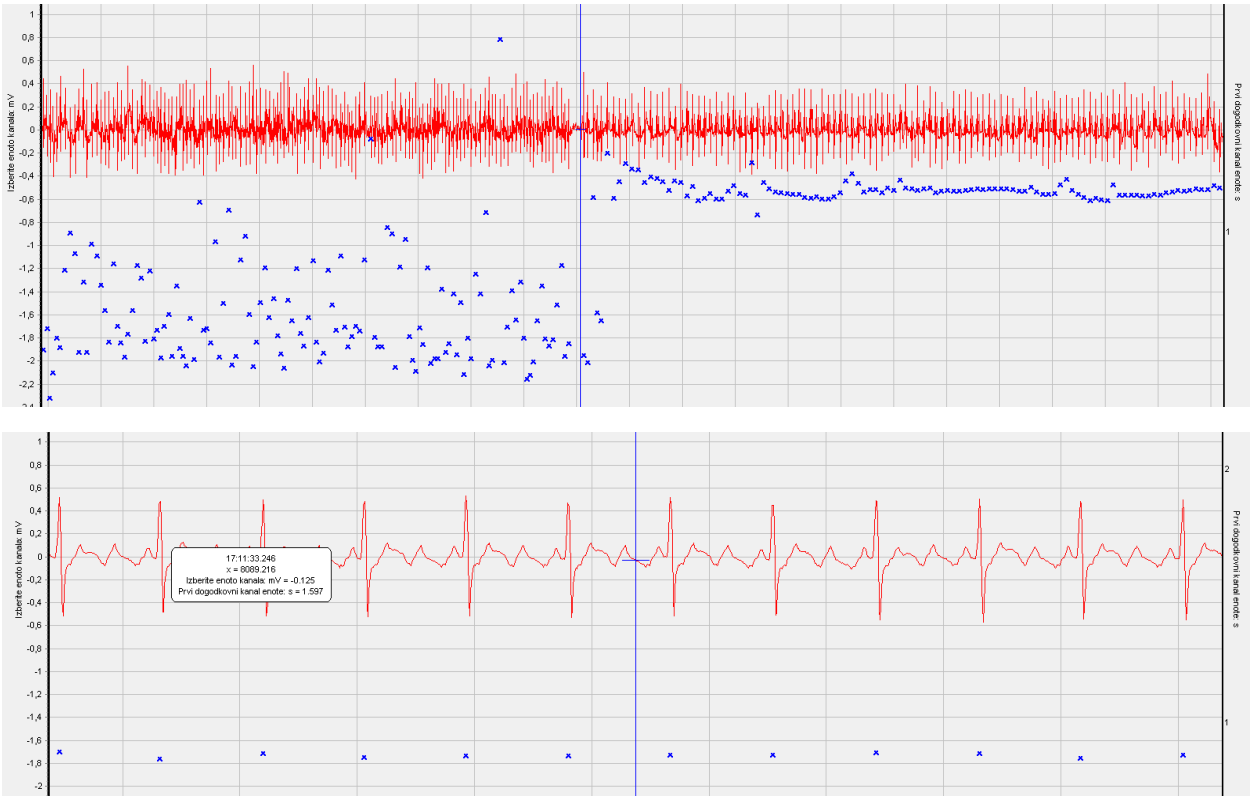

Figure 4. (above) Transition from AF to sinus rhythm. (below) Typical night-rhythm in AFL with ratio 1:3 for ventricular to atrial beats with an average RR interval of 880 ms.

C. *BSPM of AFL*

After the confirmation of IAR, AFL in our particular case, several options are available for management or treatment of arrhythmia. In any case, the reason of arrhythmia and its structural analysis could significantly contribute to improved diagnoses and decisions about further treatment. Based on promising obtained results for the sinus rhythm we apply the developed methodology for the analysis of BSPM also in the case of AFL. In order to improve the assessment of P-waves and other atrial activities, G5R electrode placement is used, with a bit denser grid shifted slightly towards the right atria (see Fig. 1).

In the left part of Fig. 5, all 32 superimposed MECG channels from G5R placement are shown for two consecutive QRS complexes. We see that three f-waves are present per each beat. Again, only the "quiet" interval is analyzed during the third AFL f-wave before the second QRS complex, i.e. from 885 to 1172 ms. Only the atrial activity is present in the majority of this interval, therefore the interval is appropriate for the analysis of the electrical potentials of AFL in hearth atria. Some channel amplitudes of the second f-wave, near 750 ms, could be raised because of superimposed U-waves from the previous ventricular cycle, which is another reason that we select the third AFL f-wave for detailed analysis.

The extracted third f-wave interval before the second QRS complex is shown, in a magnified view, in the right part of Fig. 5. As explained in previous section its start and end point are aligned with zero potential, because there should be no ventricular hearth activity inside this interval.

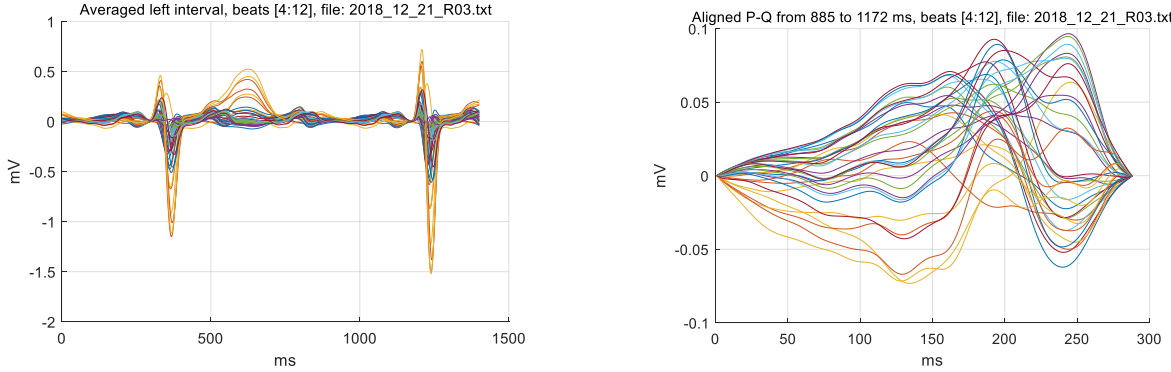

Figure 5. (left) 32 MECG channels of G5R for single beat in AFL. (right) Corresponding "quiet" period, i.e. third AFL f-wave, before second QRS complex with aligned start and end points.

The MECG data shown in Fig. 5 are transformed now in BSPM in the same way as described in Subsection *A* for the case of sinus rhythm. Fig. 6 shows two BSPM frames at 266 ms with maxima track for the same IAR rhythm as shown in Fig. 4, when measured by ECG gadget, and in Fig. 5, when measured by MECG. Left BSPM frame of Fig. 6 is obtained with G5R electrode placement. The red line in the graph below BSPM marks again the time of current frame and the black curve with circles represents the signal that would be measured by ECG gadget. We see that it resembles the measured signal from Fig. 4, which is expected. For comparison, the right BSPM frame is obtained with G5R-sparce placement with a subset of just 10 electrodes from original G5R.

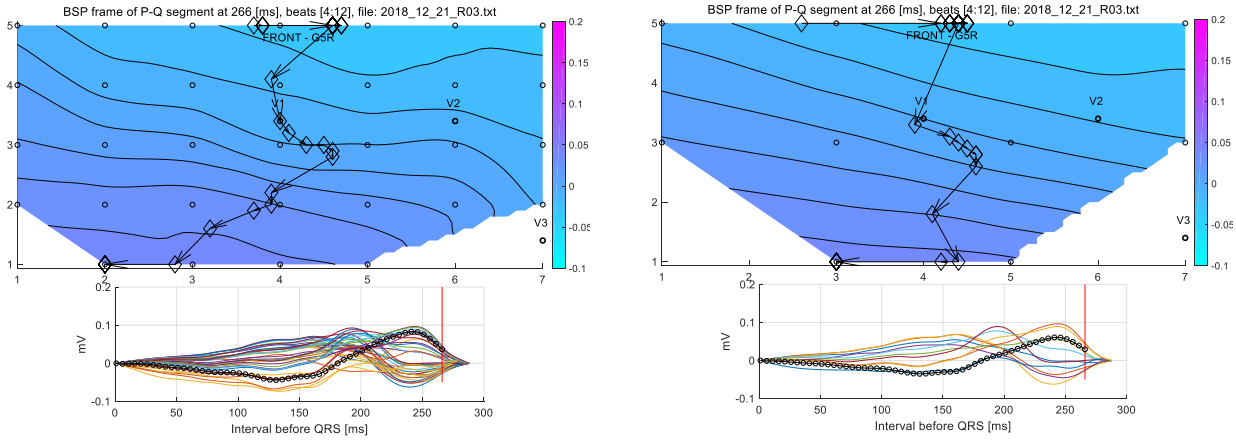

Figure 6. (left) BSPM frame at 266 ms from G5R for AFL with superimposed track of BSPM maxima. (right) The same frame obtained by a subset of 10 electrodes from G5R.

The IAR BSMP maxima track is significantly different from the sinus case. It is cyclic; however, we cannot determine exactly the heart segment where, reentrant or focal, cycle initiates. Based on the track of BSPM maxima, we could suppose that the f-wave initiates in the upper part of the left atrium near pulmonary veins, which is quite common source of IAR. The BSPM maximum proceeds towards down (atrial septum), until it enters the right atrium. Then it travels to the lower part of RA and eventually reaches the atrio-ventricular node, which triggers the ventricular beat in each third IAR cycle in average. An alternative start of the IAR cycle could be near the central part of the right atrium or in atrial septum with the same cyclic conduction path as above. The animated results are visible in "avi" file available on given link.

IV. Discussion and Conclusion

The obtained results suggest that the described methodology could be useful for detection and treatment of IAR, however, some of potential limitations are listed in the rest of this section.

Repeatability of results was tested on more beats of the same measurement and also on several measurements from different persons. Even that the preliminary results confirm our hypotheses, more systematic statistical analysis is necessary. A definite interpretation of the atrial activity, on the basis of BSPM, is to be validated by an analysis of a larger set of MECG measurements on different persons.

The spatial sensitivity was tested by experiments on a single person with different electrode placements and with disregarding some of electrodes data. For improved conclusions we should repeat the procedure on a set of individuals both healthy and with IAR. Several experiments with the same methodology on a single person and with a single placement should be performed for checking the results repeatability. Finally, a whole set of experiments should be run on a test group of female and male participants to confirm appropriate sensitivity and repeatability of results.

We assumed that the heart is in a center of a cylinder and project the body potentials to the heart surface without any spatial transformation. It is expected that a spatial transformation could improve the spatial sensitivity. Therefore, some of the proven regularization techniques for the electrocardiographic imaging should be applied also for the atrial activity [19].

It remains an open question to which extent the information about the hearth status differs, if obtained by analysis of body gadget ECG measurements [20] with proximal electrodes, which measures a local voltage between two proximate points on the body surface [21], or by a standard bipolar or unipolar lead, with more distant electrodes, which measure a global voltage between to body surface points on a lead specific plane.

The proposed methodology seems to be time consuming form practical point of view, in particular for placing of electrodes. But the number of electrodes is reasonably low and their grid could be implemented in single piece as a multi-electrode sticking plaster. At the same time, using MECGs is the only non-invasive method available for at least approximately locating sources of IARs, whose identification may be crucial for delivering a successful further treatment. Even just knowing which atrium is the source of IAR may be a valuable a priory information for the ablation procedure.

In future work, we plan to analyze cases of more common supraventricular ectopic beats where P-waves are superimposed on the previous T-waves, by using precise alignment and subtraction of T-wave signals. Also, we will improve the mathematical background of the proposed methodology with the goal to obtain higher resolution and sensitivity.

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Enriching Heart Monitoring with Accelerometer Data

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Abstract **- Information communication technologies can support physicians for more effective and improved quality of diagnoses. A lot of available medical data from body sensors and advanced medical devices have to be pre-processed and analysed with efficient methods. We propose an enhancement of an existing ECG signal, e. g. from a wearable ECG device, with accelerometer data. The feasibility study aims to extract and recognise a patient's pose and activity from accelerometer data that is added to a standard ECG body sensor. The time-aligned ECG and accelerometer data are fused in order to add valuable information for the interpretation program. The proposed accelerometer data processing method provides information about patient activity, besides the ECG data. A physician or an interpretation program have further insight into whether the change in heart rate is caused by the irregular heartbeats or by the patient's movement activity. We have validated the proposed methodology on real measurements with ECG and accelerometer data.**

Keywords – ECG; accelerometer; signal; processing; healthcare

I. INTRODUCTION

Today, modern technology allows us to collect various data on electrical and muscular functions of the heart for a long period uninterruptedly. The extended time scale of ECG measurement is essential because in some cases the symptoms of the disorder can reappear after a long period. Now, due to the increased time period, the collected ECG data is more subjected to the influence of external factors incurred by user's daily activities. Furthermore, the increased time period produces an extensive amount of collected ECG data which significantly increases the time required for data conditioning and diagnoses.

The information on the user's daily activities was already recognised as significant extension to the ECG measurements. Therefore, the Holter users need to write down the information on their daily activities regularly. In practice, this information usually ends up faulty with lots of activity events missing or misaligned in time with collected ECG data. Such information leads to an increased medical technician time for data cleaning, an increased physician time for making a diagnosis and an increased error rate in diagnosis.

In previous studies, an approach to overcome these problems was automatically augmentation of ECG data with data collected from the accelerometer sensor. Combining accelerometer with the ECG data enables additional insights into patient current activity state.

In previous studies, an approach to overcome these problems was automatically augmentation of ECG data with data collected from the accelerometer sensor. Combining accelerometer with the ECG data enables additional insights into patient current activity state. Several prototypes of a system which fuses the ECG data with accelerometer data to monitor the current physical state of the user in wellness facilities have been presented in [1] and [2]. An adaptive reduction of artefacts caused by electrode-skin impedance change during motion was described in [3]. Additionally, accelerometer data were used to detect specific user's physical settings or the context, as presented in [4]. Context detection were presented for health and ECG monitoring applications in [5] and [6].

In the present feasibility study, we propose and evaluate a simple method for fusing ECG and accelerometer data streams with the aim to improve ECG interpretation accuracy regarding disturbing noise, e.g. electrode movements, muscular activity, etc. For example, if a user is in a lying pose and not active, his heart rate could not be higher than 80 beats/s, or, if the user is highly active, its beat rate is expected to be between 80 and 180 beats/s. However, the results from the beat detector could be interpreted now with higher fidelity even that the interpretation results are based on a potentially more disturbed ECG signal.

The paper is structured as follows. In Section II we describe the sensor system for measurement data acquisition and the data collection protocols. The analysis of the signals and the proposed method for pose and activity estimation are given in Section III. Finally, we conclude the paper in Section IV.

II. MEASURMENT

A. Sensors

Experimental measurements of ECG and activity data have been obtained by two high sensitive separate sensors: a wireless ECG body sensor and a motion sensor.

The wireless ECG body sensor, produced by Saving d.o.o. Slovenia, with the commercial name "Savvy", was used in our work. Savvy is graded as a medical device with CE certificate, dimensions of 10 cm and weight of 15

g including a small battery, LBT radio and a low-power signal processor. Its analogue part is designed in a way that it is able to capture significantly smaller signals than in standard ECGs, because of a smaller distance between differential electrodes. A 10-bits A/D converter is used and sample rates of up to 512 samples/s can be set. The measured ECG is wirelessly transmitted to a personal terminal, e.g. a smart-phone, where it is saved in a file with a custom protocol [7]. The design of the Savvy sensor hardware and firmware is a compromise between technical performances and extremely low power consumption. The ECG sensor is nonobtrusive with a complete autonomy of 7 days of continuous measurement, which make it ideal for long-term heart rhythm monitoring. Note that the accelerometer module is already incorporated in the Savvy sensor in order to be activated by sensor firmware after the presented feasibility study will be finished.

The motion data have been obtained from a separate custom prototype motion sensor based on Arduino Due [8] for controlling MPU9250 device [9]. The MPU9250 is a two-chip MicroElectroMechanical System (MEMS) with both chips packed into a single package. The first chip is a highly sensitive 3-axis gyroscope and 3-axis accelerometer, both with 16 bits A/D converters and sample rates of up to 8000 samples/s. The second chip is a 3-axis electronic compass based on a highly sensitive Hall sensor technology AK8963 with selectable 14/16 bits A/D converters and sample rates up to 100 samples/s. The motion data analysis is performed in our case with the 3-axis accelerometer only. Data acquisition and moving window filtering is performed by a custom Arduino firmware. The measured data are passed to an output communication port and saved as a log file in the textual format.

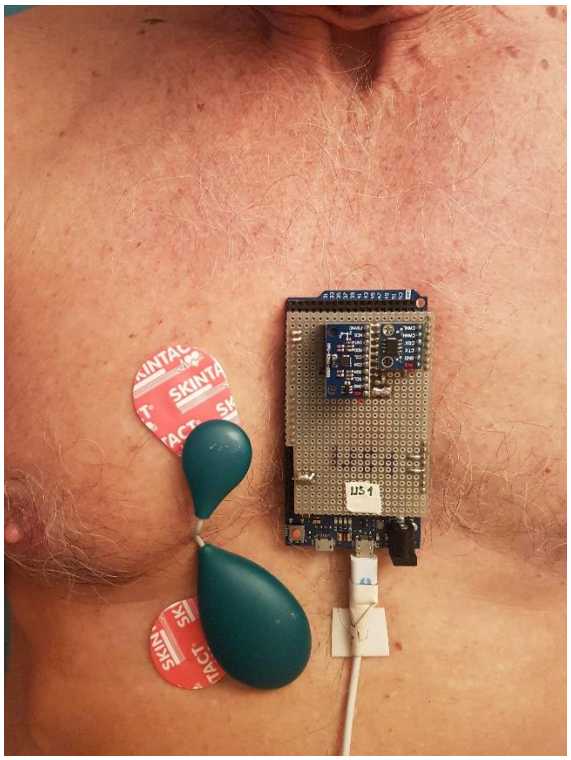

Figure 1. ECG and motion sensors fixed on the frontal side of the thorax.

TABLE I. MEASUREMENT PHASES

Phase	***Activity***	***Pose***	***Duration [min]***
1	lying	pre-measurement resting	2
2	activation of both sensors	5 hand-taps on both sensors	0.25 - start of measure ments
3	resting	laying on back	2
4	resting	laying on right arm	2
5	resting	laying on stomach	2
6	resting	laying on left arm	2
7	resting	sitting	2
8	resting	staying upright	2
9	walking	staying upright	2
10	running	staying upright	2
11	deactivation of both sensors	5 hand-taps on both sensors	0.25 - end of measure ment

B. Measurment protocol

The ECG and motion sensors have been fixed in the proximity of the heart on the frontal side of the thorax as shown in Fig 1. The Savvy sensor is fixed with standard ECG electrodes while the motion sensor is fixed with self-adhesive tape. In order to time align both received data streams, a clearly detectable event on both sensors is required. For that purpose, we use a few hand taps on both sensors before start measurement. The sample rate of ECG was 128 samples/s while each of 3-axis of motion data is sampled by 100 samples/s.

The ECG and motion data have been measured approximately 18 minutes in a continuous measurement separated into 11 steps under the protocol shown in TABLE I. Transitions between the phases typically last about 15 seconds. The transition time is a part of the duration time for each phase of the measurement.

C. Data

Raw signals for the accelerometers, in each dimension, and the ECG are shown in Fig 2 Because we use two separate sensors, a time alignment was performed by comparing the effect of simultaneous hand-taps on both sensors. In our case, shown in Fig 2, a shift of +1876 ms was applied on all three acceleration data channels.

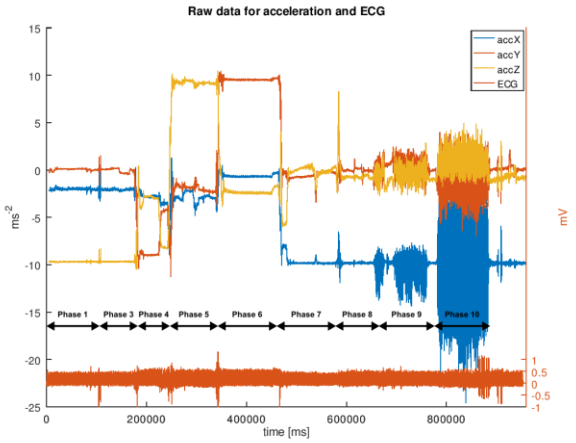

Figure 2. ECG and acceleration measurements aligned in time.

The raw acceleration data contain an initial constant error of the device. This error is called bias, and it differs for each sensor unit. To gain more accurate results, the raw accelerometer data were corrected by subtracting the bias values. In our case, the accelerometer sensor has bias values equal to:

Xbias = 0.095094 ms^{-2},

Ybias = 0.0389 ms^{-2},

Zbias = -1.3567 ms^{-2}.

Bias value for each axis can be acquired by measuring acceleration values when the axis is placed vertically to the gravity in both directions, positive and negative. The bias is then computed as an average between these two values.

III. ANALYSIS

A. *Pose estimation*

The acquired accelerometer data were used for estimating body pose of a person using the device. For this purpose, we defined six different poses to be determined:

- Pose 0 – undefined pose,
- Pose 1 – laying on back,
- Pose 2 – laying on right arm,
- Pose 3 – laying on front,
- Pose 4 – laying on left arm,
- Pose 5 – straight up.

The pose was estimated through the two-step process. First, all of the acceleration data were filtered with second-order Butterworth low-pass filter with cut-off frequency at 0.2 Hz. The primary purpose of this step is to remove the high-frequency activity component from raw data. Filter cut-off value of 0.2 Hz was chosen as the best trade-off between time delay and noise reduction. The values were obtained by running a series of benchmark tests with the second-order low-pass filter. This step is not essential. However, it ensures better quality and robustness of end pose estimation results. The second step is rule-based estimation with a threshold equal to 4.905 ms^{-2}, which is half of the gravity acceleration. Taking into account the gravity acceleration is time-invariant, the vector sum of all axes value must be equal to the gravity acceleration. If a single axis gains value greater than half of the gravity acceleration, then two other axes must have lower values. Therefore, the first axis is the dominant one.

Intermediate and final results of the pose estimation are shown in Fig 3. Filtered acceleration data for X, Y and Z axes are presented with blue, red and yellow lines, respectively. Estimated poses are displayed with a green line.

B. *Activity indicator*

Similarly, the activity indicator is also determined through the two-step process. In this case, we extract high-frequency activity component from row data by filtering each channel of acceleration data with second-order Butterworth high-pass filter with cut-off frequency at 0.5 Hz. Likewise in low-pass filter for pose estimation, the cut-off of 0.5 Hz showed to be the best value to separate low-frequency pose information from high-frequency activity information. After applying the filter, absolute values of filtered data are averaged with moving-average (MA) with 100 samples wide window. The end activity

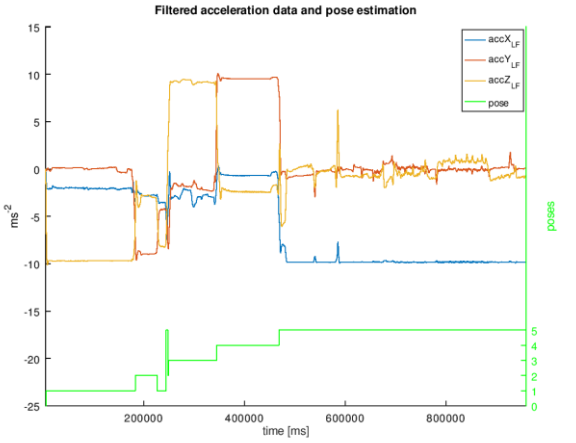

Figure 3. Filtered acceleration data and pose estimation.

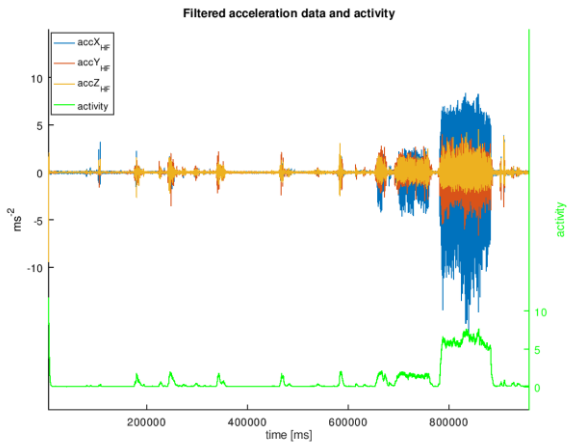

Figure 4. Filtered acceleration data and activity.

result is a sum of the X, Y and Z axes values.

All results of the activity determination process are shown in Fig 4. Filtered acceleration data for X, Y and Z axes are presented with blue, red and yellow lines, respectively. Activity is presented with a green line. Activity values represent the magnitude of change in acceleration, and thus can also be expressed in ms^{-2} units.

C. *Calculation complexity*

From the practical and economical point of view, for the upgraded ECG device should perform the necessary data processing and analysis either on the existing microprocessor inside the ECG sensor or on a smartphone device which communicates with the ECG sensor. In both cases either computing, memory or communication resources are limited, and thus all of the processing needs to be simplified to minimise the count of operations. The resource limitations are the main reason to use second-order Butterworth filter which requires for each filtered value only 5 multiplications and 4 additions/subtractions between two float values:

$$F_n = b_0 * X_n + b_1 * X_{n-1} + b_2 * F_{n-2} - a_1 * F_{n-1} - a_2 * F_{n-2} \quad (1)$$

The original MA 100 samples wide window requires minimally 4 operations (2 multiplications and 2 additions/subtractions) and the last 100 samples and the mean value of the previous sample has to be stored. To additionally reduce calculation and memory complexity, we replaced the MA with an exponential moving-average (EMA). EMA can be calculated by a simple equation:

$$EMA(t) = X(t), \qquad t = 1$$

$$EMA(t) = \alpha * X(t) + (1 - \alpha) * EMA(t-1), \qquad t > 1 \quad (2)$$

In this case, we use α equal to 0.01 to represent values similar to the MA with 100 samples wide window. If we use a buffer to store 3 values (α, 1-α, and EMA of the previous sample), the calculation in (2) includes only 2 multiplications and 1 addition between two float values. As shown in Fig 5, for this case the difference between MA and EMA is negligible.

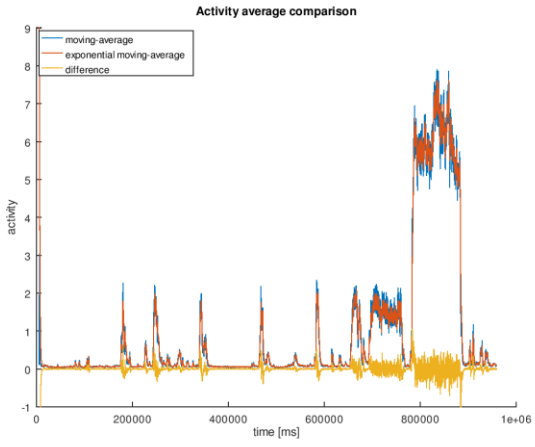

Figure 5. Activity moving-average and exponential moving-average comparison.

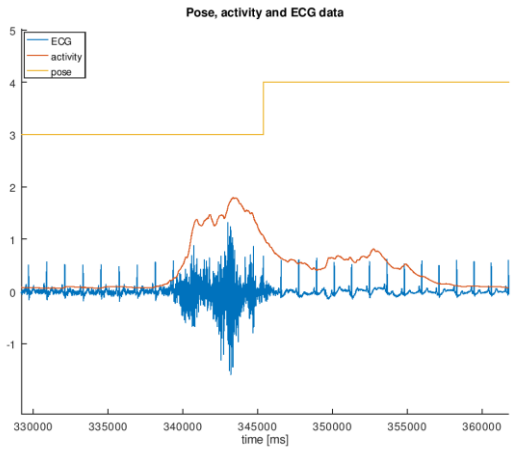

Figure 6. A zoomed interval of pared ECG signal (blue) with activity (red) and pose (yellow) information during transition between phases 5 and 6.

D. *Pairing ECG and accelerometer signals*

After we extracted pose and activity information from accelerometer data we combined it with the ECG signal. In Fig 6 we can see that the transition between poses (yellow line) raises physical activity (red line) which influences the ECG signal. For the case in the figure, we can conclude that artefact in ECG signal is triggered by external cause (e.g. change in body pose) and not internally (e.g. heart disease).

IV. CONLUSION

In this paper, we presented our research results aiming at enriching ECG data collected from Savyy ECG body sensor with pose and activity information. Activity and pose estimation were extracted from data collected with the accelerometer device fixed to the user's frontal side of the thorax. The obtained experimental results show a high correlation between actual and estimated pose and activity. The results provide an additional real-time context of the user condition to make ECG data more interpretable. Furthermore, we built a model to calculate pose and activity estimation that exhibits a very low number of simple mathematical operations. Such a model is suitable for devices with limited processing power such as extremely low power signal processors, or low power radio communication with smartphones or similar personal devices.

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Accurate Segmentation of Dermoscopic Images based on Local Binary Pattern Clustering

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***Abstract* - Segmentation is a key stage in dermoscopic image processing, where the accuracy of the border line that defines skin lesions is of utmost importance for subsequent algorithms (e.g., classification) and computer-aided early diagnosis of serious medical conditions. This paper proposes a novel segmentation method based on Local Binary Patterns (LBP), where LBP and K-Means clustering are combined to achieve a detailed delineation in dermoscopic images. In comparison with usual dermatologist-like segmentation (i.e., the available ground-truth), the proposed method is capable of finding more realistic borders of skin lesions, i.e., with much more detail. The results also exhibit reduced variability amongst different performance measures and they are consistent across different images. The proposed method can be applied for cell-based-like segmentation adapted to the lesion border growing specificities. Hence, the method is suitable to follow the growth dynamics associated with the lesion border geometry in skin melanocytic images.**

Keywords - Segmentation, Lesion Detection, Medical Imaging, Dermoscopy

I. INTRODUCTION

Almost any cell in the body can develop cancer, and in the case of skin cells, melanoma is the deadliest occurring type [1]. By using digital technology (*e.g.* dermoscopy) and image processing techniques, it has been possible to early detect suspicious skin lesions and, when detected at an early stage, melanoma presents high cure rates [2].

Early detection of specific features of each type of lesion by image processing algorithms enables the use of Machine Learning (ML) techniques with great success in the automatic classification of dermoscopic images [3]. These specific features used to feed ML algorithms are usually divided into two groups according to its origin (*i.e.*, lesion or skin). Accordingly, amongst all image processing steps commonly used in dermoscopic images, the identification of the region of interest (ROI) is of central importance in the classification framework [4]. In addition to the ROI delineation, this segmentation procedure is also used, not only to extract other information regarding the lesion itself, but also about the dynamics of its growing process [5].

The manual (round-like) segmentation obtained by dermatologists, and used as ground-truth in the majority of image datasets, is mostly performed to identify surgical borders for excision, lacking an objective rule or metrics. Moreover, variations in lightning conditions can influence contrast and blur, thus precise identification of skin lesion boundaries poses a problem to manual segmentation [6]. Even when clinicians are guided to perform a cell-like based delineation of the lesion, this procedure has proven to suffer from high inter- and intra-observer variability [6-8]. As a consequence, the resulting ground-truth, cell-based like, hand segmentation lacks definiteness.

In the literature, a broad range of segmentation algorithms mostly covering the above mentioned round-like segmentation have been proposed, ranging from smoothing and thresholding, to color space conversions, and exploiting specific aspects of skin dermoscopic images, as reported in [9]. In fact, this wide range of methodologies is related with the datasets diversity regarding physical acquisition conditions (e.g., light, angle of view), anatomical and local artifacts (e.g., hairs, skin curvatures) and equipment properties (e.g., lens, light, image resolution) [10, 11].

In some recent proposed segmentation methodologies [12-14] the results achieve accuracy levels above 90%. Additionally, in other works, preprocessing techniques have been proposed (illumination correction, contrast enhancement and hair removal) to improve similarity indexes. In particular RGB color space conversion to *CIE L*a*b** was proposed in [15] to ease hair removal prior to segmentation and in [16] an averaging filter was applied to the luminance channel. These recent methodologies for segmentation reported overlapping scores of 90% and 83%, respectively, showing a high degree of similarity between ground-truth and automatic segmentations. Other recent threshold based approaches have also emerged, such as iterative thresholding [17], threshold fusion [18, 19] or hybrid thresholding [20]. In addition, other methods have also been proposed, combining different categories, such as clustering [21, 22], soft computing (neural networks [23, 24] and evolution strategy [25]), supervised learning [26], active contours [27] and gradient [28].

Although cell-like based delineation is quite useful for assessment of lesion growing dynamics, it is difficult to obtain a ground-truth reference for each image. Note that this type of segmentation is absent in datasets and the manual delineation can be influenced by external factors.

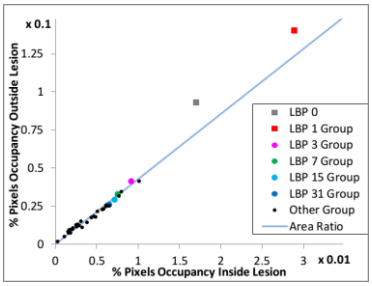


Figure 1. Invariant LBPs Presence Ratio for image IMD021 [35].

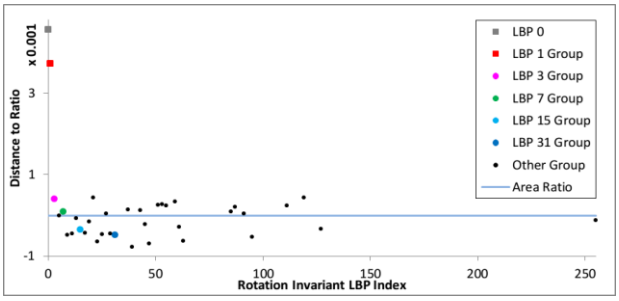


Figure 2. Invariant LBP significance for image IMD021 [35].

This work presents a contribution to overcome the previously described shortcomings, by proposing an algorithm for cell-based like segmentation based on Local Binary Patterns (LBP) and clustering, which is independent of human factors.

This paper is organized as follows: Section II resumes the algorithm background and in Section III the proposed method is presented. In Section IV the experimental results are presented and the work is concluded with a discussion and conclusions part in Section V.

II. LOCAL BINARY PATTERNS

In general, regions of normal skin in dermoscopic images present flatter texture when compared to regions within the lesion. This characteristic can be exploited in order to identify those different spots by using LBPs [29].

A. LBP and Rotation Invariants

The LBP operator is a 2D texture descriptor that assesses local variations on the image, and codes them in terms of a spatial pattern with an associated grayscale scheme. The underlying idea behind LBP operators is that texture has locally two complementary aspects: a spatial pattern and a corresponding strength. In fact, LBPs can be seen as an image operator, whose output is an array of integer labels describing small-scale variations (high frequency content) in the image. These labels, or their statistics, can then be used for further image analysis. One simple variant of classical LBP as presented in [29] is defined in (1) for each image pixel.

$$\mathrm{LBP}=\sum_{p=0}^{7} s\left(I_p - I_c\right)\cdot 2^p,\ s(x)=\begin{cases}1 \text{ if } x>0\\ 0 \text{ if } x\le 0\end{cases} \qquad (1)$$

In the process of obtaining the LBP, each pixel I_C is compared to its neighbors I_P (i.e., 8 pixels I_P surrounding the central pixel I_C in a 3x3 arrangement) producing a binary number with 8 digits. According to (1), this number is then converted to a decimal base (which, in the case of 8-bit images, conducts to LBPs ranges from 0 to 255). The histogram of the obtained LBPs can then be used to generate image features.

The direct application of (1) leads to a high number of possible combinations of binary patterns, hence other derivations of this methodology have been proposed in the literature depending on the types of images and processing objectives. One of the possible formulations is to select only the patterns that are invariant to rotations, since this reduces the number of patterns and also because these invariants are associated to some geometric primitives within an image (corners, edges, flat regions, dark and bright spots) [30]. Apart from the 00000000 and the 11111111 LBP sequences, almost all binary patterns can be visually rotated by applying a binary shift. As an example, 01110000 and 00111000 are rotation invariants. This creates subsets of patterns that can be accounted for by one representative of each invariant class, as in [30].

This type of invariant LPBs can still be refined to achieve a set of rotation invariant patterns, containing a specific number of transitions in the binary sequence (between 0s and 1s and vice-versa). For each group of the same invariant LBPs, if *n* is the smallest decimal number within the group then the representative of the class is labeled as LBP*n*. In particular, when the number of transitions is at most two, this set is called uniform pattern of LBP (uLBP) and the total number of uLBPs are 58, considering 8 neighbors.

B. LBP Invariants in Dermoscopy

The number of binary transitions within an invariant LBP is related to its ability to discriminate between different texture patterns. In fact, the larger the number of transitions the more likely is the change to a different pattern upon rotation in digital domain [30]. Accordingly, a plausible hypothesis is that a reduced number of transitions allow to capture local texture variations and also to identify the locations where such variations are mostly regular (i.e. the segmentation borderline). This hypothesis was tested by means of a set of experiments by assigning LBPs either to skin or to lesion, according to the texture properties of the corresponding image regions.

Firstly, for each image, the ratio between the lesion area and the whole image was obtained, by using the ground-truth segmentation and the number of pixel in each region. This defines the slope of a reference line in plane (x,y), where x and y represent the percentage of each invariant LBP inside and outside the lesion considering the whole image. For one dermoscopic image (Fig.1), the presence of each type of LBP*n* (*n*=0, 1, 3, 7, 15, 31 and others in black) below or above the reference line indicates their dominance in either lesion or normal skin, respectively. LBPs that are positioned above the reference line are dominant outside the lesion area, while LBPs positioned below are dominant inside the lesion area. Additionally, the greater the distance from the origin the greater the presence of a given LBP in the image.

By analyzing Fig. 1, it becomes clear that LBP1 and LBP0 are the densest type of LBPs, both belonging to the normal skin region. For a better understanding, data in Fig. 1 was rotated (according to the reference slope) to

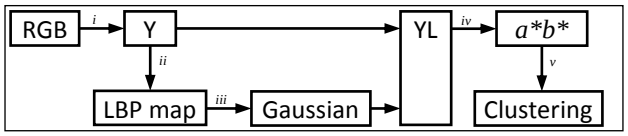


Figure 3. Processing work flow: a given RGB image is converted into greyscale (Y) whereat a LBP map is extracted and passed through a Gaussian filter (L); then Y and L are mapped together and converted into the *a*b** coordinate color space; finally a clustering algorithm processes the space into two clusters.

align the reference line with the x-axis and then the distance of each LBP group to the line in Fig. 1 appears as presented in Fig. 2. In this figure, the x-axis defines LBP group pattern number as its index.

This representation reinforces the conclusion that rotation invariants LBP0 (formed by LBP '0') and LBP1 groups (formed by LBPs of '1', '2', '4', '8', '16', '32', '64' and '128', also known as LBPs of power of 2 or the LBP1 group) are more present in the normal skin region where the aforementioned property regarding flat textures exists. This result can be mostly reproduced for the other dermoscopic images from the dataset, and can be used for several purposes. In particular, these invariant LBPs can be used to support segmentation methodologies, which is the main subject of this work.

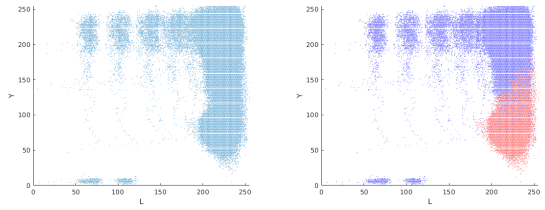
III. PROPOSED METHOD

The segmentation method herein described exploits the fact that lesion and healthy skin tend to exhibit different texture pattern variations. In particular, and given the discussion carried out in Section II, a lower density of LBPs of the groups '0' and '1' is used as an indicator to identify lesion areas. That information, together with the image luminance, which, on its own is known to be a reliable indicator of the lesion area [31], is then fed to a K-Means clustering algorithm.

The overall method proposed for lesion segmentation based on LBP clustering is depicted in Fig. 3. There, the main processing steps are: *i)* conversion of the RGB image to greyscale, with luminance Y determined from (2); *ii)* determination of LBPs groups '0' and '1' and the corresponding L binary map; *iii)* gaussian smoothing the L map and fitting in the [0-255] range; *iv)* space conversion from YL to *a*b**; *v)* and group data into 2 clusters using K-Means. Then, some morphological operations are applied to ensure that no small artifacts exist within the lesion perimeter or, in contrast, in the surrounding skin (which incorrectly masks the area with holes).

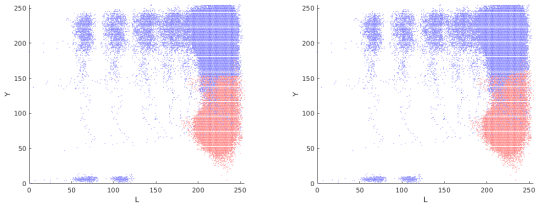
A. Luminance and LBP data

For a given dermoscopic image in RGB format, the corresponding luminance (*Y*) is obtained following the ITU recommendation [32], expressed in (2), and this information is then used to determine the associated LBP as given by (1). Then a binary map L is built based on LBPs from the groups '0' and '1' as follows: pixels with LPBs from these groups are mapped as L=0, while for those with no such LBPs are mapped as L=1. Following the previous arguments, L=0 is expected to be dominant in healthy skin regions while L=1 should dominate in the lesion region.



(a) YL (b) YL ground-truth

Figure 4. Luminance (Y) and LBP indicator (L) for the dermoscopic image IMD078 [35] (L was previously smoothed using a Gaussian filter and converted to a [0-255] scale). Points were associated to either lesion (red) or healthy skin (blue) based on the provided ground-truth segmentation.



(a) YL clustering (b) Y_NL_N clustering

Figure 5. Clustering of YL data (image IMD078 [35]) in its original format (a) and after normalisation (b). Points color represent their cluster association.

$$Y = 0.2989 \times R + 0.5870 \times G + 0.1140 \times B \quad (2)$$

A representation of both Y and L, as shown in Fig. 4, makes it clear about the relevance of such a joint analysis: pixels associated with the lesion are mapped near the lower right corner (*i.e.* high L and low Y) while healthy skin scatters over the top of the diagram (high/low L and high Y). Since the kind of mapping shown in Fig. 4 is characteristic of dermoscopic images, the segmentation challenge can be seen as how to accurately group the pixels associated to the lesion.

B. Clustering

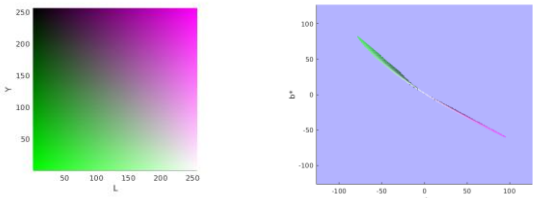
To provide supporting evidence for the method proposed to convert the YL space into the *a*b**, the following study was carried out. The image data as represented in the form of YL maps (see Fig. 4) was fed into the clustering algorithm to assign pixels either to lesion or healthy skin. The results obtained with the K-means, presented in Fig. 5a, show a limited accuracy when compared with the ground truth (Fig. 4b).

Since the clustering performance can be severely affected by data sets with different scales and/or variance [33], a further normalization of the data was implemented for the YL representation, as expressed in (3) and (4). This leads to data sets (Y_N , L_N), both with zero mean and unit variance. Clustering these normalized data sets leads to what is shown in Fig. 5b, which seems in much better agreement with ground truth data.

$$Y_N = \left(Y - Y_\mu\right) / Y_\sigma \quad (3)$$

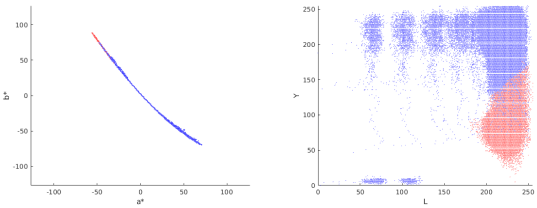
$$L_N = \left(L - L_\mu\right) / L_\sigma \quad (4)$$

Moreover, a further representation of the YL data, prior to clustering, was also considered to provide a better discrimination. This representation is inspired on the *CIE*



(a) (L,Y,L) (b) (L,Y,L) in *a*b**

Figure 6. Visualization of Y representing pink and L representing green (a) and its representation in the *a*b** space of the *CIE L*a*b** color space (b).



(a) YL in *a*b* (b) YL in *a*b** clustering

Figure 7. Data visualization for image IMD078 [35] in the *a*b** space (a) and its resulting K-Means clustering (b). Points color represent their cluster association.

*L*a*b** color space [34], where colors like green and pink are kept well further apart. If each point in the YL space is assigned a *RGB* color given by (*L*,*Y*,*L*), the color distribution shown in Fig. 6a is obtained. Therefore, applying the *RGB* to *CIE L*a*b** transformation leads to the *a*b** representation shown in Fig. 6b. As expected, such operation keeps the top left and the lower right corners of the YL space well separated. Since this space conversion has implicit normalization, it also reduces the data spatial spread. Fig. 7a presents the *a*b** representation of YL dermoscopic data, with Fig. 7b showing the promising results of a K-means based clustering. In the proposed method, this space conversion is implemented before clustering, as shown in Fig. 3.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed methodology was tested on a set of 200 dermoscopy images (80 common nevi, 80 atypical nevi, and 40 malignant melanomas) which comprise the PH^2 dataset [35] of 765x572 pixels. A MSI GT Series GT683DXR-603US Laptop (Intel Core i7 2nd Generation 2670QM 2.20GHz, 64-bit CPU, 12 GB of Memory RAM) was used to execute and calculate the mean execution time of the proposed method, which is of 1.16 seconds on CPU.

The dermoscopic images (8-bit RGB color images) were obtained under the same conditions through Tuebinger Mole Analyzer system with a 20x magnification factor. The database includes the ground-truth segmentation masks that were used to assess the performance of the proposed segmentation algorithm.

Three measures were applied to compare the segmentation provided by the proposed algorithm with the one obtained by the ground-truth masks.

The Border Error (BE) metric, displayed in percentage, is defined in (5), measures the non-overlapping segmentation regions between the proposed segmentation method (SM) and the dataset ground-truth segmentation (GT).

TABLE I. RESULTS FOR PH^2 DATASET

	Complete Dataset			Filtered Subset		
	BE	***TDR***	***FPR***	***BE***	***TDR***	***FPR***
μ	37.572	67.892	18.457	14.156	88.400	5.224
σ	33.163	31.985	24.057	4.731	6.152	3.719
CV	0.883	0.471	1.303	0.334	0.069	0.713

$$BE(SM,GT)=\frac{Area(SM\oplus GT)}{Area(GT)}\times 100 \quad (5)$$

To quantify incorrect segmentation (skin versus lesion) the True Detection Rate (TDR) defined in (6) and the False Positive Rate (FPR) defined in (7) were also applied acting as a discriminative factor over the Border Error metric. The TDR measures the ratio of pixels that are correctly classified as lesion and the FPR measures the ratio of pixels that are incorrectly classified as lesion.

$$TDR(SM,GT)=\frac{\#(SM\cap GT)}{\#(GT)} \quad (6)$$

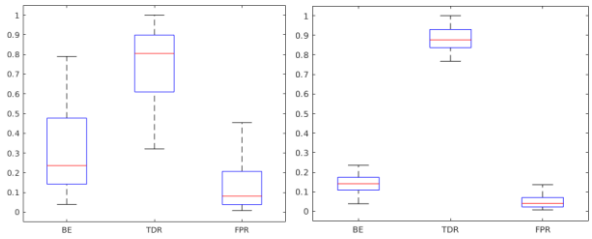
$$FPR(SM,GT)=\frac{\#(SM\cap \overline{GT})}{\#(GT)} \quad (7)$$

A concise inspection of the whole database allows us to identify few tricky images; in which any segmentation algorithm will certainly fail (e.g. some lesions are not completely captured by the image). Hence, two datasets were tested. The original PH^2 dataset, and the one obtained by removing the images where the border vanishes or where hairs are present, the so-called filtered dataset.

Statistical descriptors were calculated for each of the above defined metrics (5-7) for the two datasets, in particular the mean (μ), standard deviation (σ), and coefficient of variation (*CV*). The results can be found in Table I.

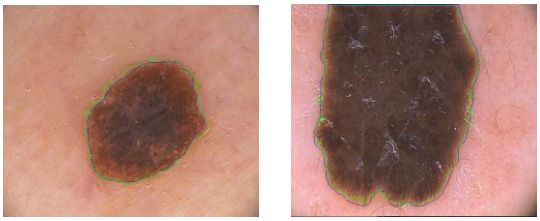
The results in Table I confirm the expected superior performance for all the metrics when the filtered subset is used for segmentation. In fact, by comparing the figures between both sides of Table I, it is possible to observe a reduced dispersion of data at the filtered dataset. As an example, FPR *CV* in the whole dataset is bigger than one indicating $\sigma > \mu$. This massive data dispersion is reinforced by the box-plots presented in Fig. 8a and Fig. 8b, highlighting the reduced variability amongst data from the filtered dataset.

The statistics for the filtered dataset, in particular the reduced BE and high TDR, points to a segmentation algorithm having good performance. Comparisons with other segmentation methods cannot be straightforwardly done without taking into consideration that the segmentation method proposed in this work was designed to obtain fine segmentation borders able to follow the irregular pattern of a cell-based like growing. However, most of the available algorithms aim to obtain segmentation masks as close as possible to the ground



(a) Complete dataset. (b) Filtered subset.

Figure 8. Segmentation metrics boxplot for the PH^2.



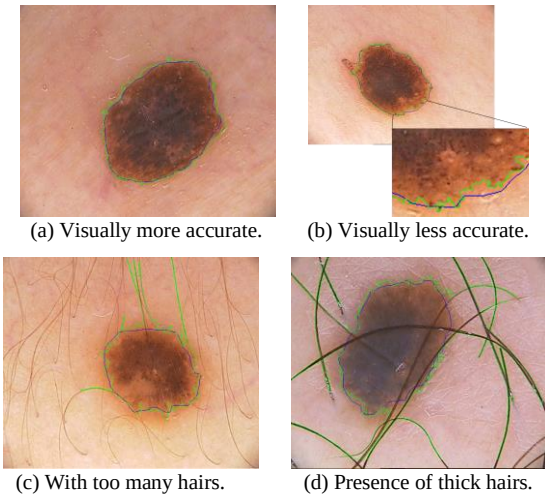
(a) Outside boundaries. (b) Inside boundaries.

Figure 9. Example of an accurate segmentation. Ground-truth is presented with a blue line, and the proposed method results in green.

truth, which in general do not have detailed boundaries as pointed out in Section I. The segmentation matching between the output of an automatic procedure and the one obtained by human experts must be interpreted with caution. The ground-truth segmentation is mostly obtained having predefined assumptions (e.g. the definition of surgical margins) thus targeting different objectives. In [28] a gradient-based metric ($G_{\perp}$) is presented to assess the accuracy of a segmentation border based on the rationale that the segmentation contour is expected to separate regions with substantially different tonalities. Accordingly, the higher the image gradient at a delineation line, the higher the confidence in the delimitation of the lesion area. The results indicate that, on average, the proposed method attains a $G_{\perp,Prop}$ of 60.018 on the filtered subset. In comparison to [28], the proposed method achieves a quotient gradient $G_{\perp,Prop}$ / $G_{\perp,GT}$ of 1.593 for the PH^2 dataset and 1.891 on the filtered subset, showing the efficiency of the segmentation method while still providing contour detail.

Fig. 9a and Fig. 9b are examples of good segmentation results where the algorithm closely matches the ground truth segmentation but provides extra detail to the lesion border thus generating small border errors that translate to increases in FPR and decreases in TDR. Both Fig. 10a and Fig. 10b are examples of bad segmentation. Fig. 10a visually seems segment closer to the lesion core while Fig. 10b actually misses a region of the lesion (upper-left stem). Fig. 10c and Fig. 10d both depict results when hairs are present near the lesion area. In Fig. 10c there are many hairs passing through the lesion and the border segmentation gets elongated along the darker groups of hair. In Fig. 10d the presence of thick hairs makes provides the worst case scenario result.

To investigate the algorithm performance within the type of lesions in the dataset (Atypical Nevus-AN; Common Nevus-CN and Melanoma-M) the previously defined metrics and statistics were calculated and shown in Table II, for the filtered subset.



(a) Visually more accurate. (b) Visually less accurate.

(c) With too many hairs. (d) Presence of thick hairs.

Figure 10. Example of an inaccurate segmentation. Ground-truth is presented with a blue line, and the proposed method results in green.

TABLE II. EXPANDED RESULTS FOR FILTERED SUBSET

	BE			***TDR***			***FPR***		
	AN	***CN***	***M***	***AN***	***CN***	***M***	***AN***	***CN***	***M***
μ	13.287	15.159	13.864	89.529	87.085	88.870	4.789	5.290	7.472
σ	5.189	4.334	2.970	6.398	5.897	5.186	3.380	3.968	3.884
CV	0.391	0.286	0.214	0.071	0.068	0.058	0.706	0750	0.520

Globally, it is possible to observe different results for each type of dermoscopic image. Additionally, there is a trend associating lower *CV* values to some degree of malignancy. In fact, *CV* values for melanoma indexes are the lowest for any type of lesion. This result should be regarded with some caution and confirmed by testing other datasets.

V. CONCLUSION

In this paper, an unsupervised approach for accurate border detection in dermoscopy images, based on LBP sequences and K-means clustering, is presented and validated using a certified dataset and the provided human blind segmentation. The proposed methodology comprises of 3 main phases: LBP image enhancement, *YL to a*b** space transformation, and clustering.

To assess the performance of the proposed method three metrics were tested (BE, TDR and FPR) jointly with the standard statistics. In a first analysis, the results clearly show the dependence of the algorithm from the dataset quality, thus a filtered subset was used by removing low quality images. The results regarding the segmentation for this new filtered dataset show reduced variability amongst the defined performance measures, thus indicating the good segmentation consistency across all images. Moreover, the analysis of the filtered dataset by image type indicates a *CV* decreasing in the Melanoma group. This finding will be probably related to the type of segmentation of the ground truth, and puts forward the need for using different approaches to assess automatic segmentation.

The geometric shape provided by the proposed segmentation algorithm is suitable to identify the real lesion border (instead of the common smooth lines) and can be further applied for a cell-based like segmentation adapted to the lesion border growing. Once this growing process is distinct in different types of lesions (e.g. in particular in the melanoma group) the ability to extract this feature with an algorithm having the aforementioned properties can be used to classify skin lesions based on cell-based like segmentation. This work will be done in the near future.

ACKNOWLEDGMENT

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Feature Extraction for Heartbeat Classification in Single-Lead ECG

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***Abstract*—The recent trends in ECG device development are heading towards wireless single-lead ECG sensors. The lightweight design of these wireless sensors allows the patients to wear it comfortably for a long period of time and during their ordinary everyday activities. Long-term ECG recordings are intended to help in detection or diagnosis of heart diseases. These measurements are significantly longer and more heterogeneous than the measurements performed at a controlled hospital environment. Consequently, their manual inspection is a tedious, hard and expensive job. An alternative is to use computational techniques for automatic classification of heartbeats and arrhythmia detection. In this paper, we investigate methods for feature extraction in single-lead ECG for the purpose of heartbeat classification. The used feature extraction methods originate from the field of time series analysis. The obtained features are then coupled with a classification algorithm to obtain predictive models. The usefulness of the proposed approach is demonstrated on the MIT-BIH arrhythmia database. Results show that features that emerge from different scientific areas can provide information for separation of different class distributions that appear in heartbeat classification problem.**

***Keywords*—ECG, single-lead, classification, feature, arrhythmia**

I. Introduction

Unobtrusive wireless ECG measurements from devices employing smaller number of leads provide opportunity for continuous supervision for the patients with cardiovascular disorders. The main advantage of these ”off the person” measurements is obtaining longer and more heterogeneous measurements, meaning the measurements are acquired during different daily activities and, therefore, are more disturbed by noise. Nevertheless, these devices enable real-time tracking of the state of the patient, at a cost of more complicated tasks for automatic detection of specific type of arrhythmia.

Advancement of Medical Instrumation (AAMI) provides standard to which different methodologies for heartbeat classification are being tested. Similar recommendations are also part of the IEC 60601-2-47 standard. A part of the recommendation is to use the MIT-BIH database for benchmark [1]. The MIT-BIH database is well established standard database for testing different heartbeat classification methodologies. The database consists of 48 half-hour expert labeled two-channel ambulatory ECG recordings collected from 47 subjects. It includes heartbeats from 5 classes, including: nonectopic (N), supraventiricular ectopic beat (SVEB), ventricular ectopic beat (VEB), fusion beat (F) and unknown beat (Q).

Recent studies overview different sets of features being employed for the task of ECG arrhythmia classification [2] [3]. Most of the studies focus on feature extraction from measurements from at least two leads. However, it was shown that differential ECG leads provide different ECG signals from standard bipolar or unipolar ECG leads [4] [5]. Nevertheless, it was confirmed that the ECG from a differential lead is appropriate for hearth rhythm diagnostics [6]. Moreover, it has been shown that domain specific time series features might not be informative enough for solving a given time series classification task [7]. Furthermore, time series features derived from other domains showed to be competitive or better than the domain specific features. Combining global time series features under the AAMI inter-patient paradigm is the main focus on this work. The inter-patient paradigm refers to the process of discarding heartbeats from same patients in both training and test sets. The final goal is to find features that characterize different classes of heartbeats.

The remainder of the paper is organized as follows. Section II gives overview of the state-of-the-art methodologies for arrhythmia classification according to the AAMI standard and the domain specific global time series features derived for time-series classification. Section III presents the methodology. Section IV presents the results and discusses the usefulness of the features in distinguishing the different classes. Section V concludes the work and discusses further research directions.

II. Related work

Traditionally, the problem of heartbeat classification is recognized as a problem of classification of time series. Until recently, the main focus was on extraction of useful features from time series. However, with the recent advances in the area of deep learning, the focus is shifted towards automatic learning of features from time series [8] [9] [10].

The state-of-the-art employs 9-layered end-to-end convolution neural network with batch-weight loss to tackle the imbalance of the problem [10]. Namely, due to the nature of

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the process, it is expected that most of the heartbeats will belong to the N class. Arrhythmia and its different forms are usually present with far less heartbeat examples. In data science literature, presence of such rear categories among majority of others is known as imbalance of the problem. The data from the MIT-BIH database from a single lead (MLII) are used. The impact of neighbouring heartbeats is reported to have great significance on improving the performance. Specificity or True Negative Rate is reported instead of False Positive Rate, as recommended by AAMI. Under the inter-patient paradigm, it is reported that the results from the studies in [11] and [12] are outperformed on all of the 4 measures (accuracy, positive predictivity, sensitivity and specificity) as recommended by AAMI, except for sensitivity in [11] and accuracy in [12].

In [11], an end-to-end system for automatic arrhythmia classification is proposed. It consists of 4 standard processes as described in [3]: preprocessing, noise removal, feature extraction and classification. Total of 15 features separated in 3 groups (R-R intervals, beat intervals and morphological features) are used. These features are domain specific. It is important to note that features are extracted on both leads from the MIT-BIH database. The final prediction is given as a combination of the output of two weighted linear discriminant classifiers. This work employs filtering of the signal, which might result in discarding important artifacts of the heartbeats and increase the prediction time.

Despite wavelets and R-R based features, other popular features include: duration of QRS complex, distance between fiducial points of the heartbeat, PCA (principle component analysis) features on raw signal, ICA sources of the raw signal, GDA (Generalized Discriminant Analysis), Random Projections, high order accumulative features, correlation dimensions, highest Lyapunov exponents, Hermite transformations, fractal dimension features, Fourier transformation, vectrograms and others. A detailed overview on the domain-specific features used for arrhythmia classification are given [2] and [3].

The work presented in [13] is one of the first that utilizes feature selection techniques for selecting the most relevant domain-specific features for heartbeat classification. Incremental wrapper and filtering approaches based on mutual information are utilized for selecting the top performing features from more than 200 features available. Their results show that it is possible to use single-lead ECG for the task of classification of heartbeats. Although they follow the AAMI procedure for splitting the heartbeats, they do not evaluate the performance as the standard suggest, neither provide the confusion matrix. So, direct comparison with their results according to the standard is not possible.

III. Materials and Methods

Recent findings show that domain specific features alone might not be enough for solving a given time series classification task [7]. In [14], a library for extracting global features from time series data, named HCTSA (Highly Comparative Time Series Analysis), is proposed. The features originate from interdisciplinary studies interested in dynamical modeling. Such global features quantify patterns in time series across the full time interval. The experiments in [14] show that features facilitate interpretable insights, are often selected from unexpected literature (drawing attention to novel features for specific application) and best performing classifiers are often constructed using a novel combination of interdisciplinary features (e.g., combining features from economics and biomedical signal processing). Motivated by these conclusions, we employ this library to the problem of heartbeat classification on a single-lead ECG (MLII) from the MIT-BIH database, following the AAMI recommendations.

The HCTSA library combines time series global feature operators derived across various scientific areas during the years. Roughly, it can be organized into 14 groups: statistical, measures of distribution, correlation, basic function representation, stationary, scaling, entropy, non-linear time series analysis, non-linearity, time domain transformations, model fitting and forecasting, domain specific operators, fanciful operations and others. Each of these groups has its own subgroups of operators. Setting different parameters for operations yields different features. Thus, instead of 1064 basic operations, one can easily finish with few thousand features. Increasing the number of features comes with a cost expressed in time needed for computation and increasing the correlation between the generated features. The later can increase the noise in the data and consequently make harder to distinguish the right features for performing the classification task. Regarding the time complexity, calculating features is expensive. However, selecting the right features will result in low cost for obtaining predictions by a pre-trained model. This makes the approach useful in scenario where a fast prediction is needed. The implementation of the library is in MATLAB and is freely available for non-commercial purposes[1].

The 44 records from lead MLII of the MIT-BIH database are first segmented. The cut-off time for the segments is 200 ms before the R peak time – the approximate duration of the PR interval. The segmented heartbeats are given as input to the HCTSA library and the result are 7873 produced features per heartbeat. Some of the operations showed to be not suited for small number of samples and resulted in errors that are tracked by the library. The processing of the calculated features is performed with removing the features where these errors appeared, which resulted in 3324 total number of features.

Since many of the features are product of one particular operator instantiated with different parameter settings, high correlation between the features could be expected. To assess the relevance of the features, we perform feature ranking using random forests impurity scores [15]. The feature ranking has two goals. First, it provides additional insights into the feature relevance/importance for the classification. Second, it can help in reduction of the number of features used fo classification. To select the features, a threshold on the relevance is imposed.

[1] https://hctsa-users.gitbook.io/hctsa-manual/

In such a way, the features that have higher relevance over the specified threshold, are preserved.

The last step in the workflow is using algorithms to build predictive models. As a set of predictive modeling algorithms, AdaBoost and Gradient Boosting, implemented under the sckitlearn library, were used[2]. According to the AAMI guidelines, we calculate four performance metrics: accuracy, positive predictivity (pp), sensitivity and specificity. Their definitions are as follows:

$$accuracy = \frac{TP + TN}{TP + TN + FP + FN}, \quad (1)$$

$$pp = \frac{TP}{TP + FP}, \quad (2)$$

$$sensitivity = \frac{TP}{TP + FN}, \quad (3)$$

$$specificity = \frac{TN}{TN + FP}, \quad (4)$$

where TP, TN, FP and FN are the numbers of true positives, true negatives, false positives and false negatives, respectively.

IV. Results and Discussion

The time required for computation of all features for 100 733 time series was 240 hours on a single machine with 32GB of RAM and Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz processor. This is a big overhead, but the used post-processing methods aim at reducing the number of features thus reducing the time overhead.

The average features rankings with gini impurity criteria method for all the classes are given in Table I. The confusion matrix for the best performing model AdaBoost is given in Table II. In the following, we discuss the obtained results.

A. Dataset representation

Fig. 1 represents visualization of the training dataset obtained with t-distributed stochastic neighbor embedding (TSNE) from the MIT-BIH database, as discussed in [11]. A clear observation of the classes can be distinguished, with the VEB class belonging to the top head of the predominantly N class spherical shape, with partially localization of SVEB and F classes. Given the spread of the SVEB classes, it can be concluded that algorithms will have hard time in distinguishing the SVEB class from the N class. However, comparing the VEB and the N classes, the separation is more clear.

In Fig. 1, a dozen groups of points are observed. With close inspection of these groups, it can be concluded that they belong to the same patient (Fig. 2). It is important to note that, although the majority of the heartbeats for one patient will happen to belong to one group, there exist heartbeats that do not belong to the same group, if the heartbeats are of different class. For example, beats for the patients 208 and 209, as observed in Fig. 1. This is encouraging findings since it is a sign of existing good features in separation of at least some of the classes.

[2]https://scikit-learn.org/stable/

TABLE I
Top 5 average ranks for the features for the classes N, SVEB, VEB, F and Q

vs all	average rank	feature name
N	1.7272	CO Add Noise 1 gaussian firstUnder75
	2.2727	CO TranslateShape circle 25 pts fives
	6.5000	EX MovingThreshold 01 01 maxq
	8.4545	EN CID minCE1
	8.5909	SP Summaries pgram hamm w10 90
SVEB	4.6818	CP ML StepDetect l1pwc 005 medianstepint
	4.7727	FC Surprise T2 50 3 udq 500 tstat
	4.9090	PP Compare resample 1 2 gauss1 kd resAC2
	9.31818	CP ML StepDetect l1pwc 02 minstepint
	11.5454	length
VEB	2.5454	CO AddNoise 1 gaussian firstUnder75
	3.6363	SP Summaries pgram hamm w10 90
	4.5454	EN CID minCE1
	6.5454	CO StickAngles y std p
	7.0454	PH Walker momentum 2 w std
F	15.4545	DN SimpleFit sin1 resruns
	19.9545	CO TranslateShape circle 15 pts threes
	21.0000	PH Walker biasprop 01 05 res runstest
	25.3181	PP Compare spline44 gauss1 kd resruns
	30.1818	HT DistributionTest lillie ev
Q	2.9545	FC LocalSimple mean1 ac1
	3.5454	FC LocalSimple mean3 ac1
	7.0000	MF steps ahead ar 2 6 rmserr 1
	7.6818	FC LocalSimple mean2 ac1
	10.9545	MF AR arcov 2 a3

TABLE II
Confusion matrix for our method. *number of trees 500, learning rate 0.1*

	Class	N	SVEB	VEB	F	Q
	N	43832	25	396	3	0
True	SVEB	1721	15	100	1	0
Label	VEB	708	76	2432	4	0
	F	281	1	106	0	0
	Q	3	0	0	4	0

B. Feature ranking

From the results presented in Table I, according to inter-class feature importance, it can be conducted that the two most common classes, N and VEB, have features that occur frequently as top ranked. Moreover, the same top ranked features are shared between the N and VEB classes. For example, *Co add noise* – the best ranked feature comes from chaos theory. It is a measure of chaos, calculated by adding Gaussian noise to the time series in increasing manner across some range of values and then measuring the mutual information at each point by calculating histograms. The larger the measure, the greater the relative intensity of the chaos is. Predominantly, the values for the N beats tend to be positively valued. According to this measure, positive values indicate chaotic behaviour. Conversely,the VEB heartbeats tend to have negative value for this feature. For both N and VEB, this is the most important feature.

The *normalized length* feature is closely related with one of the most exploited features in heartbeat classification literature – normalized R-R interval. *Normalized length* measures the

length of the time series normalized with respect to the average length of the patient-specific heartbeat. Fig. 3 depicts the *normalized length* feature vs. the *CO add noise* feature. It can be seen that the *CO add noise* feature makes separation between classes VEB (blue) and N (red) with observation that VEB heartbeats tend to have larger duration with respect to normal ones. Inspection of the N heartbeats with negative value for the *CO add noise* feature suggests that they belong to patient that experiences VEB heartbeats. Combining this novelty feature together with previously known features enables clearer separation of classes N and VEB. The same discussion for the SVEB and the VEB classes can be drawn in parallel. In Fig. 4, one can also observe a clearer separation of the VEB vs all other classes, which the second ranked feature *CO TranslateShape circle 25 pts fives* imposes. This feature is instantiate from the CO basicrecurf function operator. It calculates the number of points that are close to certain geometric shapes in a plots generated from the time series with lag *t*. As such, those represent measures for point density estimation.

Regarding the categorization of the SVEB class, such calculated global features do not preserve the local deviation of the SVEB and the N classes. These two types are distinct only in the PR interval of the beat. The global time series features diminish the effect of this local property and thus it is harder to separate the classes N and SVEB. Therefore, a more suitable way would be to threat that part of the heartbeat as separate time series. Extracting features on that part, hopefully will bring additional discriminate power.

For class F, the average feature rankings suggest that there is no strong feature for classification of this class. The time series for class Q are varying by large margin in patients, and are of little support. Although, *FC LocalSimple mean1 ac1* appears quite frequently as top ranked feature, its impact can not be well determined due to overlapping of class distributions by large extend.

Finally, another representation of the data is presented in Fig. 5. This figure illustrates the difficulty of the prediction problem at hand. Namely, only 68.58 % of the variance in the dataset is explained with the first three components.

C. Predictive model

The confusion matrix on the test set, reported in Table II, shows that the proposed features are good enough for separation of VEB and other classes. The accuracy, sensitivity, positive predictivity and specificity for the VEB class are: 0.97, 0.76, 0.80 and 0.99 accordingly, which are quite good given the imbalance of the problem. All SVEB heartbeats tend to be predicted as N due to the previously discussed reasons. The accuracy, sensitivity, positive predictivity and specificity for the SVEB class are: 0.96, 0.01, 0.13, 0.99. The low value for the sensitivity is unsatisfactory. The F and Q beats as expected, are not distinguishable and thus are miss-classified.

Compared to the state-of-the-art methods that extract features from a single-lead ECG, our approach is poorer in performance and solving the task. One of the explanations

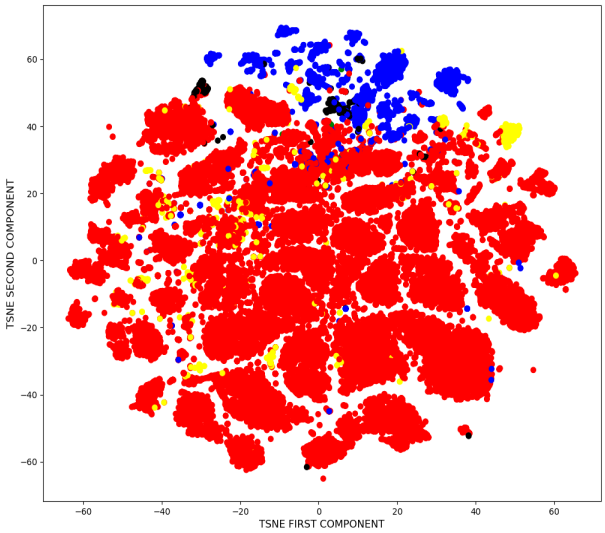

Fig. 1. TSNE representation of the training MIT-BIH dataset represented in two dimensions. Classes: N=Red, VEB=Blue, SVEB=Yellow, F=Black, Unknown=Green.

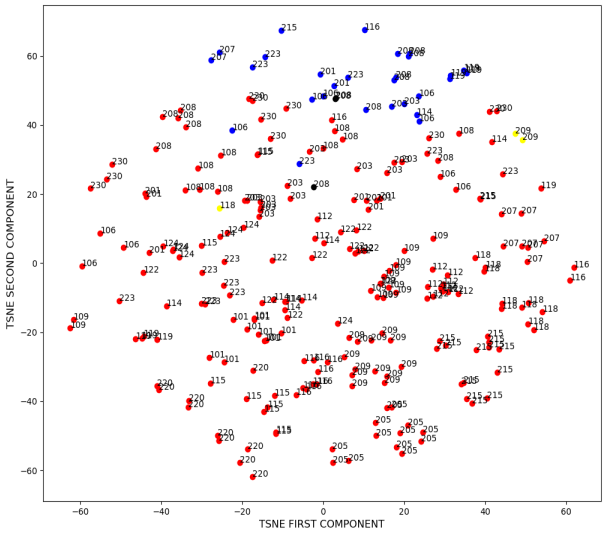

Fig. 2. TSNE representation of the training MIT-BIH dataset represented in two dimensions along with patients IDs to present the clustering groups depicted in Fig. 1. Red=N, Blue=VEB, Yellow=SVEB, Black=F, Green=Unknown.

is that the work perfomed in [10] extracts patient specific features. As depicted in Fig. 1, the heartbeats of same patient tend to cluster themselves in groups. This might reflect the belief of unique anatomy of a patients' cardiovascular system, which implies different characteristic features of the types of

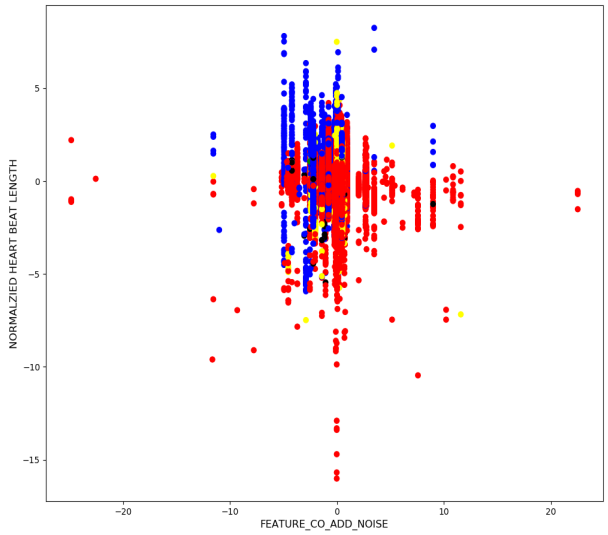

Fig. 3. Feature *CO add noise* – x axis and Feature *normalized time series length* – y axis. Depicts the separation of VEB versus SVEB and N.

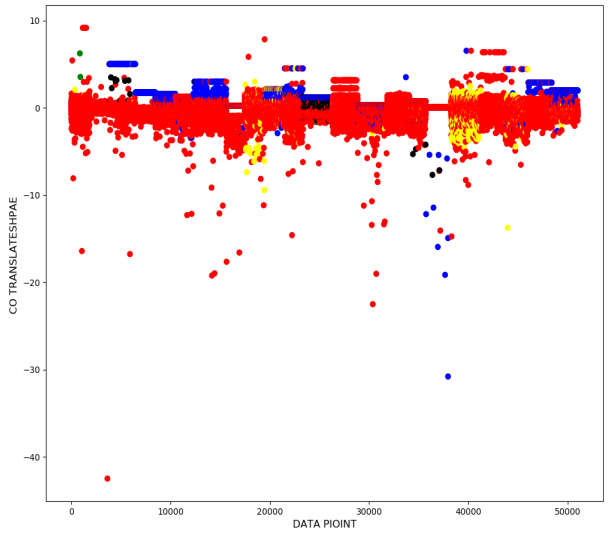

Fig. 4. *Sample ID* – x axis and Feature *CO TranslateShape circle 25 pts fives* – y axis. Depicts the separation of VEB and N.

arrhythmia a patient might experience. Also, in their work, an information for the neighbouring heartbeat is used, which seems useful, since the heartbeats are not independent.

V. Conclusion

It this paper, we propose methods for feature extraction in single-lead ECG for the purpose of heartbeat classification. The extracted features belong to the domain of global time series features derived from various technical and scientific

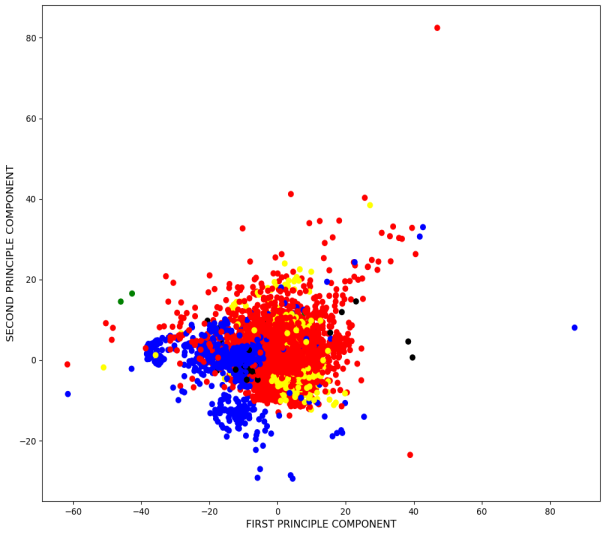

Fig. 5. PCA representation of the training MIT-BIH dataset represented in two dimensions. The first 3 components express 68.58 % of the variance in the data.

areas. Results show that features that emerge from different scientific areas can provide information for separation of different class distributions that appear in the heartbeat classification problem.

The extracted features are disriminative for the VEB class versus the remaining 4 classes. However, a clear distinction between nonectopic and SVEB heartbeats is absent. This is due to the focus of the employed time series features to extract the global properties - nonectopic and SVEB heartbeats are different mostly in the PR interval. Thus such global approach might not be suitable. As future work, we would investigate if adding extracted information from different wave forms of the ECG provides greater diversity in the problem expression.

Since the literature shows that the neighbouring heartbeats can help in expressing the differences between the classes, for future work, global time series features on two heartbeats can also be extracted. This will preserve the local correlation between the heartbeats. The focus on this work is primarily on weather features from various domains are helpful in describing the problem of heartbeat classification. However, in order to exploit the information these features provide, using different algorithms with different parametarization should also be conducted. Any other further work should take this in consideration.

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A Methodology for Laser Speckle Simulation in Controlled Dynamic Processes

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***Abstract* - The use of coherent light in imaging is the basis of several technologies that extends from nanotechnology, biomedicine, structural biology to metrology. Regarding laser speckle imaging in health-related conditions, in recent years several applications have been developed, emphasizing the potential of laser speckle as a functional imaging methodology, either used as individual methodology or in a multimodal imaging scheme. To assess distinct acquisition methodologies, several experimental protocols have been tested, but also new activity descriptors have been developed. These image processing derived descriptors are core to the speckle characterization in dynamic physiological conditions. Accordingly, the use of computer simulation algorithms to obtain the phenomena, avoiding acquisition noise is a research topic with great interest among the community, as a way to test the descriptors performance in a controlled way. In this work, a methodology for laser speckle simulation of dynamic processes is presented. The proposed algorithm allows controlling the way the process varies by setting a linear, quadratic, sinusoidal or mixt behaviors, during the simulation period.**

Keywords – Computer simulation, Laser Speckle, Computer Vision, Signal Processing

I. INTRODUCTION

Speckle is an optical interference phenomenon obtained when a coherent source of light is projected into a rough surface. The scattering surface can either be static or have micromovements due to some dynamic process (occurring in it or underneath the surface itself) able to modify its texture along time. Although the physical principles have been firstly described by Newton, the advances in camera technology and sensors (CCD sensors), as well as in laser technology, emerged as an impulse to look at the speckle interferometry in a different perspective. Instead of a noisyphenomenon to be avoided, laser speckle became an information source to be studied, as it carries information about the dynamics of the scattering surface. In research areas related with synthetic aperture radars [1], biomedical imaging ultrasounds [2] and optical coherence imaging [3], speckle interference of the reflected wavefronts is filtered to improve the accuracy of the obtained information. Also in industrial applications, laser speckle have been used to measure deformation, shape, and roughness of materials (Speckle metrology),

More recently, with the advances in optical sensors, major attention has been devoted to the reflected wavefronts as a vehicle of information about the dynamics occurring in the sample surface. Of particular biomedical interest are perfusion studies related to cortical ischemia [4], blood flow speed [5] and the assessment of burn recovery [6], among other biomedical studies.

Given the type of information that is captured by the camera sensors and its inherent complexity and variability in statistical terms, several descriptors have been proposed to establish quantitative measures regarding the speckle variation pattern [7 -9]. The way to assess the accuracy of such measures is mostly done by performing experimental tests, where stimulus-response protocols are followed as a way of assessing sensitivity/specificity regarding the predefined stimulus.

The validation of activity descriptors based on experimental procedures can be replaced/complemented by computational simulation. This procedure has gained some relevance in speckle imaging in the last years, contributing to a clear insight into the physical phenomena under study. Computer simulation of speckle has the advantage of generating the phenomenon avoiding the errors and noise associated with the experimental process. The test of new descriptors based on simulated signals is also a way of avoiding previous processing (e.g. filtering) in the experimental signals. In the majority of the acquisition systems it is difficult to fully characterize *a priori* the type of associated noise, thus simulation algorithms are seen as a very useful tool in speckle imaging research.

In this work, an algorithm for speckle simulation will be presented to enable computer simulation of syntectic speckles in controlled dynamic processes. The algorithm is based on the Copula simulation model proposed by Duncan and Kirkpatrick [10] and will be tested by using classical activity descriptors with and without added noise. The simulation algorithm will be tested in controlled dynamics processes with linear, quadratic, sinusoidal and mixt sinusoidal variation profiles.

In the following of this work, in section II the simulation algorithm will be presented, and in section III the results will be shown and discussed. The last section is dedicated to conclusions and future work.

II. SIMULATION ALGORITHM

A. Mathematical background of the Copula

Methodologies for computer simulation of speckles often use Fast Fourier Transform (FFT) of a phase matrix

[11]. By using solely this approach the output of each simulated speckle are independent of each other. In [10], Duncan and Kirkpatrick proposed a methodology based on a temporal correlation function, which is summarized in this section.

The Copula algorithm is based on the Sklar's Theorem, in which a two-dimensional distribution function H and two marginal distribution functions F and G are related by the existence of copula C, as in (1)

$$H(x,y) = C\big(F(x), G(y)\big). \qquad (1)$$

Let X_1 and X_2be two uniformly distributed, statistically independent, random variables (RV). By applying the Box-Mueller transformation to each of these two variables, two new variables are obtained (as shown in (2)) representing polar coordinates of the points from X_1 and X_2,

$$\begin{aligned} Y_1 &= \mu + \sigma\sqrt{-2ln(X_1)}\cos(2\pi X_2) \\ Y_2 &= \mu + \sigma\sqrt{-2ln(X_1)}\sin(2\pi X_2), \end{aligned} \qquad (2)$$

where in (2) μ is the mean and σ is the standard variation. The obtained joint density distribution of the bivariate function (Y_1, Y_2) is a Gaussian with mean and standard deviation μ and σ respectively. This method produces a pair of random variables having an arbitrary correlation coefficient that will be used in the proposed methodology to relate the sequence of simulated speckle frames.

B. Computer Simulation Algorithm

According to the method proposed in [10] to create the simulated speckle, a circle of radius D/2 filled with complex numbers with phases uniformly distributed in the interval $]0, 2\pi[$ is created inside a square having $L \times L$ dimensions. The exponential probability distribution of the speckle pattern will be obtained after the multiplication of the 2DFFT of the square by its complex conjugate.

At the proposed methodology, to obtain the phase angle a multiplicative height m is introduced as defined in (3), where $T_j, j = 1,2$ is obtained by a percentile transformation from $Y_j, j = 1,2$ in (2), and i is the frame index in the simulation.

$$\phi_{x,1} = 2\pi m_i T_1;\ \phi_{y,2} = 2\pi m_i T_2 \qquad (3)$$

The algorithm proposed by Duncan and Kirkpatrick in [10] was built to produce continuous phase trajectories between the two bounds of the correlation interval (e.g. $-1 < r < 1$). The multiplicative factor proposed at the present work to be included in the process of obtaining the phase, will maintain the above characteristics but also introduces a varying controlled weight factor. This will maintain the correlation dependence between frames associated to a given trend.

III. Experimental Results and Discussion

Image processing of speckle frames allows obtaining qualitative and quantitative measures of the dynamics of the process under study. Classical measures include contrast, some of its derivative measures (e.g. perfusion, velocity,…) and Time History Speckle Pattern (THSP) among others. Contrast, as defined in (4) is the Coefficient of Variation of the intensities in each frame, where $\sigma_I$is the standard deviation and $\bar{I}$ the mean.

$$K = \frac{\sigma_I}{\bar{I}}. \qquad (4)$$

In this work, the contrast will be used as a measure to test the results of the proposed algorithm. In order to calculate the contrast, a kernel matrix is applied, whose dimension must be suitable to the speckle graining size. The simulated speckle size depends on the relation between L and D (dimension of the square and diameter of the circle) previously defined. The quotient between kernel size and speckle size, as defined in (5), will be used to study the minimum kernel size to be used in the simulations in order to avoid oversampling.

$$\rho = \frac{Kernel_{size}}{Speckle_{size}}. \qquad (5)$$

A. Definition of parameters for the simulation

Previous studies have shown that the minimum speckle size to avoid undersampling is the double of the pixel size [11]. Likewise, the kernel size needs to be adapted to avoid undersampling issues in the spatial averaging when calculating the contrast.

In order to test the contrast variation with the ratio ρ defined in (4), a set of simulation studies were conducted whose results can be found in Fig. 1. A sequence of simulated static speckle was created using the above described method considering $m(i) = 1,\ i = 1, 2, \ldots, N$ where N is the number of simulated frames (in this particular case, the simulation is the same as proposed in [10]). Additionally, by using the obtained simulations, Gaussian noise was added to test the effect of noise in the imposed predefined trend. The range for the level of added SNR was defined to include the minimum level of 5, according to the rose criterion.

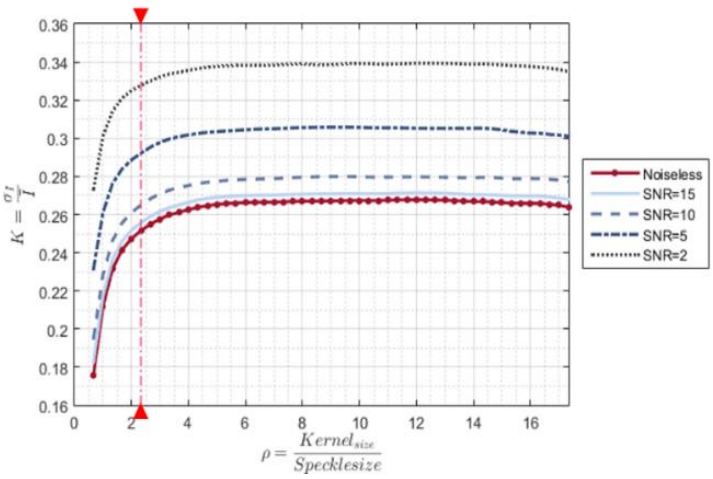

Figure 1. Contrast variation as a function of the ratio ρ.

According to the results in Fig. 1, contrast values present an initial increasing pattern tending to stabilize as ρ

increases. This pattern is the same for the cases where the noise was added, in which an overall inverse relation is seen between SNR and contrast values.

The dashed vertical line in Fig. 1 indicates the ρ value for the minimum speckle size (i.e. 2) and kernel size 7.

B. Dynamic simulations

The main objective of this work is to present a methodology to simulate speckles obtained from dynamic processes, in which the activity trend is previously known. To test the ability of the algorithm to reproduce the predefined trend, 5 mathematical models for the activity variation were simulated. In Fig. 2 the five models are presented in the left column: linear monotonic (A), parabolic (B), sinusoidal (C), sinusoidal crescent (D), mixt monotonic sinusoidal (E). The corresponding contrast obtained with the simulation studies is presented in the tight column. In the simulations a speckle size of 4 $\left(\frac{L}{D} = \frac{256}{64}\right)$ was applied jointly with a kernel of dimension 9 for the contrast calculations.

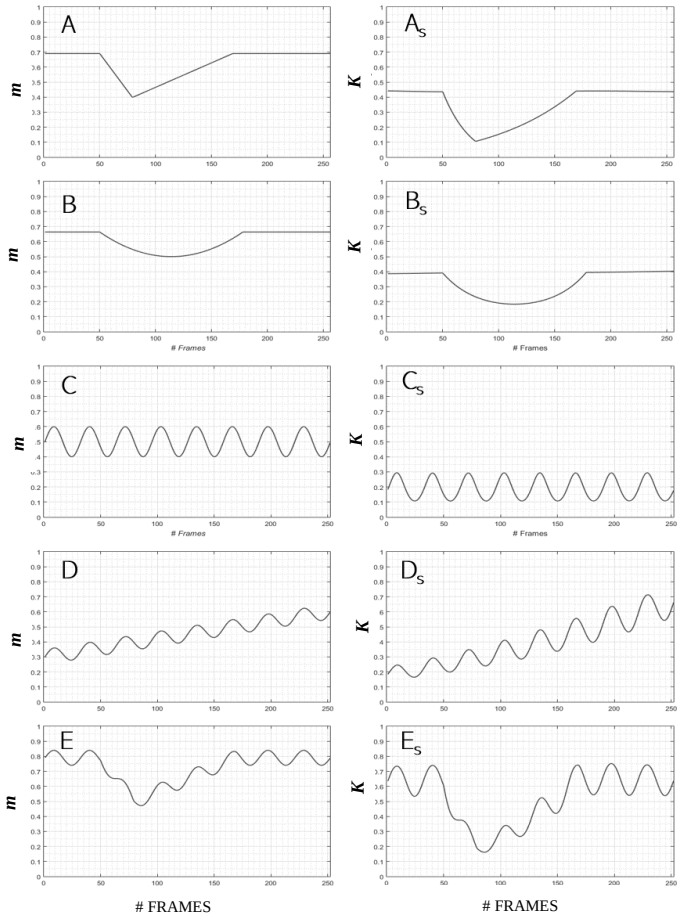

Figure 2. Nature of the dynamic process (at the left) and contrast after simulation (right column).

As is possible to observe by comparing the left and right graphs in Fig. 2, the contrast for each frame follows the trend pattern created in the simulation. Although this is a qualitative assessment, and no relation between the $m(i)$ values and contrast were exploited, the proposed approach can be used to validate new dynamic descriptors.

The influence of the added noise in the simulation was also studied, by joining in the monotonic linear case three noise levels ($SNR = 10, SNR = 5$ and $SNR = 2$). The results are presented in Fig. 3

From the results in Fig. 3 it is possible to observe slight variations in the contrast curve, however, the global pattern and contrast values do not seem to be influenced by the noise level (compared with the noiseless contrast graph, the first graph in Fig. 3, A_s). In fact, the contrast calculation is itself a form of filtering (a spatial low pass filter) thus the noise does not influence the contrast profile.

IV. CONCLUSION

In this work, a method to simulate dynamic speckle from a process in which the dynamic behavior (e.g. activity) is known was presented. The algorithm is derived from the Copula methodology, and adapted to encompasses controlled correlation between frames

To test the proposed algorithm, 5 mathematical models for the activity were tested. Moreover, one model was also tested against 3 SNR noise levels. The results point to an algorithm that can be used to simulate dynamic speckle patterns which are also robust against noise.

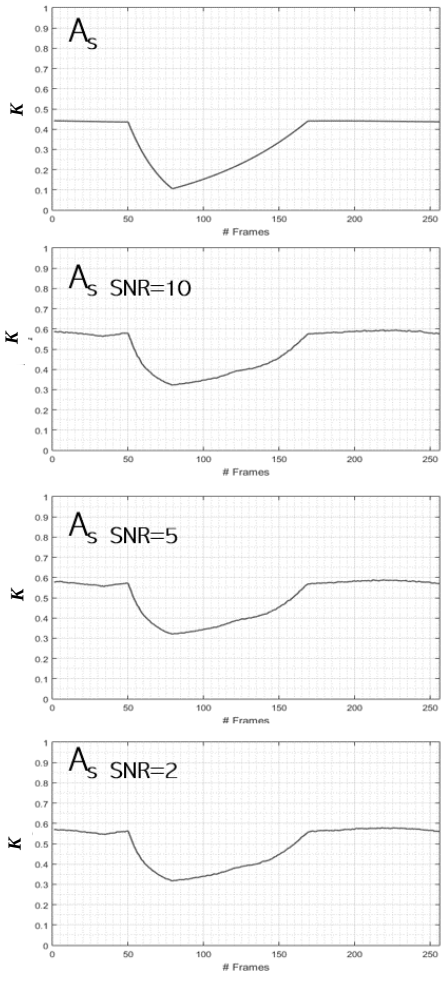

Figure 3. Contrast after simulation with linear pattern and for three levels of noise.

ACKNOWLEDGMENT

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Properties of the generalized Robinson-Foulds metric

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Abstract **- Comparing hierarchical structures is a problem with many applications in various fields of biology. In this work we address the problem of comparing phylogenetic trees and quantifying their dissimilarities. The most commonly applied measure of similarity between phylogenetic trees is the Robinson Foulds (RF) metric. The Jaccard-Robinson-Foulds (JRF) metric (of order k) has been recently proposed as a generalization of the RF metric that preserves its widely appreciated properties but increases its resolution and robustness. Here, we conduct thorough experimental analysis of the JRF metric and variations thereof on both real world and simulated data. Our main aim is to deepen the understanding of the properties of this generalized RF metric in comparison to the classical RF metric and other matching based distance measures. To compute the JRF distance between trees, we employ the recently proposed branch-and-cut solver Trajan.**

Keywords **- Robinson-Foulds metric; Phylogenetic trees; dissimilarity measures**

I. INTRODUCTION

Phylogenetic trees organize biological species (taxa) in a hierarchical relationship. Their nodes can also represent other entities like tumor subclones that have formed during tumor evolution [12]. Even more, protein-protein interaction (PPI) networks embed a hierarchical structure that can be that can be reconstructed by hierarchical clustering methods [13]. Comparing phylogenetic trees can quantify their similarity under different reconstruction methods, and provide valuable insights into the symbiosis between the evolution of a parasite and its host, for example [14]. The most popular measure of phylogenetic tree similarity is the *Robinson-Foulds* (RF) *metric* [1] whose main idea is to match identical nodes (or clades) of one tree to another. It can be efficiently computed but provides a very conservative and "low resolution" dissimilarity measure that is unable to discern between similar structures and is not robust against minor tree changes [11, 15]. In [2] a generalization of the RF metric has been proposed that aims to alleviate some of its shortcomings by enforcing a bijective mapping between the tree nodes which preserves the ancestral relationships. Alternative metrics for trees either exhibit unfavorable properties [9, 10, 11] or are hard to compute in practice [8]. Even though the computation of the generalized Robinson-Foulds metric is NP-hard it has been demonstrated in [2] that it can be efficiently computed using state-of-the-art branch-and-cut solver Trajan **[**16**]** which solves an integer linear programming (ILP) problem and makes the solving of medium to large sized instances feasible in practice.

In this work, we demonstrate experimentally that the Jaccard-Robinson-Foulds (JRF) metric (of order k) generalizes the classical RF metric and provides a higher resolution view on tree dissimilarity. Furthermore, we investigate its relationship to other matching based distances. We will also present the empiric running times for our data.

The paper is structured as follows. In the following subsection we will give the basic definitions which will be used throughout the paper. In Section II we will review the classical RF metric and its generalizations (JRF) as introduced in [2]. In Section III we report properties of the generalized Robinson-Foulds metric observed on both simulated and real-world instances. We conclude in Section IV.

II. PROBLEM FORMULATION

A. Basic definitions

Let $T_1 = (V_1, V_2)$ and $T_2 = (V_2, E_2)$ be two rooted, labeled, unordered trees with node labels over an alphabet Σ. Furthermore, let C_1 and C_2 be sets of all clades of T_1 and T_2, respectively. Given a scoring function $\delta : C_1 \times C_2 \to [0, \infty)$ that measures dissimilarity between clades we can define the distance d between T_1 and T_2 as the minimum cost of a matching M between clades in C_1 and C_2 as follows

$$d(M) = \sum_{(Y_1, Y_2) \in M} \delta(Y_1, Y_2) + \sum_{\substack{Y_1 \in C_1 \\ Y_1 \text{ unmatched}}} \delta(Y_1, -) + \sum_{\substack{Y_2 \in C_2 \\ Y_2 \text{ unmatched}}} \delta(-, Y_2).$$

The cost of leaving Y_1 unmatched is $\delta(Y_1, -)$ while the cost of leaving Y_2 unmatched is $\delta(-, Y_2)$. The RF metric is a binary counting scheme that penalizes clades that occur exclusively in one tree, i.e. $\delta(Y, -) = \delta(-, Y) = 1$,

while $\delta(Y,Y) = 0$ and $\delta(Y_1,Y_2) \geq 2$ for $Y_1 \neq Y_2$. Different approaches may be defined, as seen in [9, 10, 11], by choosing different dissimilarity measures δ. First measure we will consider is symmetric difference which is defined as follows

$$\delta(Y_1,Y_2) = |Y_1 \cup Y_2| - |Y_1 \cap Y_2|,$$

with $\delta(Y,-) = \delta(-,Y) = |Y|$. Likewise, we can define Jaccard weight of order k as

$$\delta(Y_1,Y_2) = 2 - 2 \cdot \left(\frac{|Y_1 \cap Y_2|}{|Y_1 \cup Y_2|}\right)^k,$$

with $\delta(Y,-) = \delta(-,Y) = 1$. Note that RF is a special case of Jaccard weight ($k \to \infty$). In our paper, unless stated otherwise, we will consider the Jaccard weight of order 1. Finding the matching minimizing $d(M)$ can be phrased as maximum matching problem [2].

B. Arboreal matching

In contrast to the matching underlying the RF metric, the matching that minimizes $d(M)$ does not necessarily respect the tree structure. Ancestry relationship can be violated in two ways. Two edges can be "crossed" (Fig. 1a), or matched clades can be descendants in only one tree (Fig 1b).

Hence, in [2] the authors defined the notion of arboreal matching which is identical to the notion of Tai mapping [6]: for any two pairs $(u_1,v_1),(u_2,v_2) \in M$, one of the following conditions holds:

I. $u_1 = u_2$ iff $v_1 = v_2$,
II. u_1 is descendant of u_2 iff v_1 is a descendant of v_2.

In [2] it is proven that arboreal matching is NP-complete. Despite that, [16] developed an efficient tool Trajan that heavily relies on branch-and-cut technique. They introduced the two novel sets of cuts that rely on two types of ancestry violations (see Fig 1.):

- *Crossing edges clique constraints* – a maximal set of pairwise crossing edges between two fixed root-to-leaf paths, and
- *Semi-independent clique constraints* – a maximal sets (cliques) of pairwise semi-independent edges.

III. Experimental results

In this section computational results will be given and discussed. We have generated datasets which consist of 10000 trees with 50 leaves as well as 1000 trees with 75 and 100 leaves from Yule and Uniform distributions

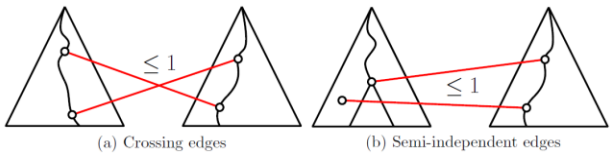

Figure 1. Two types of ancestry violations

which create biologically plausible random trees, where all phylogenetic trees are equally likely under the former model, and the latter one assumes a constant speciation rate [3]. We have also obtained 1000 real-world green algae phylogenetic trees from [4]. Trees will be compared using metrics induced by symmetric difference and Jaccard weight dissimilarity measures.

This section is comprised of three main parts. In subsection A we will argue about metrics induced by Jaccard weight being the generalization of RF metrics. Subsection B will deal with the importance of two aforementioned constraint sets. Finally, we are going to give general results regarding the distance distributions and running times for all of the datasets.

All tests were conducted on a server computer with two Intel(R) Xeon(R) E5-2697 v4 @ 2,30GHz processors with 18 cores / 36 threads each, 320GB @ 2,40GHz DDR4 memory operating on Scientific Linux 7.5 (Nitrogen). C++ compiler used to compile Trajan was GCC 4.8.5 20150623.

A. Convergence to the RF metrics

We have already mentioned that the metrics induced by Jaccard weight converge towards the original RF metrics when their orders increase. In this subsection we will try to experimentally support that claim, i.e. that the metrics induced by Jaccard weight are a generalization of the RF metrics. To that end we have analyzed instances from 100 leaf Yule and green algae datasets which we tested subsequently with increasing values of Jaccard order k until convergence was reached. The convergence point was confirmed by the tool found in [5].

In Fig. 2 we present the distances for green algae dataset. For each integer k we have made a box-and-whiskers plot depicting the normalized distance distribution quantiles while the dashed horizontal black line at $y = 1$ represents the RF distance. Distances of the metrics induced by Jaccard weight indeed converge towards the ones obtained by the RF metrics. If we were to run unconstrained matching instead of arboreal matching it would not be clear as to how many clique constraints do the computed matchings violate. Fig. 3 shows that with increasing values of k the number of conflicts decreases. Note that zero violations must occur once the non-arboreal distance converged to the RF distance. The same figure also shows the difference in distance distributions of the metrics induced by Jaccard weight with regards to arboreal matching and

unconstrained matching. We can see that as Jaccard converges towards RF, unconstrained matching becomes a good approximation of arboreal matching.

We have run the same experiments on the random instances from both distributions. Figs. 4 and 5 show the results obtained for the 100 leaf instances from Yule distribution which follow the same pattern as the green algae instances with the convergence being reached for a far smaller *k*.

B. Impact of the constraint sets

In the last subsection we have argued that for sufficiently large *k* unconstrained matching does not violate the ancestry in the context of arboreal matching. Since RF metrics can be computed in polynomial time and computing its generalization is NP-hard it is important to argue the benefits of computing the arboreal matching over the RF metrics.

Fig. 6 represents the histogram of distances computed using Jaccard weight of order 1 from 50 leaf uniform dataset while the RF distances for the same dataset fall within only 3 different values – 92, 94 and 96. Most of the instances (slightly less than 80%) produce an RF distance of 96. It is clear that the generalized RF metrics provide a far greater "resolution", i.e. a wider distance distribution. This means that the generalization of the RF metrics could be more suitable for the procedures which rely on detecting slight differences between the trees. The rest of the random datasets yielded comparable results where the distance distribution of the Jaccard weight induced metrics was wide in comparison to the very discrete RF distances**.** RF distances of green algae instances are slightly more diverse as can be seen in Fig. 7. But, akin to the previous results, the generalized RF metrics show a wider distribution which is presented in Fig. 8 (blue).

On the other hand, as hinted in Figs. 3 and 5, there exist significant differences between arboreal and unconstrained matching for Jaccard weight of order 1. Unconstrained matching produces a lot of conflicts of which around 95% are semi-independent clique violations. In Fig. 8 we have shown the demeaned distance distributions of arboreal and unconstrained matching for green algae instances. We have run a similar experiment on green algae instances using unconstrained matching with metrics induced by symmetric difference. The resulting distribution is given in Fig 9. The summary of the distribution of conflicts for this and all following experiments in this section is given in Table I.

It has been shown in [7] that a polynomial time algorithm exists for computing matching which does not violate crossing edge constraints when using symmetric difference dissimilarity measure (MC distance). More precisely, in [7] it was proven that distance doesn't change in presence if crossing constraints. Therefore, on the green algae dataset, we have computed matchings which only satisfy crossing edge constraints and counted the amount of produced semi-independent conflicts (see

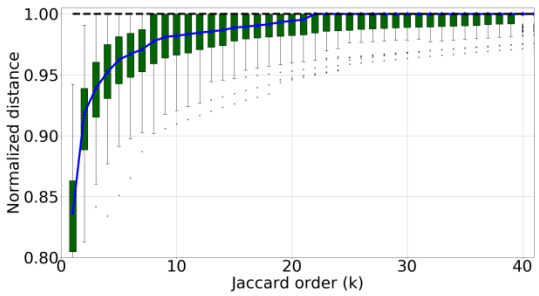

Figure 2. Normalized Jaccard weight distances of green algae dataset for increasing *k*

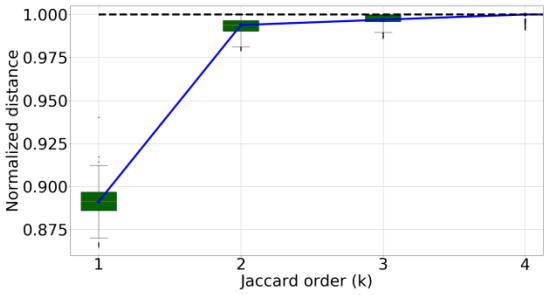

Figure 4. Normalized Jaccard weight distances of 100 leaf Yule dataset for increasing *k*.

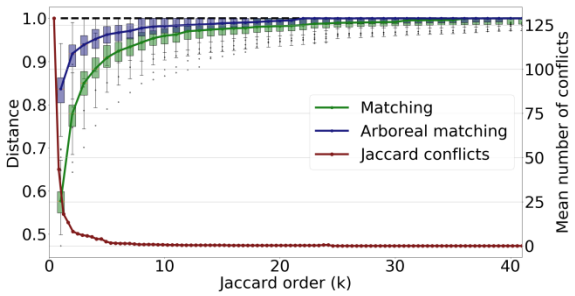

Figure 3. A comparison of unconstrained and arboreal matching distance distributions with a number of produced conflicts for green algae dataset

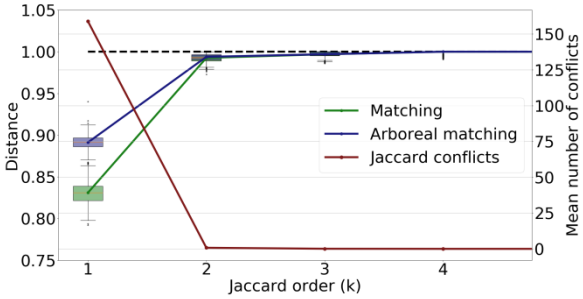

Figure 5. A comparison of unconstrained and arboreal matching distance distributions with a number of produced conflicts for 100 leaf Yule dataset.

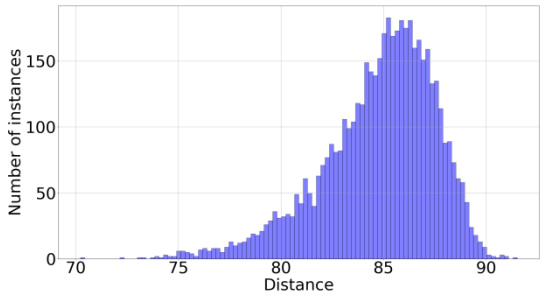

Figure 6. Distribution of the distances of 50 leaf instances from uniform distribution with Jaccard weighted arboreal matching

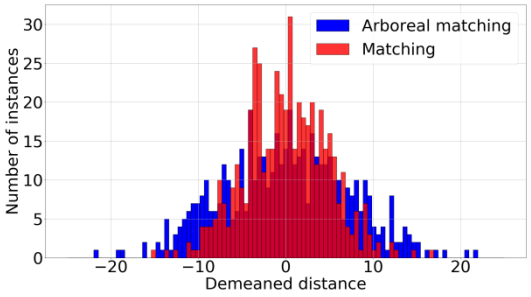

Figure 8. Demeaned distribution of distances (arboreal matching and unconstrained matching) induced by Jaccard weight from green algae dataset

TABLE I. DISTRIBUTION OF CONFLICTS FOR UNCONSTRAINED MATCHING AND MATCHING WITH CROSSING CONSTRAINTS

		Conflicts				
		Mean	**St dev**	**Q1**	**Q2**	**Q3**
Matching	**Symmetric**	216,32	60,86	176,75	205,00	252,00
	Jaccard	141,69	48,91	103,00	142,00	174,25
Matching with crossing constraints	**Symmetric**	202,40	60,14	163,00	190,50	238,25
	Jaccard	91,05	38,31	63,00	85,00	113,25

Table I). It is worth noting that not a single instance ended up having no conflicts. Also, the distances we computed agreed with the values obtained by unconstrained matching. Following the previous experiment, we have also tested how does green algae dataset perform with arboreal matching and Jaccard induced metrics of order 1 against the same metrics without explicitly enforcing semi-independent constraints. The distance distributions are shown in Fig. 10 while the number of produced conflicts is located in Table I. Like before, no matching was conflict-less, which indicates the importance of enforcing the semi-independent constraints in computation of the arboreal matching.

C. Distribution details and running times

In Figs. 12 and 6 we present the distance distributions for 10000 random trees from uniform distribution using arboreal matching with symmetric difference and Jaccard weight, respectively. For both dissimilarity measures around 99 percent of the distances fall within 3 standard deviations around the mean while around 95% and 40% of the distances are within 2 and 1 standard deviations, respectively. This may infer that both symmetric difference and Jaccard weight induce comparable resolution. Fig. 11 gives a plot of running times (Trajan) for each of the dissimilarity measures with the values sorted by symmetric difference running time. It is clear that the empirical running times are in favor of Jaccard weight by quite a margin. Summary for the dataset is given in Table II.

Trees with 50 leaves from Yule distribution yield similar results and the main results are summarized in Table II. We can see that the "resolution" is similar regardless of the dissimilarity measure used while the running times are again lower for the Jaccard weight. We have presented the results of the remaining random datasets, namely 1000 uniform and Yule instances with 75 and 100 leaves in Table III.

Figs. 8 and 9 (blue) depict distance distributions for the green algae dataset. The distance induced by symmetric difference has a mean of 580,05 and a

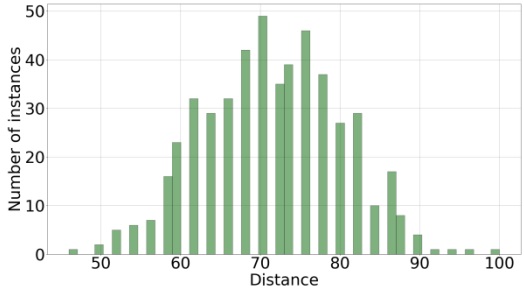

Figure 7. Distribution of the RF distances of green algae instances

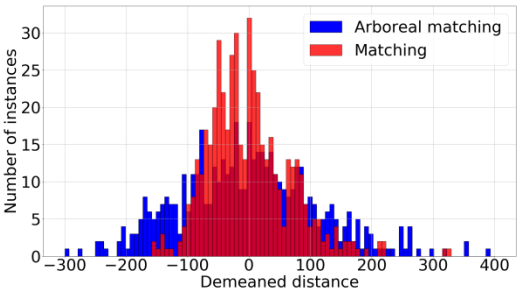

Figure 9. Demeaned distribution of distances (arboreal matching and unconstrained matching) induced by symmetric difference from green algae dataset

TABLE II. SUMMARY FOR THE RANDOM 50 LEAF DATASETS

		Distance		% of data within n-th st dev			Running time (s)		
		Mean	**St dev**	**1**	**2**	**3**	**Min**	**Mean**	**Max**
Uniform 50	**Symmetric**	589,37	72,87	40,06	95,66	99,02	3,85	50,46	565,53
	Jaccard	84,75	2,77	39,15	95,52	98,88	0,17	3,98	92,54
Yule 50	**Symmetric**	425,40	28,46	38,06	95,27	99,46	2,10	22,59	189,23
	Jaccard	83,92	1,72	38,33	96,58	99,48	0,09	0,85	21,14

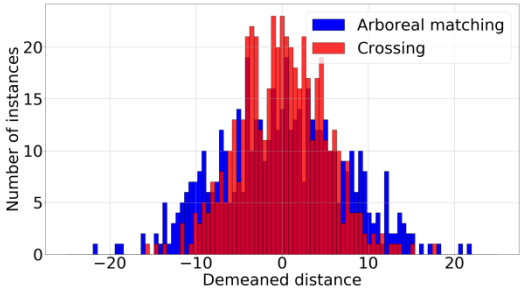

Figure 10. Demeaned distribution of distances (arboreal matching and crossing) induced by Jaccard weight from green algae dataset

standard deviation 113,80 while the Jaccard distances have a mean 52,91 and standard deviation 7,21. Both distributions have more than 99% of their values within 3 standard deviations while Jaccard has 96,6% within 2 and 66% within 1. On the other hand, symmetric difference places 94,99% of the distances within 2 standard deviations and 69,34% within one. Similarly to the random trees, the computation time for green algae instances largely favored Jaccard weight which mean time was 4,77 seconds as opposed to 459,05 seconds required for symmetric difference. The extremes were relatively close to mean for Jaccard with a minimum of 0,65 seconds and a maximum of 24,40 seconds. Unlike the former, symmetric difference saw a minimum of 14,64 seconds, which was even quite above the mean for Jaccard, and a maximum of 4210,82 seconds.

The common trend for all data is that Jaccard weight and symmetric difference offer comparable resolutions while the running time of symmetric difference is larger.

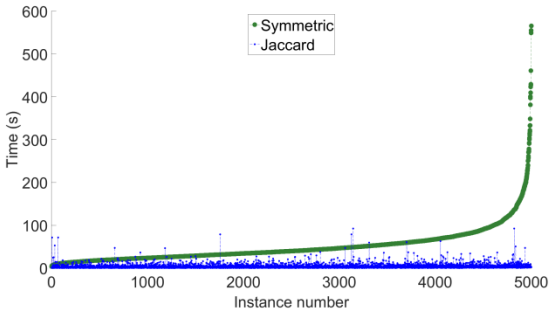

Figure 11. Running times of 50 leaf instances from uniform distribution with symmetric difference and Jaccard weight

IV. CONCLUSION

We have tested the properties of the metrics induced by symmetric difference and Jaccard weight which did honor ancestry relations. Both have been tested on simulated and real world datasets for the differences in "resolution", i.e. how well can the metrics discern between various trees, relations to other metrics such as RF and MC, and running time. We have concluded that the "resolution" of both metrics is similar while the running time favors Jaccard weight by a large margin.

Since RF metric can be generalized to more complex hierarchies such as directed acyclic graphs (DAG) it opens an avenue for further research. Since, as well as phylogenetic trees, DAGs are data structures which describe a lot of biological processes and it would be beneficial to study the distances between them in the context of generalized RF metric.

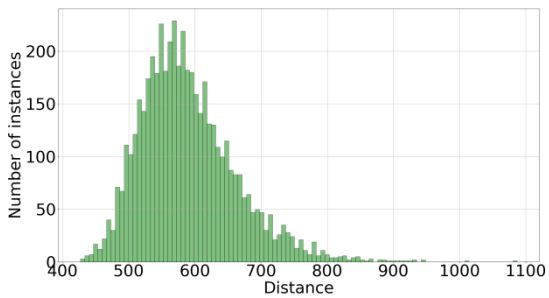

Figure 12. Distribution of the distances from 50 leaf uniform distribution using symmetric difference

TABLE III. MAIN RESULTS FOR THE RANDOM 75 AND 100 LEAF DATASETS

		Dataset and dissimilarity measure							
		Uniform75		Yule75		Uniform100		Yule100	
		Sym	Jaccard	Sym	Jaccard	Sym	Jaccard	Sym	Jaccard
Distance	Mean	1138,46	132,32	753,88	129,34	1830,27	179,18	1124,18	174,52
	St dev	141,42	3,30	43,76	1,89	243,41	3,53	60,56	2,00
% of data within n-th st dev	1	45,50	40,60	41,00	35,60	39,40	37,80	37,88	41,80
	2	94,20	94,20	95,40	96,20	95,80	94,00	95,79	94,80
	3	98,80	98,40	99,20	99,00	99,20	99,80	99,40	99,60
Running time (s)	Min	43,09	0,30	16,86	0,20	221,39	0,57	82,61	0,22
	Mean	379,50	23,35	163,31	1,66	2514,42	103,05	1000,10	4,27
	Max	5676,33	1990,04	3266,62	22,07	27071,3	5947,51	35059	75,38

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Evaluation of User Satisfaction with the ECGalert System

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***Abstract*—This paper offers an insight on user satisfaction with ECGalert, a heart monitoring service based on a wearable device. We report results from a survey that gathered the opinions of both the patients and doctors, as well as the evaluation of user experience on a random sample. In addition, several other events were organized to include a random sample of the general population, including screenings on three different events: world heart day, a marathon and a stair climbing competition. The results show that the majority of respondents have a positive attitude towards telemedicine systems. A very interesting fact is that even the older population is keen on change of the attitude towards a new and improved technology, mostly due to the increased comfort and new offered possibilities for real-time monitoring.**

***Index Terms*—Cloud Computing, ECG, User experience,**

I. Introduction

ECGalert [1] is an innovative wearable heart monitoring system that provides users the tools to continuously monitor their health with the aid of modern technology. The system uses Bluetooth communication to exchange data between the ECG sensor and the mobile application. Once received by the smartphone application, the data is uploaded to the Cloud server, where further processing is performed enabling real-time remote monitoring and examination.

The system can detect several heart problems, arrhythmia and health concerns, such as several ventricular or supraventricular beats, as well as arrhythmia rhythm episode identification, including normal sinus rhythm, atrial fibrillation, bigeminy, trigeminy, ventricular or supraventricular tachycardia, couplets, long runs etc.

Recommendations on ECG monitoring [2] include continuous short-term recorders (up to 24 or 48h) or intermittent long-term measurements (up to 2 years). Almost all available device for ECG monitoring can process data and enable examination and monitoring after the measurement is done. When the patient returns the monitor; the data stored within the flashcard memory are digitized and downloaded to a local workstation or transmitted over the Internet to a central workstation. Only then can it be determined whether the ECG tracings were of adequate quality and whether any diagnostic information was obtained. The computer-scanned Holter recording is read by a trained technician who then forwards the report to the physician for final review and official interpretation. Mittal et al. [3] describe a spectrum of ambulatory external electrocardiogram (AECG) monitoring modalities, as presented in Fig. 1.

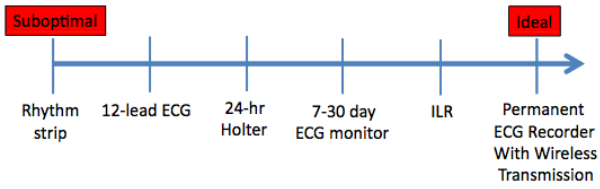

Fig. 1. Spectrum of AECG monitoring modalities [3]

ECGalert is a medical device that offers an online continuous monitoring tool. Recorded data is offered to a physician for analysis and examination without waiting for the measurement to finish the ECG. According to the spectrum presented in Fig. 1, ECGalert is classified as the *ideal medical device* for external ECG monitoring.

The question whether ECGalert will fully replace the outdated Holter monitors as medical devices for short-term heart monitoring and implantable loop recorders as medical devices for long-term heart monitoring largely depends on good user experience and acceptance by the users. ECGalert is intended as an essential and indispensable component for longer measurements, especially in cases where arrhythmia can not be detected if the patient is monitored by conventional methods, or invasive techniques must be used.

Ives et al. [4] define user satisfaction as ”the extent to which users believe the information systems available to them meets their information requirements”. In this paper, we measure the satisfaction of the participants using the survey and interview methods.

Norman et al. [5] define user experience as ”encompassing

all aspects of the end-user's interaction with the company, its services, and its products". We aim to maximize our user experience by assessing the needs of our target demographic and incorporating their requests into our products.

Usability is defined as the ease of access and ease of use of a product. It is a very important factor in our analysis, since our goal is to identify how the new wearable monitor is accepted in comparison to outdated wired technology. However, comfort is not our only motivation, since the overall service includes a wide set of features such as real-time continuous monitoring and an integrated alerting system. For these reasons, it is evident that a seamless and pleasant user experience is of crucial importance, because we believe it may significantly speed up the process of acceptance in the general population.

The goal of this study is to evaluate the openness and acceptance of modern telemedicine approaches by the older population, as well as the user satisfaction of our target demographic. Furthermore, we took advantage of this opportunity to perform a more thorough analysis of ECGalert in regard to its success in correctly identifying arrhythmia.

In this paper we present our findings and some related statistics regarding the user experience and satisfaction with ECGalert.

The structure of this paper is as follows. Related work is presented in Section II and the ECGalert system is explained in detail in Section III. Our methodology is explained in Section IV. Section V presents the results. Finally, a discussion is given in Section VI.

II. Related work

A nice overview of modern commercial ECG sensors is presented by Trobec et al. [6], especially regarding devices that use a reduced number of leads and can be attached to the user's chest as wireless body sensors.

The primary goal of long-term monitoring is the improvement of the diagnostic yield [7], which is lately performed by ultra-portable devices referred to as ECG patch monitors.

Lobodzinski [7] concludes that portable monitoring devices have attracted a lot of interest and attention for evaluating cardiac rhythms in real-world environments such as the workplace or home, by making radical miniaturization and redesign of wireless, waterproof wearable devices.

Fensli et al. [8] present a new approach for measuring patient acceptance of wearable sensors which they named the Sensor Acceptance Model. They argue that it is of great importance to compare new technologies to more traditional methods through a patient acceptance study. Four relevant dimensions measured by 19 items are defined in their study, in order to assess the patients acceptance of using a new type of wearable medical equipment.

Steele et al. [9] focused on performing qualitative research into the perceptions, attitudes and concerns of elderly persons towards wireless sensor telemedicine solutions. They focused their study on independent elderly people, where they noted their attitude as generally positive. Furthermore, they concluded that independence is highly valued by elderly people and therefore any technology that can prolong that independence is highly regarded. Additionally, privacy of health data appears to not present great importance to this demographic. They also found that cost is the most prominent determining factor influencing their acceptance of wireless telemedicine solutions.

Vaganas et al. [10] explore the advantages and shortcomings of a transnational telephonic ECG system. They note high physician acceptance of the system application. However, according to their study, only 80% of the recorded ECG were of good or moderate quality, with the remaining 20% being impossible to interpret. They concluded that their data showed high acceptance rates among the patients, with a slightly lower acceptance rate among the physicians because of the increased number of unnecessary telephone calls. However, the authors argue that this increased number of calls is a sign of significantly lowered numbers of unnecessary hospital visits.

Sinnapolu et al. [11] propose a real-time system that can monitor heart activity in drivers. Their goal is to reduce the number of deaths caused by persons who experience a heart attack while driving. Their idea is an example of medical challenges solved by IoT and cloud computing.

Wildenbos et al. [12] emphasize the impact of well-designed user interfaces for applications that are aimed at the elderly. Design elements such as simplicity, big-enough buttons and intuitive navigation are among the most important details when creating a user interface. However, they find that the elderly often experience additional challenges which can not be overcome by the application design. Anxiety caused by technology, lack of computer literacy, as well as physical impairments of the user are the most common factors that keep users from taking advantage of innovative mHealth solutions.

Baladin et al. [13] give a detailed analysis of the main trends in mHealth. They present multiple use cases where this technology may be applied in both developed and developing countries. The paper also provides comprehensible clustering of mHealth applications in four different categories depending on their purpose. Most notably, the authors propose a new approach to monitoring health parameters by measuring health data on airplanes.

III. Description of the ECGalert system

ECGalert [1] is a medical device that serves as a heart monitoring system that comprises of several components. The first element in the overall system is the wearable SAVVY ECG sensor [14], which is a replacement for the traditional heavily-wired heart monitor. It can be attached to the body in multiple positions using medical-grade electrodes. The sensor samples the ECG measurements and transfers them to the connected mobile device over a Bluetooth connection.

The mobile application stores the data transmitted from the SAVVY ECG sensor. Once the data is received, it is neatly displayed in a live graph which represents the current ECG signal. The user has the ability to monitor their heart, as well as the option to mark an event of significant heart activity.

GENERAL INFORMATION		HEART RATE		PAUSES AND ABERRANT BEATS	
Analyzed Beats	2980	Min HR-4	62 BPM at 27.10.2017 00:27:33	SA Total	0
Total Recording Duration	00:28:51	Max HR-4	190 BPM at 27.10.2017 00:11:51	Maximum SA	/
Normal Sinus Rhythm Duration	(0.00 %) 0s	Average HR-24 Hours	103 BPM	Micro SA Total	0
ECG Monitoring Start	27.10.2017 00:00:00	Min HR-Hourly	103 BPM at 27.10.2017 00:00:00	Total Aberrant Beats/Runs	2
ECG Monitoring End	27.10.2017 00:29:00	Max HR-Hourly	103 BPM at 27.10.2017 00:00:00		

HRV - TIME DOMAIN		HRV - FREQUENCY DOMAIN		HRV - OTHER	
SDNN	178 ms	ULF	838 ms^2 peak at 0.000 Hz	Poincaré SD1	181.65 ms
ASDNN	11 ms	VLF	2617 ms^2 peak at 0.008 Hz	Poincaré SD2	201.99 ms
SDANN	34 ms	LF	4533 ms^2 peak at 0.045 Hz	Poincaré SD1/SD2	0.9
NN50	1509 / 1931	HF	9186 ms^2 peak at 0.109 Hz	DFA $\alpha 1$	0.68
pNN50	78 %	HF/LF	0.493	DFA $\alpha 2$	0.62
rMSSD	212 ms				

VENTRICULAR ECTOPIES		SUPRAVENTRICULAR ECTOPIES		ATRIAL FIBRILLATION	
VE Total	445	SVE Total	2	Number of episodes	21
VE-Pair Total	64	SVE Pair Total	0	Total duration	00:23:18.1 (80.78 %)
Short V-Runs (3≤n<6)	19	Short SV-Runs (3≤n<6)	0	Longest duration	00:04:41.2 at 27.10.2017 00:19:14
Long V-Run Total (n≥6)	2	Long SV-Run Total (n≥6)	0	Min HR	67 BPM at 27.10.2017 00:23:29
Longest V-Run	9 at 27.10.2017 00:04:51	Longest SV-Run	/	Max HR	183 BPM at 27.10.2017 00:01:00
Min HR Long V-Run	167 BPM at 27.10.2017 00:04:51	Min HR Long SV-Run	/		
Max HR Long V-Run	188 BPM at 27.10.2017 00:25:40	Max HR Long SV-Run	/		
VE's per 1000	149	SVE's per 1000	1		
VE's per Hour	926	SVE's per Hour	4		

ATRIAL FLUTTER		VENTRICULAR TRIGEMINY		VENTRICULAR TACHYCARDIA	
Number of episodes	2	Number of episodes	1	Number of episodes	21
Total duration	00:05:01.8 (17.44 %)	Total duration	3.6s (0.21 %)	Total duration	27.2s (1.57 %)
Longest duration	00:04:40.2 at 27.10.2017 00:12:30	Longest duration	3.6s at 27.10.2017 00:10:40	Longest duration	3.6s at 27.10.2017 00:04:50
Min HR	69 BPM at 27.10.2017 00:15:55	Min HR	112 BPM at 27.10.2017 00:10:43	Min HR	160 BPM at 27.10.2017 00:01:29
Max HR	163 BPM at 27.10.2017 00:16:09	Max HR	112 BPM at 27.10.2017 00:10:43	Max HR	192 BPM at 27.10.2017 00:01:41

Fig. 2. An example of summary information presented in the ECGalert report

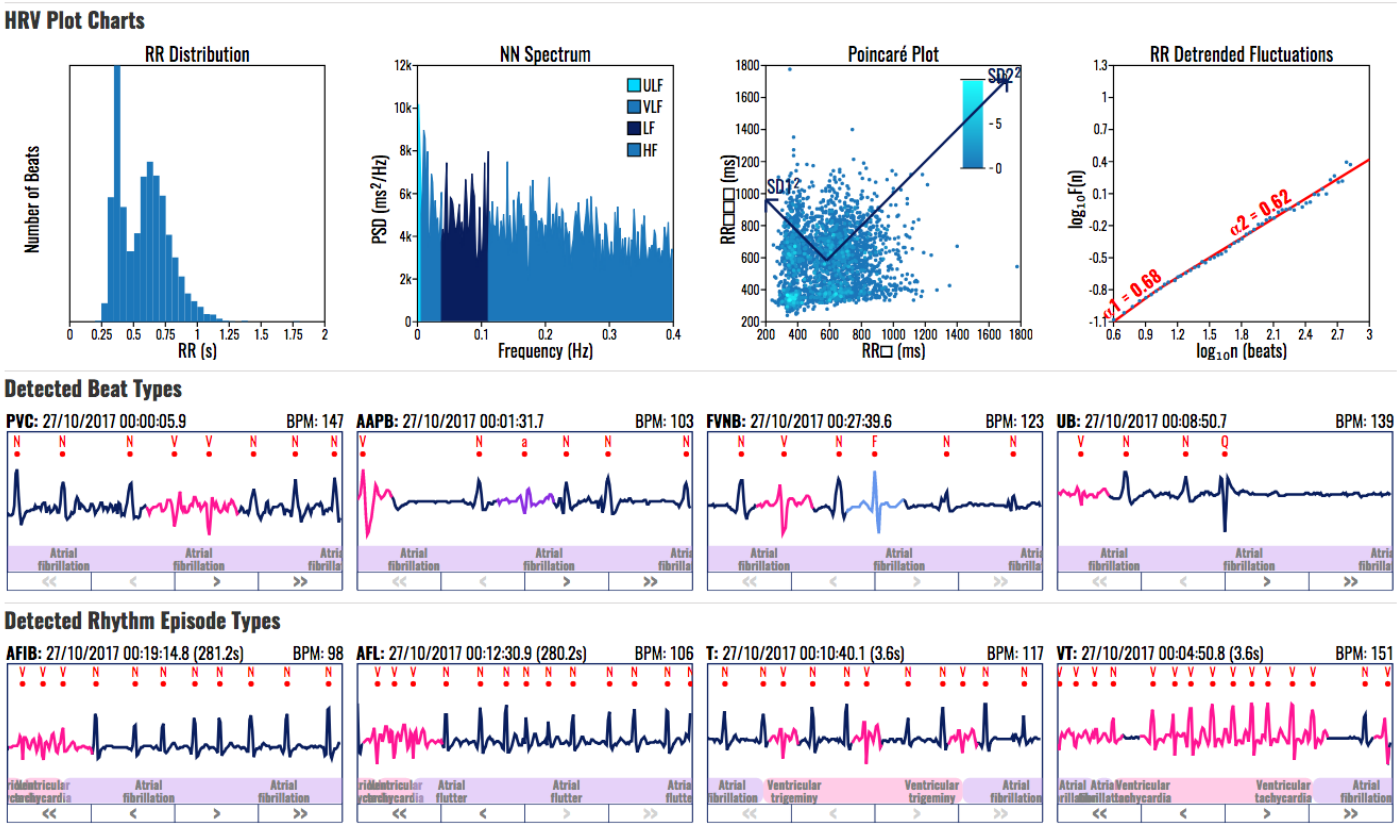

Fig. 3. An example of HRV charts and characteristic beat types and rhythm episodes presented in the ECGalert report

Once the user connects to Internet, the ECG recording will be uploaded to the cloud for further processing. The cloud service analyzes each recording in 30s segments where beats and rhythm episodes are classified into several categories which are later presented to the user in the Web application.

The background cloud-based service on the smartphone can collect and monitor measurements from a SAVVY ECG sensor, process and store them securely on a private-cloud site. The service includes the conversion of the time-aligned ECG measurements into common medical data formats ready for further exploitation in various applications. Our product uses arrhythmia classification based on the decision tree classical approach for its analysis.

The ECGalert system can detect and classify the following beat types:

- Normal,
- Ventricular,
- Supraventricular, and
- Fusion of Ventricular and normal beats;

as well as the following types of rhythm episodes:

- Bigeminy,
- Trigeminy,
- Supraventricular (atrial) ectopies,
- Atrial fibrillation and flutter,
- Ventricular tachycardia and fibrillation.

The ECGalert data analytics service can process ECG data files and generate information files on detected heartbeat types and rhythm episodes. Our solution includes a superior service for QRS detection, advanced beat classification and extended rhythm episode analysis. A typical example of a report is presented in Fig. 2. Fig. 3 presents HRV-related charts and characteristic beat types and rhythm episodes.

The resulting files are stored in a conventional textual format which is passed to the statistical module that computes the number of occurrences, their type and length, average, minimum and maximum rate, and other relevant statistical information such as SDNN, ASDNN, SDANN, NN50, pNN50, rMSSD, HR-4 and HR-24. The data analytics has been proven to be accurate in detection of Normal, Ventricular, Supraventricular (Atrial) and fusion beat types, as well as the detection of multi-variant ventricular forms. The rhythm analysis section successfully detects ventricular-run episodes, bigeminy, trigeminy, supraventricular (atrial) ectopies, including bigeminy, trigeminy, as well as atrial fibrillation and flutter, ventricular tachycardia and fibrillation. For all identified rhythm episodes the ECGalert system determines the duration, start time, average heart rate within the duration of the rhythm episode, a quantification number of atrial and ventricular ectopies, information about shortest, longest and average duration of rhythm episodes, etc.

The system supports the classification of heart arrhythmia as problematic, dangerous or life threatening. The integrated alerting system will automatically contact the concerned patient, instructing them to see a doctor within a certain time frame - a week, one day, or immediately - depending on the severity of the arrhythmia.

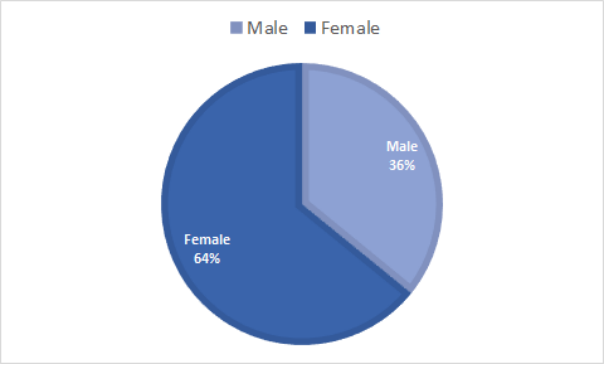

Fig. 4. Ratio of female and male participants

max age	88
min age	21
avg age	66.55
std dev	11.20

TABLE I
SAMPLE USED IN OUR SURVEY AND INTERVIEW

IV. METHODOLOGY

In this paper we do not analyze direct methods, and depend on the conducted survey and interview methods as measurements of user satisfaction and user experience. Questionnaires and interviews are indirect measuring methods if usability is analyzed [15], since the focus is not on the user interface functions, but rather on the opinion and experience of the users.

A. Conducting the survey and interviews

For our study we screened 78 people for common heart arrhythmia and other heart health problems. The study was conducted on September 29th, 2018 in Skopje, Macedonia and the event had a duration of 2 hours. The screening was conducted free of charge in light of World Heart Day. The goal was to carry out a screening of the older population. The average age of the screened population was 66.5 years old, as presented in Table I. Approximately 63% of the screened participants were female.

Only 52 participants agreed to be interviewed and participated in our survey regarding their experience with the device.

The screening was performed so that a SAVVY ECG sensor was placed on each patient, and their ECG was recorded for a duration of 5 to 10 minutes. A doctor monitored the heart activity using our mobile application, and made decisions based on the ECG signal. Later on, the recorded ECG signals were analyzed by additional doctors through our online monitoring tool, and they further confirmed the automated detection of arrhythmia. During user satisfaction evaluation and throughout the whole event, ECGalert [16] was used to provide doctors and patients with the tools to carry out the screening.

TABLE II
THE CONTENT OF THE CLOSED QUESTIONED SURVEY

ID	Question
Q1	What is your general satisfaction from the ECGalert system?
Q2	Do you have any previous experience with traditional heart monitoring devices?
Q3	How would you rate your experience with ECGalert?
Q4	Is there another feature you would like to see included in our product?
Q5	Would you recommend our product to a friend?

B. Designing the Survey and Interviews

The goal of the survey was to be able to evaluate the familiarity of the general population with traditional heart monitoring devices, as well as assessing their experience and acceptance of modern and innovative solutions such as ECGalert.

We designed the questions keeping in mind that not everyone may have knowledge of the disadvantages of traditional methods of heart monitoring such as reduced mobility, discomfort and low usability. We also took advantage of this opportunity to receive constructive feedback on our product, appraising the needs of the end user.

C. Other methods

Our company has previous experience with the organization of massive screening events. The first such event took place during the annual Skopje Marathon in 2017. Twenty five participants were fitted with the SAVVY ECG sensor before running the 5km and 20km marathon, and the sensor recorded their heart activity throughout its duration.

The average length of the measurement was 30 minutes for the 5km marathon and 90 minutes for the 20km marathon.

The stair climbing event was held on October 11th, 2018, as a competition where thirteen participants were fitted with the wearable SAVVY ECG sensor. Their heart activity was recorded for the duration of the competition. The shortest time required to climb 12 floors was about one minute and the worst was two minutes. These measurements were then processed by our system and reviewed by our doctors.

All participants were interviewed for their user satisfaction and experience. The participants were only required to describe their comfort level and whether they found the device easy to use. The main goal was to test the performance and user acceptance of the system, as well as conduct a free evaluation of heart health for the participating individuals.

V. RESULTS

This section presents the results from the realized survey, and analysis of the interviews. This section only presents data collected on September 29th.

A. Survey

Out of the 78 people we screened, our doctors were able to diagnose 16 patients with arrhythmia, heart disease or irregularities. 62.8% of the participants were female as presented in Fig. 4 and Table I, and 83% of the patients were in the age range of 50 to 75. All recordings were of good quality and were successfully interpreted by our participating doctors.

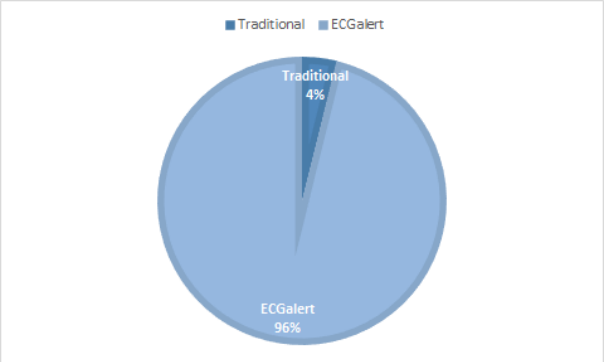

Fig. 5. User preference

From the results we observed that 48% of the surveyed participants had previous experience with traditional heart monitoring devices such as the Holter.

96% of the surveyed participants with previous experience with traditional heart monitors rated their experience with ECGalert as superior to traditional methods, as shown in Fig. 5.

They noted the measuring was more comfortable and they noticed increased mobility. The process was rated as ”easier and quicker”. The remaining 4% rated our product as equal to more traditional methods.

55.7% of the surveyed participants reported that they had personally purchased health monitoring devices in the last 5 years.

B. Other methods' results

The two additional events also provided us with important data that was used to further improve our system. Evaluation and constant advancement of our beat detection and classification system is crucial for increasing user satisfaction.

Interviewed participants were happy to use advanced online remote monitoring medical devices, especially because most of them were young and had previous experience with similar heart rate measurement devices. They were pleasantly surprised that the device itself does not limit movement or the ability to partake in physical activities. Since the use of smartphones is more common in this demographic, the participants showed a positive attitude toward the ECGalert system.

C. Results from the marathon event

Six participants out of 25 did not use the medical device properly (the electrode was disconnected, or due to sweat it had lost contact).

The other nineteen participants recorded their measurements and were analyzed while they were running.

The ECG records on seven participants were with a lot of noise due to muscle movement, and did not have sufficient

quality to be interpreted, while the remaining twelve ECG records where sufficient.

Besides the real-time monitoring, one of our doctors later reviewed the measurements in detail, and analyzed arrhythmia and irregularities detected by ECGalert. Exceptional cases included a case where one of the participants experienced arrhythmia after running, and another that started experiencing long pauses after the physical activity. The remaining participants showed good heart activity.

D. Results from the stair climbing event

During the stair climbing competition our system most commonly detected PAC and PVC beats, and most often episodes of ventricular bigeminy, ventricular trigeminy, supraventricular and ventricular tachycardia. The heart rate increased when the participants climbed higher floors.

Interestingly, a dangerous arrhythmia was detected in one of the patients. He was treated immediately by our doctor.

VI. Discussion

Some of the participants were referred for further examination to establish a more detailed analysis of their heart condition, and in-depth analysis of other relevant factors which include echocardiography among other methods.

Only 48% of the patients that were surveyed stated that they had previous experience with traditional heart monitoring devices such as the Holter monitor.

Only one of the participants answered that they would like an additional feature added to the system, suggesting that we incorporated blood pressure measurements in our device.

All of the surveyed participants answered that they would recommend ECGalert to a friend.

The participating doctors consider our product highly regarded, as it significantly reduces the time to diagnosis. Additionally, continuous 24-hour monitoring allows users to be easily diagnosed even if their symptoms appear in irregular intervals.

VII. Conclusions

We conducted a survey with the screened patients, as well as interviews with the participating doctors as a method of evaluation of user satisfaction.

Overall, our findings imply that ECGalert has been accepted by the population and will increase the quality of life by making affordable personalized health-care and real-time continuous heart monitoring accessible to the general population.

Additionally, the study also reveals some hints on how to improve the overall service, such as combining blood pressure and glucose measurements in addition to the ECG.

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Performance Evaluation of Atrial Fibrillation Detection

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***Abstract*—Atrial Fibrillation (AFib) is one of the most common cardiovascular diseases that can cause serious consequences if it is not treated on time. Although AFib is defined as an irregular rhythm with the absence of P waves in the electrocardiogram signal, still the algorithms for AFib detection are not perfect. When analyzing the state-of-the-art literature, we found several problems in identification consistent methodology that will allow comparison of different methods. The inconsistency problems are found in defining the set of benchmark tests and in interpretation of the key performance indicators.**

In this paper, we present three different methodologies and argue which key performance indicators should reveal the best performance evaluation. Choosing the F1 score allows conveying the balance between the positive predictivity value (precision) and sensitivity (recall). Also, we found that the way the true and false positives, and true and false negatives are determined varies from one approach to another and argue on which performance evaluation approach is the most relevant.

***Index Terms*—Atrial Fibrillation, ECG, performance evaluation**

I. Introduction

Atrial Fibrillation (AFib) is an abnormal heart rhythm characterized by rapid and irregular heartbeats. Approximately 2% of people younger than age 65 are diagnosed with AFib and about 9% of people aged 65 years or older [1]. The early detection of AFib is crucial for people who suffer from cardiovascular diseases, the elderly or stroke patients to whom second stroke prevention is of primary importance [2]. Multiple algorithms for automatic detection of AFib have been developed and tested in terms of various statistical measures of performance.

The methodologies of performance evaluation of AFib detection algorithms are based on the following: 1) the selection of the key performance indicators among various statistical measures, 2) calculation method within detection of AFIB, and 3) selection of the testing and learning dataset.

The most frequently encountered statistical measures are Sensitivity, Specificity, and Positive Predictivity Value, although some use accuracy or other relevant indicators. Some have used accuracy, or specificity measures, the others sensitivity only, without positive predictivity rate. And some authors show that their algorithms reach high sensitivity values (over 95%), although the achieved positive predictivity rate is low.

The calculation methods may differ by a selection of an evaluation parameter, including the following: 1) evaluating to which episode each detected beat belongs, 2) the number of detected episodes and 3) the duration of the detected episode.

Many authors use different datasets, analyzing, one or more different reference databases, including a selected set of records, training the algorithms on a particular set and then testing it on the remainder of the set.

Several reference electrocardiogram (ECG) annotated databases are used for testing of developed AFib detection algorithms. The most used and recommended are found on the Physionet's web site [3], including the MIT-BIH Arrhythmia (MITDB), MIT-BIH Atrial Fibrillation (AFDB) and MIT-BIH Normal Sinus Rhythm (NSRDB) Database.

A typical researcher or development company faces a problem to find what is the best solution among a lot of results published in different papers. Therefore, in this paper, the research question is to find a performance measure that will enable easy evaluation and comparison to other algorithms. Our objective is to analyze the performance evaluation methods to detect AFib detection, and discuss relevant key performance indicators.

For this purpose we specify three different methods for performance evaluation and discuss their advantages and problems.

The paper follows the next structure. Section II gives the background and explains the stastical measures and their application. Related work is presented in Section III. Section IV introduces three methods for performance evaluation of Afib detection. The obtained results are analyzed and discussed in order to reveal which performs better in Section V, along with analyzes of problematic issues in choosing the datasets. The conclusions and future work directions are presented in Section VI.

II. Background

This section explains used statistical measures and datasets in performance evaluation of AFib.

A. Selection of statistical measures

Statistical measures that are most frequently used for identifying the correctness of detection methods in medicine are

sensitivity, specificity, positive predictivity value and accuracy [4],[5].

The first step in calculating the performance of one proposed diagnostic method is seeing how the results are compared to the real patient results. This yields the following fundamental terms for test performance [6]:

- *TP* (true positive) - the rhythm episode is present in the reference case, and the testing algorithm detects it correctly,
- *FP* (false positive) - when the reference case does not contain a rhythm episode that the testing algorithm detects,
- *FN* (false negative) - the rhythm episode is present in the reference, but the testing algorithm does not detect it,
- *TN* (true negative) - the rhythm episode is not present in the reference case and the testing algorithm also does not detect its existence.

The following measures are being widely used in performance evaluation.

Sensitivity (SEN), also known as hit rate or true positive rate (TPR), measures the proportion of correctly identified positive cases (sequences correctly classified as AFib) in regards to the actual number of positive cases (all sequences identified as AFib) and is calculated by (1).

$$SEN = \frac{TP}{TP + FN} \tag{1}$$

Specificity, calculated by (2), measures the proportion of negative cases that are correctly classified (sequences correctly classified as not AFib) versus the total number of negative cases (all sequences identified as not AFib) in the observed sets.

$$SPC = \frac{TN}{TN + FP} \tag{2}$$

Positive Predictivity Value (PPV), also known as precision, is the proportion of positive results that are true positives (sequences correctly classified as AFib) in regards to the total number of positive results (both true and false positives) acquired with the detection method, calculated by (3).

$$PPV = \frac{TP}{TP + FP} \tag{3}$$

Accuracy (ACC) is calculated by (4) as the proportion of correct results including both the true and false positives (correctly classified sequences) in regards to the total number of sequences analyzed by the detection method.

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \tag{4}$$

A statistical measure of a test's accuracy that combines SEN and PPV is known as F1 score. The F1 score, also called F score or F Measure, is calculated by (5) and it represents the harmonic mean of the precision and sensitivity.

$$F1 = 2 \cdot \frac{PPV \cdot SEN}{PPV + SEN} = \frac{2 \cdot TP}{2 \cdot TP + FP + FN} \tag{5}$$

The usual method to detect randomness of a signal and data stream is Shannon Entropy. It is successfully applied to detect the presence of AFib in patients. The analyzed data stream consists of RR intervals from a patient's ECG record, and the presence of AFib can be diagnosed by comparing the calculated entropy to a predefined threshold value. There are other methods based on ML or similar methods. In this paper, we are interested in the performance evaluation, and not in the method AFib is detected.

B. Selection of datasets

Three datasets have been widely used in previous AFib detection: MIT-BIH arrhythmia (MITDB) and MIT-BIH Atrial Fibrillation Database (AFDB), and Normal Sinus Rhythm (NSRDB) freely available on PhysioNet [3]. Their details are presented in Table I.

TABLE I
ECG DATABASES FOR TESTING IN OUR EXPERIMENTS

MIT BIH Database	Arrhythmia MITDB	AFib AFDB	Normal NSRDB
Records	48	25	18
Records with AFib	7	25	0
N. of Afib episodes	43	25	0
Duration of Afib	98:30:50.4	2:08:31.3	0:00:00.0
Record length	30 min	10h	20-24h
Sampling frequency	360 Hz	250 Hz	128 Hz

The NSRDB is used to evaluate the correctness of a method when it is being used on patients with normal heartbeats and to find the level of false diagnostics the proposed testing method makes. AFDB is used to test the performance of a method when Atrial Fibrillation is strongly present in the observed population because all of the records are records with AFib present. The Arrhythmia database contains records from patients with multiple arrhythmic conditions and is suitable to test how the algorithm performs in a set of patients with various arrhythmia.

III. RELATED WORK

Many authors have tackled the problem of Atrial Fibrillation and have used different techniques and metrics to account for the method's acceptance. Table II presents the analysis of related work in relation to different databases used and a different set of statistical parameters.

Lee and al. [7], tested the proposed method on portions of four datasets: the MITDB, AFDB, NSRDB and a custom-made clinical 24-hour Holter AF database with 25 records. The metrics used to evaluate the performance of the algorithm were sensitivity and specificity, without analyzing the positive predictivity rate.

The method proposed by Zhou and al. [8] uses four publicly-accessible datasets for training and testing. The method is trained on the Long-term AF database and is tested on all the files from MITDB, AFDB, NSRDB. It uses all relevant statistical parameters (sensitivity, specificity, positive predictivity value, and overall accuracy).

Afdala et al. [9] evaluates the performance of their algorithm on AFDB in terms of accuracy, sensitivity, and specificity, without analyzing it on other two datasets.

TABLE II
DATABASES AND METRICS USED BY DIFFERENT AUTHORS FOR PERFORMANCE EVALUATION OF AFIB DETECTION

Author	MIT-BIH AFIB database (AFDB)				MIT-BIH Arrhythmia database (MITDB)				MIT-BIH NSR database (NSRDB)			
	SEN	SPC	ACC	PPV	SEN	SPC	ACC	PPV	SEN	SPC	ACC	PPV
Lee et al. [7]	98.2%	97.7%	-	-	91.1%	89.7%	-	-	/	99.7%	-	-
Zhou et al. [8]	96.89%	98.25%	97.67%	97.62%	97.33%	90.78%	91.46%	55.29%	/	98.28%	-	-
Afdala et al. [9]	91.04%	89.01%	89.79%	-	-	-	-	-	-	-	-	-
Dash et al. [10]	94.4%	95.1%	-	-	90.2%	91.2%	-	-	-	-	-	-
Petrucci et al. [11] RRP Episodes Duration	91% 93%	-	-	92% 97%	-	-	-	-	-	-	-	-
Petrucci et al. [11] DRR Episodes Duration	92% 89%	-	-	78% 90%	-	-	-	-	-	-	-	-

Dash et al. [10] use the MITDB and AFDB databases to test the algorithm for sensitivity and specificity, without analyzing the positive predictivity rate.

Standard ANSI/AAMI EC57 established a method for testing and reporting the performance of algorithms used to detect cardiac rhythm disturbances, including the ST segment [12]. The same measurement and evaluation methods are being described by the ANSI/AAMI/IEC 60601-2-47:2016 standard [13]. Particularly, it specifies the basic safety and essential performance of ambulatory ECG systems. Both these standards evaluate the performance of AFib detection based on a number of episodes and duration.

Petrucci et al. [11] follow these standards and evaluate the sensitivity and positive predictivity of the results for the two methods they propose in terms of episodes and in terms of duration. The first algorithm is RR prematurity (RRP) and the second delta RR (DRR).

IV. PERFORMANCE EVALUATION METHODS

Three methods and the corresponding performance evaluation metrics are proposed and described for AFib detection.

The performance metrics used in all these methods are Sensitivity and Positive predictivity value. The method is specified by the scope of how the corresponding statistical measures are calculated:

- analysis of beats,
- a number of episodes, and
- AFib episode duration.

They differ in the way the TP, FP, and FN are determined.

The first method is the *Beat oriented analysis* method, which is most frequently used and is based on a comparison of the detected rhythm episode to an analyzed beat compared (at a moment in time when a heartbeat occurred). This value is compared to the reference rhythm episode associated with the analyzed beat. The number of true positives is calculated as the number of beats associated with an episode for which, there is an overlap in time with those truly present in the test data-set. The number of false positives is equal to the number of beats associated with an episode for which the testing algorithm has detected an AFib episode, but there is no overlap with the reference database. Similar to this, the number of false negatives is the number of beats associated with an episode found in the reference algorithm for which there is no overlap with the testing algorithm.

The second proposed method is the performance evaluation in terms of *Number of episodes* which compares the number of detected AFib episodes versus the number of referenced AFib episodes present in the annotated ECG recordings. The number of true positives is calculated as the number of episodes for which, there is an overlap in time with those truly present in the test data-set. The number of false positives is equal to the number of episodes for which the testing algorithm has detected an AFib episode, but there is no overlap with the reference database, and the number of false negatives as the number of episodes found in the reference algorithm for which there is no overlap with the testing algorithm.

The final proposed method is the *Duration method* which compares the duration of the AFib episodes calculated by the algorithm in regards to the duration of the AFib episodes in the test database in terms of the two used metrics. In this method, the evaluation is performed based on the duration of overlap in detected AFib episode by both the reference and testing algorithm. The number of true positives is calculated as the duration period for which, there is an overlap in time with those truly present in the test data-set. The number of false positives is equal to the duration period for which the testing algorithm has detected an AFib episode, but there is no overlap with the reference database, and the number of false negatives as the duration period found in the reference algorithm for which there is no overlap with the testing algorithm.

The methods are tested on the files from the Physionet's [3] MITDB, AFDB and NSRDB. The obtained results are presented in a comparable fashion.

V. DISCUSSION

This section presents a visual representation and drawbacks of the three different methods for performance evaluation. This is followed by comparative analysis and selection of an optimal method.

A. Illustration of performance evaluation methods

Fig.1 illustrates the beat-based method. The performance evaluation is based on determining the Shannon entropy for each beat, and if it is above the threshold it is assumed that it belongs to AFib episodes, otherwise to Normal sinus

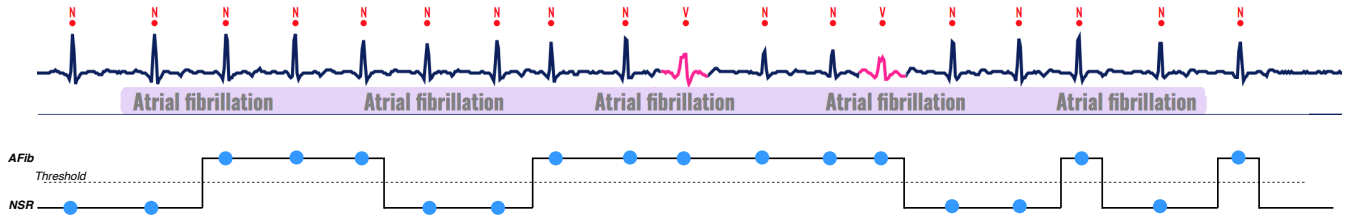

Fig. 1. Illustration of the beat-based method.

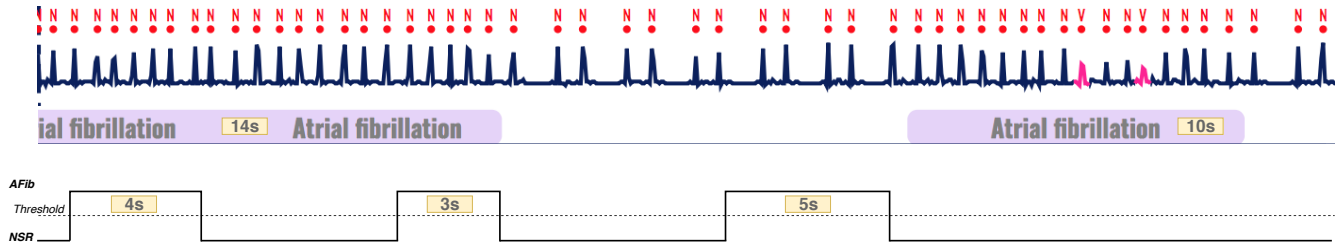

Fig. 2. Illustration of the episode and duration-based methods.

rhythm (NSR) episode. Note that in the figure, the first beat is TN (true negative, since the algorithm determined correctly NSR). The second beat is FN (since the algorithm has not detected the existence of AFib). The third beat is TP (since the algorithm correctly detected AFib). The last beat is FP (false positive), since the algorithm wrongly predicted AFib. The overall evaluation is then obtained by analyzing all the beats in TP, TN, FP, and FN categories, and calculating the SEN and PPV according to (1) and (3) correspondingly.

The example presented in Fig.1 results with 10 TP, 1 TN, 6 FN and 1 FP. This leads to a calculation of SEN=62.50%, meaning the algorithm has detected only 10 out of 16 beats that belong to AFib episode, and PPV= 90.91%, which means that the algorithm has only one false detection and ten correct.

Fig. 2 illustrates the performance evaluation using the episodes and duration-based methods. There are two AFib episodes in the analyzed segment and the algorithm detected three episodes. Only the first episode has an overlap with the detected AFib episodes, leading $TP_{Ref} = 1$, $FN_{Ref} = 1$ when analyzed from the reference annotations perspective, and $TP_{Test} = 2$ and $FP_{Test} = 1$ when analyzed from the testing algorithm annotations perspective. This leads to sensitivity SEN=50.00% meaning that only one episode is correctly detected out of two AFib episodes in reference annotations and PPV=66.67%, which means two out of three detected episodes were correctly detected.

However, applying the duration-based method, then $TP_{Ref} = 4 + 3 = 7sec$ and $FN_{Ref} = (14 - 4 - 3) + 10 = 17sec$ when analyzed from reference annotations perspective. When analyzed from testing algorithm annotations perspective then $TP_{Test} = 7sec$ and $FP_{Test} = 5sec$. The evaluation results are SEN=7/24=29.17%, which means the percentage of time the algorithm has correctly predicted AFib, and PPV=7/12=58.33%, as the percentage of the duration of correct versus all predicted AFib episodes.

TABLE III
RESULTS FROM THE TESTING METHODOLOGIES

Method	AFDB		MITDB	
	SEN	PPV	SEN	PPV
Beat-oriented	82.74%	96.55%	92.20%	54.10%
Number of episodes	90.59%	86.62%	96.39%	23.82%
Duration-based	81.02%	96.28%	92.11%	54.59%

B. Comparison analysis

The main research question in this paper concerns what is more relevant. To analyze the episodes to which each beat belongs, to analyze the number of episodes or the duration. To illustrate the problem we have constructed an algorithm based on the determination of Shannon entropy which analyses the beat rates of the last 40 beats, using 52 bins and threshold 0.7. Table III presents results by evaluating the testing algorithm with different evaluation methods.

Although the number of the episodes-based method shows satisfactory correctness in terms of sensitivity over 90% for both analyzed databases, still it reaches a very low value on PPV when analyzing the MITDB.

The beat oriented analysis approach is the most frequently used method and the results from it are considered reliable but we want to note that this method neglects the value of the RR interval, i.e the time duration between one R peak and another R peak, which is not the case with the duration method.

The duration method gives the most relevant results. Note that the obtained values are close to those found in the beat-based method, but determine the performance more precisely.

C. Selection of the best evaluation method

Sensitivity and Positive Predictivity Value have opposed trends for different threshold values in the analysis of the Shannon Entropy AFib detection algorithm on the popular MIT-BIH Arrhythmia and Atrial Fibrillation datasets. Fig. 3

demonstrates line charts by applying our algorithm based on Shannon entropy on MITDB, calculating Shannon entropy on arrays of last 40 beats and distribution in 52 bins.

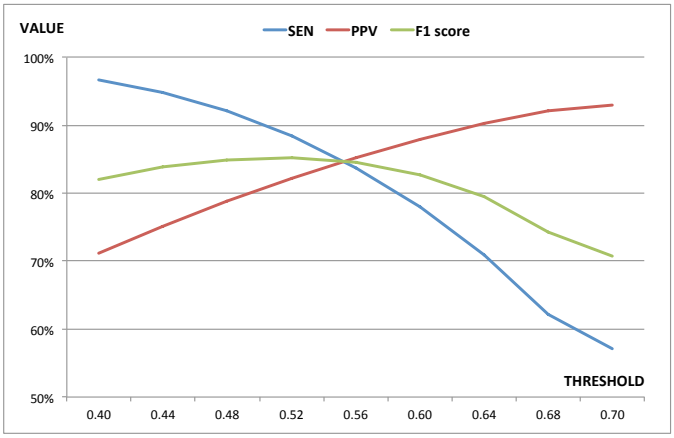

Fig. 3. Threshold level influences the SEN and PPV values.

Higher sensitivity is opposed to positive predictivity rate, as presented in Fig. 3. A typical explanation is with the following example to choose a method to shoot a fly, should we use artillery or just a bullet. Increasing the weapon size we increase the sensitivity (more chance to shoot the fly) but we can have a lot of side effects or misses, which decreases the positive predictivity rate.

This happens in the AFib detection algorithm based on Shannon entropy. Decreasing the threshold level will increase the sensitivity significantly, but, it results with a significant decrease in positive predictivity rate, as illustrated in Fig. 3.

The analyzed research problem in this paper is to choose a correct threshold value, should it be a value that maximizes SEN or PPV. F1 score as a harmonic mean between these two values is used to find an optimal value where both SEN and PPV reach high values. This is illustrated in Fig. 3.

This will reveal a value where both SEN and PPV are almost equally high over a given threshold value. However, the selection of datasets may reveal different threshold values. Although at a threshold value of 0.56 both values have equal value, the best threshold value is 0.52, where the harmonic mean of SEN and PPV is the highest. This optimal value was obtained for the analyzed algorithm on MITDB, while for AFDB is 0.7. In this case, the researcher should use a gross value of all used datasets and evaluate which threshold value reveals the optimal solution.

D. Matching measures to databases

Matching performance evaluation measures to databases is very important. MITDB and AFDB contain sequences of AFib and the best way to evaluate them is the use of SEN and PPV.

NSRDB does not contain any AFib episode, and it is nonconventional to analyze SEN, since $TP = 0$ and the expected value will be also 0. In this case, it is better to analyze the FPR (false positive rate) and SPC (specificity).

As an overall conclusion, MITDB and AFDB should be used for evaluating how precise is the testing algorithm in detecting AFib, while NSRDB, how much false detections are made with the testing algorithm.

Another important issue is how to choose training and evaluation datasets. Probably, the best way is to train the machine learning algorithm with one database, and test it with others. This makes also other problems, since the MITDB database contains also a specification of other related arrhythmias, which may introduce higher values of Shannon entropy and initiate a false detection result. For example, bigeminy and trigeminy, or frequent occurrence of ectopic beats increase the Shannon entropy and the algorithm may make wrong decisions, if it is not trained well, or if a proper algorithm does not analyze all details thoroughly.

E. Drawbacks

A serious drawback of the number of episodes-based method is that long detected episodes of AFib can be interrupted by a small sequence of another episode which either separates the record into multiple separate AFib episodes, or results into an outburst of an AFib episode that lasts for only one or two beats which are duration measured in hundreds of milliseconds.

An example is illustrated for record 203 MITDB in Fig.4. A longer AFIB episode which starts at is analyzed. Two small episodes of Ventricular Tachycardia (VT) are identified within this AFib episode. This makes three AFib episodes instead of one, although one is very small.

VI. Conclusion

The provided analysis shows that the number of episodes is not a relevant factor for performance evaluation of AFib detection algorithms. It can give just a small indication of the existence of detected AFib episodes, but not how successful is the testing algorithm.

The beat oriented analysis is a relatively good method that will reveal satisfactory results, but we confirm that the duration-based method is the best for performance evaluation.

In addition, our analysis has proven that the final goal in performance evaluation is not to develop an algorithm with high sensitivity only, but high positive predictivity rate is a must. In other words, it is not sufficient to develop an algorithm which shows how much period of relevant AFib episodes are selected, but it is necessary to find out how many periods of detected AFib are relevant. Since these values may fluctuate a lot, we recommend using the F1 score, as a balance between both these two key performance indicators. So the best algorithms, are those that score equally high on analyzed indicators.

Performance analysis should be performed on records from reference databases without AFib sequences, such as the majority of records from MIT-BIH Arrhythmia database. Evaluation of MIT-BIH Normal Sinus Rhythm database should reveal the number of false positives. In this case, the sensitivity value is 0 with reference records containing AFib, revealing

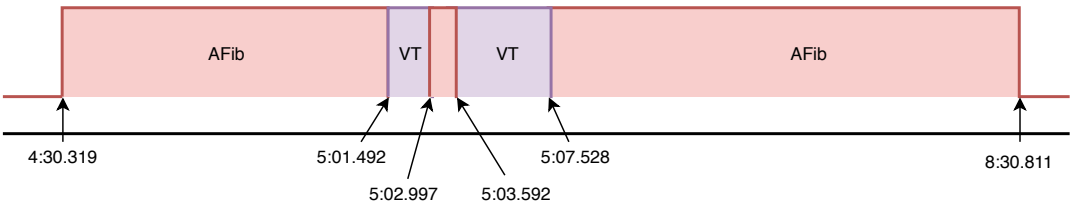

Fig. 4. Illustration of small episodes of AFib after identifying VT episodes within the analyzed AFib episode for record 203 MIT-BIH Arrhythmia database.

that specificity and false predictivity value to be used in the evaluation.

As a use-case and illustration of these performance evaluation methods we present an algorithm which classifies AFib episode based on Shannon entropy, by selecting the length (number of analyzed beats), a specific number of bins and threshold value.

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Approaches to metagenomic classification and assembly

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***Abstract* - Microbiome is an ecological community of commensal, symbiotic, and pathogenic microorganisms that share the same environment. The study of microbiome, i.e. genetic material sampled directly from environmental samples is called metagenomics. In recent years, genome sequencing methods have dramatically improved and the number and variety of sequenced genomes has rapidly increased. New technology has significantly increased the variety and complexity of the microbiome research and ever-larger datasets present new challenges in analysis of metagenomic data. Two main tasks in metagenomic analysis are classification of sequenced metagenomic data into taxonomic group of any rank, such as a species, family, or class, and assembly of the data into longer contiguous sequences. The final aim of both tasks is to correctly identify species presented in the metagenomic sample. This has various applications in medicine (e.g. infectious disease diagnosis), development of biofuels, biotechnology, agriculture, and many other areas. In this paper, we present a description of common procedures and methods for metagenomic data analysis and challenges facing these procedures. We give an overview of existing software tools and a review of public genome databases used for metagenomic analysis. Finally, we explore possible improvements to the existing methods for metagenomic classification and assembly.**

Keywords* - *microbiome, metagenomics, genome sequencing, databases, assembly, classification

I. Introduction

DNA is a long molecule that consists of large number of simple molecules called nucleotides or bases. The process of resolving the structure of a DNA molecule is called DNA sequencing. The Human Genome Project was the first attempt to determine the sequence of bases that make up human DNA and it lasted for more than 10 years [1]. Since then, the technology has rapidly advanced and today we have various sequencing techniques. Next Generation Sequencing (NGS) technologies brought lower cost and higher throughput, but also produced short read lengths [2]. Most prominent second generation sequencing technology is Ilumina, which produces nucleotide base sequences called reads, ranging from 30 bases do 500 bases and having low error rates [4]. New technologies, called third-generation sequencing, such as PacBio [4] and ONT [5], produce much longer reads with average read length of several thousand base-pairs, but with higher error rates. While the error rates of reads produced by these technologies is higher than the ones produces by NGS, their high average read length enables sequencing through extended repetitive regions, detection of mutations, identification of gene isoforms and discovery of new genes. These properties make third generation of sequencers, and the data they produce, the central point around which new bioinformatic methods should be researched and developed. They are revolutionizing the assembly and structural variant analysis of single genomes and, as their throughput improves, these technologies have tremendous potential for metagenomic classification as well.

There are many computational challenges in the field of bioinformatics, such as reconstruction of the original DNA sequence from read fragments called assembly [6] or mapping DNA or RNA sequences onto a previously assembled reference DNA. DNA assembly methods have enabled reconstruction of many genomes ranging from simple bacteria genomes to large human genomes, while mappers have been used as a tool in solving many different problems, such as the analysis of expression of genes by mapping samples of RNA sequences, or DNA assembly itself.

The analysis of microbiota, the assemblage of microorganisms presented in a defined environment [7], is another complex computational challenge that uses DNA/RNA mappers as well as assembled genomes. This field of work is, in the broader sense, called metagenomics analysis. As shown in Figure 1, the main difference between genomic and metagenomics analysis is that genomic analysis is done with a culture of a single microbe, while metagenomics analysis uses the community of many, mainly unculturable, microbial species. There are many applications of metagenomics analysis, suchs as agriculture [8], pathogen identification

[9], [10], gut microbiota analysis [11], biofuels [12] and many more. All these applications rely on different metagenomic analysis methods and software tools that provide these analysis. There are two main goals of metagenomic analysis: (1) taxonomic composition (identification of species or other filogenetic entities) and (2) functional analysis (gene identification) of the environmental sample. In the next chapter we will present main terminology related to the metagenomic research and give an overview of different methods used in metagenomic analysis. The emphasis will be on the methods that provide taxonomic composition of the sample. In the third chapter we will give an overview of currently existing tools which are used in metagenomic analysis, and, in the last chapter, we will present existing genomic databases used for metagenomic analysis.

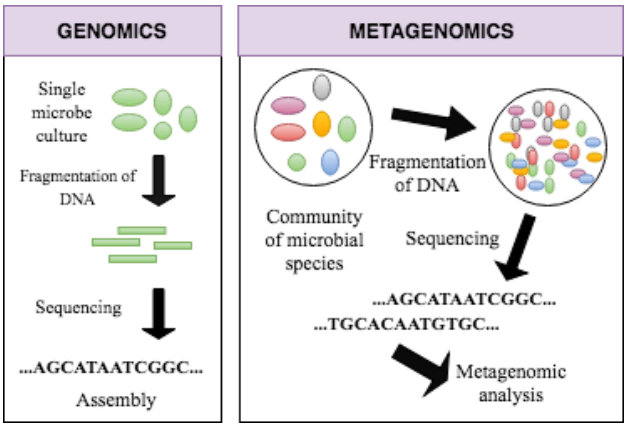

Figure 1 - The difference between genomics and metagenomics analysis

II. METHODOLOGY

As the methods for genome sequencing rapidly improve so does the number and variety of sequenced genomes. This provides many opportunities as well as challenges in extracting information from environmental samples. Different approaches to researching microbiota can be divided into three categories: metataxonomics, metagenomics and metatranscriptomics.

Metataxonomics uses sequences of marker genes which are highly conserved across taxonomic groups, such as species, to identify organisms in an environmental sample. Those genes include 16S rRNA gene for bacteria, 18S rRNA gene for eucaryotes and ITS regions of fungal ribosomes for fungi. Since it requires only sequences from one gene, this approach is less computationally complex. However it has drawbacks since it does not capture viruses, and also many organisms evade detection with 16S genes [13]. Approach that uses reads from random shotgun sequencing of microbiota, without selecting a particular gene, is called metagenomics [7]. Metagenomic analysis has achieved unprecedented performance in microbial community profiling, allowing researchers to access the composition of many different microbial communities [14]. Metatranscriptomics, on the other hand, attempts to capture and sequence RNA in a sample in order to create a profile of genes that are currently being transcribed [15]. This analysis provides insight into gene expression and regulatory mechanisms that can contribute to discovery of new and personalised drugs which can significantly contribute to human health [14].

There are two main approaches in metagenomic analysis. First approach provides results by comparing microbiota reads from a sample, to some public genome database in order to determine taxonomic composition or gene expression. This approach is called direct metagenomic classification and it has advantages over metataxonomics since it alleviates biases from marker genes that metataxonomic approaches have and identifies organisms across all domains of life. However, when there are species in the sample with no known genomes in the database, then another approach has to be used - metagenomic assembly. While the assembly of single genome is already a challenging problem, assembly of a mixed sample with many species in different abundances is even more complicated and requires special-purpose assembly algorithms [16]. The biggest problem is highly uneven sequencing depth of different organisms in a metagenomic sample. Another issue is that metagenomic sample is not likely to contain deep coverage of more than one or two species. This means that the results of metagenomics assembly will never be as good as those from assembly of a single organism. However assembly of metagenomic sample often succeeds in merging many reads resulting in contigs that can be aligned to the reference genomes more easily or analysed without the reference genomes.

All these approaches in microbiome analysis have some common steps which are implemented in most of the existing tools. Common first step is to run various quality control methods that identify and remove low quality reads. If the sample was sequenced from a host, such as human, sometimes identification and removal of host reads is also done. Remaining reads can be directly used to classify species in the sample or assembled into larger contigs. Direct classifiers use DNA mapping tools to map reads from the sample to a genome database in order to place reads into certain taxons. These classifiers can be divided into two main categories based on the amount of reads the classifier uses, (1) marker gene classifiers and (2) all-reads classifiers.

Marker gene classifiers use reduced database, consisting only of specific marker genes that identify specific species. Since this approach involves comparing metagenomic reads to a relatively small database, marker gene analysis can be a rapid way to estimate diversity of a metagenomic sample. Since marker gene methods identify only a few genes per genome, most of the reads in a sample are not classified at all.

All-reads classifiers use the whole dataset of sequenced reads and map them to the database of whole sequenced genomes. These classifiers usually use much higher percentage of sequences in their analysis than marker gene classifiers and can provide abundances of organisms present in a metagenomic sample. Direct classifiers that use reference database sometime perform a step of assembly of metagenomic reads into longer contigs and then perform contig classification. In the following chapter we will give a review of software tools that implement these different approaches in metagenomic research. A breakdown of microbiota research approaches with the list of tools for each research is given in Figure 1.

Microbiota research approach	Metatxonomics	Metagenomics				Metatranscriptomics
Research goal	species/strain identification	species/strain identification				gene identification
Sequencing type	specific gene sequencing	whole sample sequencing				RNA sequencing
Metagenomics research approach		direct classification			read assembly	
Classification methods		all reads mapping	marker gene detection	strain identification		
Tools	QIIME, UPARSE, Mothur, DADA2	Kraken, CLARK	MetaPhlAn, FOCUS, MG-RAST	StrainPhlAn, PanPhlan, Constraint, Sigma	Meta Velvet, Ray meta, IDBA, MetaSPAdes	HUMAN2, Leimena-2013, SotMeRNA

Figure 2 - Breakdown of microbiota research approaches

III. Tools

There are several bioinformatic tools that provide metataxonomic analysis of sequenced metagenomic samples by using 16s rRNA marker gene such as QIIME [17], UPARSE [18], Mothur [19], and DADA2 [20]. As mentioned earlier, these methods target only specific genes and can fail to detect many species, while not detecting viruses at all. A comprehensive analysis of metagenomic tools that use 16s tRNA gene is given in [14].

One of the first methods for assigning taxonomic labels to unknown reads was done with program BLAST [21], which classified sequences by aligning them to a large database of genomes. Certain tools used the results of BLAST and applied Bayesian rule to distribution of matches to identify species inside the sample, but these tools perform even slower than BLAST itself [21]. Since then, many metagenomic analysis tools have been developed.

Kraken [22] is a sequence classification tool which uses exact match database queries of k-mers. It is able to achieve genus-level sensitivity and precision. It uses database that connects a k-mer with the lowest common ancestor of all organisms whose genomes contain that k-mer. Using this database the Kraken is able to make a quick lookup of the most specific node in the taxonomic tree which is associated with the given k-mer. The Kraken database is built from the NCBI RefSeq database [23]. To classify the DNA sequence, Kraken collects all k-mers within the sequence into a set and forms taxonomy tree from that set. Each node in the tree is weighted with the number of k-mers that are mapped to the taxon associated to that node. Then every root-to-leaf path in the tree is scored by calculating the sum of all node weights along the path. The maximum path is called classification path and the sequence is assigned the label corresponding with the leaf of the path.

CLARK [24] (CLAssifier based on Reduced K-mers) is another sequence classification tool that matches reads with the database of genomes based on a set of k-mers.

Clark builds the reduced database of k-mers where all common k-mers between targets in the database (e.g. a collection of genomes) are removed which produces a set of genomic regions that uniquely describe each target. A read is classified as a target with which it shares the highest number of k-mers. Kraken and CLARK have been noted as most precise and fast tools that currently exist in [25].

MetaPhlAn2 [26] is a marker gene based direct sequence classification tool that mapps reads against a reduced set of clade-specific marker sequences. It infers the presence and read coverage of clade-specific markers to unequivocally detect the taxonomic clades present in microbiome sample and estimate their relative abundance. Clade-specific markers are coding sequences that satisfy the conditions of (1) being strongly conserved within the clade's genomes and (2) not possessing substantial local similarity with any sequence outside the clade. The marker set needs to be generated once for a set of database genomes. The set used in [26] contained around 1 million markers from over 7500 species. MetaPhlAn2 uses Bowtie2 [27], a fast mapper, to map reads to marker genes, assigns read counts to the microbial clades according to the alignment prediction and outputs a matrix containing relative abundances of the identified species, genus, family, order, class, phylum and kingdom. In the rare case of multiple matches with markers from different clades, only the best hit is considered. For each clade, read counts can be assigned directly using the clade-specific markers or indirectly by considering the reads assigned to all direct descendants.

Another marker gene based tool is FOCUS [28], which uses nonnegative least squares (NNLS) to report organisms profile. Focus calculates k-mer frequencies for sequences of genomes in database with length of k-mer from 6-8 bases. NNLS problem can be formalised as:

Given a matrix $A \in \Re^{mxn}$ and a vector $b \in \Re^{m}$, where $m \geq n$, find a non-negative vector $x \in \Re^{n}$ to minimize the function.

$$f(x) = 1/2 \,\|\, Ax - b \,\|, \; where\, x \geq 0 \; and \; \sum_{i=1}^{n} x_i = 1 \qquad (1)$$

In FOCUS, the reference matrix A is composed of m k-mer frequencies from n genomes, while a vector describing the user's metagenomic dataset is calculated from the k-mer frequencies of both strands from the dataset. NNLS is used to compute the set of k-mer frequencies x that gives optimal possible abundance of k-mers in the user's metagenome by selecting the optimal number of frequencies from the matrix A.

MG-RAST [29] is the tool that provides metagenomic and metatranscriptomic analysis of metagenomic data whose upload is offered to the users through the web page. The tool extracts multiple features for users to assess sequence quality and address some of the common issues like high error rates, contamination with adapters, duplicate reads. The tool maps metagenomic sequences with BLASTX [30] to the database sources of protein encoding genes [31]. In parallel the sequence data is compared to all accessed databases which include several rDNA databases, chloroplast database, mitochondrial database, and other.

All mentioned tools are used to report organisms present in metagenomic samples and profile their abundances. In some cases, such as diseases related to a single group of microorganisms, different strains in the same species may have different effect on human health This is why identification of species in a metagenomic sample is not sufficient for some applications. Identification and profile of different strains of the same species in the environment are crucial to revealing human-microbial interactions. We present bioinformatic tools that provide strain identification in a metagenomic sample.

StrainPhlAn [32] infers the strain-level phylogenetic structure of microbial species across metagenomic samples by reconstructing the consensus sequences of the dominant strain for each detected species in a sample and then comparing the consensus sequences in different samples. It uses MetaPhlAn2 to map the reads to MetaPhlAn2 marker database and uses the alignments to produce phylogenetic trees using the maximum-likelihood principle [33]. To identify the presence of multiple strains from the same species in a single sample, reads-to-markers mappings are analysed to find evidence of polymorphic sites [34] on the alignments suggestive of multiple alleles. For each position s in the alignment N_s is defined as the total number of reads covering it and T_s as the number of reads supporting the dominant allele. With the sequencing error rate E, the nonpolymorphic null hypothesis is rejected if the probability that the number of reads $N_s - T_s$ that comes from the nondominant allele is $< \alpha = 0.05$. failing to reject the null hypothesis indicates the absence of alternative alleles.

PanPhlan [35] is a tool that uses metagenomic data and achieves strain-level microbial profiling. It identifies which genes are present or absent within different strains of species, based on the entire gene set of the species' pangenome [36]. The pangenome of the species includes genes present in all strains and genes present only in some strains of a species (variable genome). The core

genome represents the genes present in all strains of a species. PanPhlAn builds the pangenome of a species by extracting all genes from available reference genomes and merging them into gene clusters. It then maps the metagenomic sample reads against the reference genomes to obtain gene coverage levels and then reconstructs the unique gene set of a strain present in the sample. A strain is predicted to be present when the abundance of species-specific genes indicates a nearly uniform coverage depth across an expected number of N gene families representing the median number of gene families of all reference genomes of a species.

ConStrains [37] is another tool that identifies organisms in a sample at strain level. ConStrains compares raw metagenomic reads to reference genomes and identifies single nucleotide polymorphism (SNP) patterns as the basis in differentiation and quantification of different strains. The tool achieves this in two steps: (1) identifies species for which SNPs are detected and quantified, and (2) transforms individual SNPs into SNP profiles that represent individual strains. First step uses MetaPhlAn for species composition. For the species with sufficient sequencing depth, a custom database of marker genes is created from the PyloPhlan marker set [38], against which the raw reads are mapped using Bowtie2. The resulting alignments are used to generate a table of coverage by base position from which SNPs are identified. SNPs are counted across samples as those positions where the minos allele had at least two counts or more than 3% in relative abundance.

The last strain identification tool presented here is Sigma [39] which uses read mapping approach with a probabilistic model, maximum likelihood estimation (MLE) of the relative abundances of all genomes measured by the percentages of reads sampled from these genomes. Sigma's strain classification method does not use any marker genes, as methods described before, and it will be described in more detail here. Sigma calculates the P-value for identification of a genome using a likelihood ratio test of the null hypothesis that the genome is not present in the sample.

Let $Pr(g_j) \in [0,1]$ be the probability of sampling a random read from the reference genome g_j. Considering only reads sampled from reference genomes in the database, we have:

$$\sum_{\forall j} Pr(g_j) = 1 \tag{2}$$

$Pr(g_j)$ is determined by the relative abundance, size, and sequencing bias of the genome g_j. Sigma estimates $Pr(g_j)$ using MLE. Consider a read r_i mapped to the genome g_j with z mismatches and a uniform probability of σ assumed for any mismatch between a read and a genome. The probability of obtaining r_i with z mismatches and $(l-z)$ matches from the genome g_i is:

$$Pr(r_i|g_j) = \sigma^z(1-\sigma)^{l-z};\ z \le U, \tag{3}$$

$$Pr(r_i|g_i) = 0\ ;z > U, \tag{4}$$

where l is the length of r_i and U is the maximum number of mismatches allowed in the alignment. $Pr(r_i|g_i)$ is calculated between each read and each genome based on their alignment and matrix Q is populated:

$$Q_{i,j} = Pr(r_i|g_i). \tag{5}$$

The probability of sampling r_i from g_i is:

$$Pr(r_i, g_j) = Pr(r_i|g_j) \cdot Pr(g_j) = Q_{i,j} \cdot Pr(g_j), \tag{6}$$

And the probability of generating r_i, since it may originate from any of the reference genomes, is:

$$Pr(r_i) = \sum_{\forall j} Pr(r_i, g_i). \tag{7}$$

MLE finds the estimate of $Pr(g_j)$ by maximizing the probability of all reads, which is the joint probability of all reads:

$$max\ Pr(r_1, ..., r_n) = max \prod_{\forall i} Pr(r_i) \tag{8}$$

$$= max \prod_{\forall i} [\sum_{\forall j} Pr(r_i, g_j)] \tag{9}$$

$$= max \prod_{\forall i} [\sum_{\forall j} Q_{i,j} \cdot Pr(g_j)]. \tag{10}$$

This optimisation problem is solved using non-linear programming method implemented in the Ipopt library [40].

Here are some of the most notable metatranscriptomic tools that try to capture all of the RNA sequences in the sample and create profiles of all genes that are being transcribed. HUMAnN2 [41] is a tool designed for analysis in both metagenomics and metatranscriptomics. It identifies a community's known species, aligns reads to their pangenomes, performs translated search on unclassified reads, and finally quantifies gene families and pathways. A tool presented in [42] uses SotMeRNA [43] and BLASTN for the removal of rRNA and tRNA reads, and megaBLAST for mRNA reads alignment to reference genome database and classifies the alignments to protein and non protein encoding regions. More on metatranscriptomic tools is given in [14].

Lastly, metagenomic assembler tools are presented in [44]. MetaVelvet [45] and Ray meta [46] are single k-mer de Bruijn graph assemblers for metagenomic data. MetaVelvet extends single-genome assembler for short reads, known as Velvet [47], to metagenome assembly. It decomposes de Bruijn graph constructed from mixed short reads by Velvet, into individual sub-graphs and builds scaffolds based on each decomposed de Bruijn sub-graph as an isolated species genome. Ray Meta constructs contigs by a heuristics-guided graph traversal. IDBA assembler [48] is iterative De bruijn graph assembler that generates contigs from iteratively constructed and refined de bruijn graphs using multiple k-mer lengths from small k's to larger k's, replacing reads with reassembled contigs at each iteration. MetaSPAdes [49] is an extension of the SPAdes assembler which uses approach similar to IDBA with iterative de Bruijn graph refinement, but also implements various heuristics for graph simplification, filtering and storage.

IV. Genomic resources

The microbial genome resources are of high importance for metagenomic research. The quantity and quality of genomes in the database greatly influences the precision of the classifiers in species identification. Most commonly used reference genome database is the database of complete and draft genomes at GenBank which has been the repository for genome sequences for more than a quarter of century [50]. GenBank genomes receive taxonomic identification by their uploaders and some genomes have incorrect species name. Another issue with GenBank data is contamination, where the vast majority of genomes in GenBank are 'draft' genomes. These are genomes for which the assembly was generated, but most of the chromosomes are fragmented into many pieces. Some of the contigs might be contaminants, i.e. they might not belong to sequenced species. The result of these contaminants is that reads from metagenomic sample will match some draft genomes extremely well because the metagenomic sample contains same contamination.

The RefSeq project uses GenBank sequences and filters them to get more curated genome resources and provides alternative database for metagenomic research [23]. RefSeq database provides, for each individual species, a complete, non-redundant and richly annotated genome sequences. Currently it contains more than 88 thousand organisms, a number that will surely grow in the future.

Since 2014 only novel species are assigned new taxonomy ID in GenBank database while assigned strain taxonomy ID stays in the database [51]. This means that single species can have genomes at species and strain level which can be challenging for algorithms that try to characterize metagenomic samples at strain level.

Clade specific markers are another important genomic resource in analysing microbiota. MetaPhlAn2 is the most prominent tool that utilises such resource. The process of identification and extraction of clade-specific core genes is given in [52]

V. Future prospects

With all the presented metagenomics research approaches and tools that analyse metagenomic samples there are certain ways in which the future research can progress beyond the state-of-the-art. In order to utilise good properties of reads created by third generations sequencers, a new metagenomic analysis tool that classifies these reads to different strains of the same species needs to be developed. A good start would be to place reads into certain classes by using methods with k-mers, similar to Kraken or CLARK. With MetaPhlAn2 marker database available, the fast mapping of the reads to the database of marker genes should be researched and if possible used alongside k-mer approach. These methods can be improved by utilising currently best mappers evaluated in [53] which have shown good results in mapping DNA or RNA third generation sequences to a reference genome. Finally, strain classification could be done with the classification algorithm used in SIGMA which would use the results provided by previous steps of algorithm. Before tackling these challenges, a thorough benchmark of currently existing tools for metagenomic classification should be done, with exact and clearly defined measures of quality of the tools.

VI. Conclusion

NGS sequencers provide powerful tool to analyse microbiota. There is a variety of tools developed to help analyze metagenomic datasets. In this paper, we presented an overview of different types of analysis of metagenomic samples. Metataxonomic methods do not capture viruses and usually don't classify many present species. Metataxonomic methods analyse metagenomic samples of RNA and provide gene expression analysis of the sample. Metagenomic methods classify read in the metagenomic sample to the reference database, or assemble them into larger contigs, both with goal to identify species present in the sample. With many applications in different areas of interest like medicine, agriculture and other, the analysis of metagenomic

samples is of high importance for future of human species and will continue at an even faster pace.

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Application of source localization algorithms in magnetoencephalography: test on a new generation of magnetometers

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Abstract - **Magnetoencephalography (MEG) is a non-invasive neuroimaging technique for measuring the activity in the brain. In the vicinity of the head it measures the magnetic field produced by the electric currents in neurons. From the measured magnetic field, using various computational techniques, we determine the location of the source. In this paper, we present the main methods for localizing activated areas in the brain with the data obtained from a 128-channel superconducting quantum interference (SQUID) system. Great emphasis is on solving the inverse problem, i.e. finding the source from the measured magnetic field around the head, with the minimization of the forward model for calculating the magnetic field inside a conducting sphere. We also demonstrate each step in the image processing of the magnetic resonance imaging (MRI), which we use for a more precise source localization. We address all the major drawbacks when using the SQUID gradiometers. As an alternative, we present the new generation of magnetometers, optically pumped magnetometers (OPM), which operate at room temperature. Compared to SQUIDs they can be placed closer to the head with the use of a custom 3D printed sensor holder. We also present the first test results with a custom system of 15 OPMs.**

Keywords - magnetoencephalography (MEG); inverse problem; SQUID system, optically pumped magnetometers (OPMs); neuroimaging

I. INTRODUCTION

The functioning of the brain is a very complex process and its understanding is still an open question within the scientific community. In order to gain a better insight into the functioning, several experimental methods for measuring the brain activity have been developed, which can be invasive or non-invasive. The most used non-invasive methods are: electroencephalography (EEG) [1], functional magnetic resonance imaging (fMRI) [2] and magnetoencephalography (MEG) [3]. In our paper we will focus on the MEG method. While there are many advantages of MEG over the other two methods, it has also many drawbacks, which will be addressed below.

Magnetoencephalography is a neuroimaging technique that measures the weak magnetic field produced by the electric currents of nerve cells [3]. The main goal of this method is to determine the location of the source of the measured magnetic field as accurately as possible. The measured magnetic fields are very weak, order of few pT, therefore the measurements must be carried out within a magnetically shielded room, this is also one of the major drawbacks. The temporal resolution of this method is around 1 ms, on the other hand, the spatial resolution is in best conditions around 2 – 3 mm [4].

Another drawback of the standard MEG method is the use of the SQUID gradiometers [5]. Although they are very accurate, they require a cooling with liquid helium, which is why they need to be placed in a bulky Dewar vessel. This is the reason why the gradiometers are not in the optimal position next to the head. Another consequence of this is that the patient must not move his head during the measurement, which is very uncomfortable. We can solve this problem with the use of a new generation of magnetometers, optically-pumped magnetometers (OPM). These sensors operate at a room temperature, therefore they don't need a cryogenic cooling and can be placed directly to the head.

The use of these new OPMs in a neuroimaging technique such as MEG is a quite new concept, which is why it still needs a lot of improvements. In a recent study A. Borna with colleagues compared the results between the use of OPMs and SQUIDs [6]. In the experiment they used an auditory and a somatosensory evoked response. The results they got, look very promising for the future use of the OPM sensors in MEG. Another very important study was made by E. Boto et al, where they made a study of a simulation where they compared two cases [7]. In the first case, the magnetometers were located like in SQUID systems and in the second case, the OPMs were close to the head (approx. 4mm). They found out that by placing the sensor closer to the head, greatly improves the signal to noise ratio (SNR).

In our work, we present some standard methods [4] used in magnetoencephalography and also test and compare the performance of the existing MEG systems based on the SQUID gradiometers with a new system based on OPM magnetometers. First, we present methods for processing the MRI scans, pre-procesing the MEG data and then solving the inverse problem. Next, we show the results as measurements of the magnetic field and the solutions of the inverse problem as locations of dipoles on

MRI scans. Lastly, we evaluate and compare the results obtained for both measurement devices.

II. METHODS

To make measurement with the MEG system and to determine the regions of increased activity, we have to do quite a few things. The SQUID device is a standard device with fixed number and locations of fixed sensors. On the contrary, the OPM measuring system has no unitary sensor holder with standard locations of the sensors. Therefore we first make a custom sensor holder with a 3D printer. For this, we obtain an MRI scan of the subjects head, and then process it with various techniques. Next, we start with the experiment for an auditory evoked response. The magnetic field was measured first with the SQUID and then with the OPM system. All the collected data must then be filtered and averaged. For the times, when we measured the greatest response, we solved the inverse problem using the least square fitting of a current dipole, which is a well known method in MEG. This work introduces the methodology and the results of one subject only, as the study is still ongoing.

A. Processing of the MRI scans

The processing of MRI scans is of great importance. Without it we couldn't build the custom sensor holders for the OPMs or determine which brain region produces the measured magnetic field around the head. In this paper we extracted the geometry of the head out of the MRI scans. For this task we created a script in the programming language Python. In this script we first import all the MRI data, which are saved either in NIfTI or DICOM file format. Then we manipulate this data so that we get a 3D matrix of values for each measured pixel. Each measured pixel has also its own x, y and z position. On the 3D matrix we then apply a Canny edge detector, which is an algorithm for detecting a wide range of edges in images [8]. The result of this algorithm is a new matrix with values 1, when a specific pixel is an edge or 0 otherwise. From this matrix we then extract only the outer pixels with values different from 0, we store their x, y and z positions in a new array. To create the model for 3D printing we have to first triangulate these points. For the triangulation we use the Poisson surface reconstruction method [9]. With this triangles we can then create a model for sensor holder using computer programs like OpenSCAD [10]. An example of a sensor holder for the OPM system is shown on the bottom part of Fig. 2. Similar helmets have been made by other research groups [11]. On the left side in Fig. 1 we show the image of all triangles generated with this method, which form a reconstructed head.

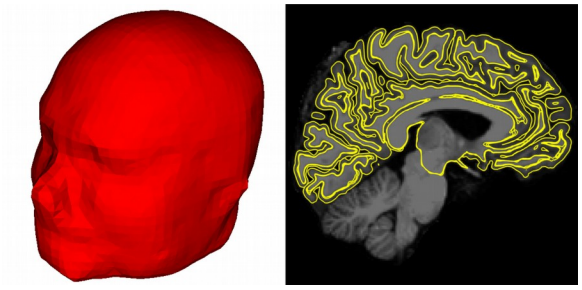
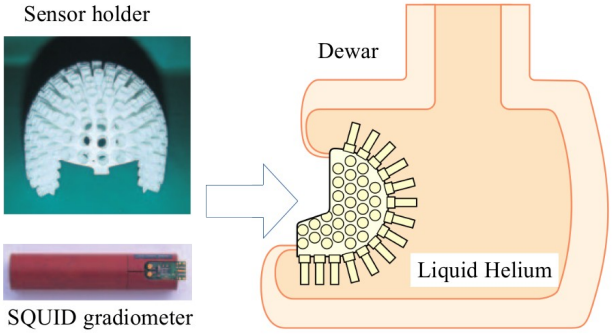


Figure 1. Reconstruction of the MRI scans. On the left side is a model of head composed of triangles, which were obtained as a result of extraction of the outer edges from the MRI scans. On the right side is the volume of the brain, obtained from the entire MRI scan of the head. Yellow lines represent the edges of individual layers of the cortex.

Our next goal was to extract only the brain area and individual layers of the brain out of the anatomical MRI. We achieved that with the use of the program called Freesurfer [12], [13]. An example of this results is presented on the right side in Fig. 1. These results will be important in our future work, where we will try to improve the accuracy of localized sources.

B. Obtaining the MEG data

The acquisition of MEG data is a very complex task. All our MEG measurements were performed inside a magnetically shielded room with a SQUID system. In addition to that, we performed some first test measurements with a system of OPM sensors. The SQUID system consists out of 128-channel SQUID sensors produced by the company Yokogawa. The sensors holder for this system is shown on the top part of Fig. 2. The whole system is cooled with a liquid helium. Each channel is a gradiometer composed of two parallel sensors separated by a 5 cm distance along the sensing direction, which is approximately perpendicular to the head surface. The OPM system consists out of 15 two-axis magnetometers, which can measure two space components. The sensors are produced by the company



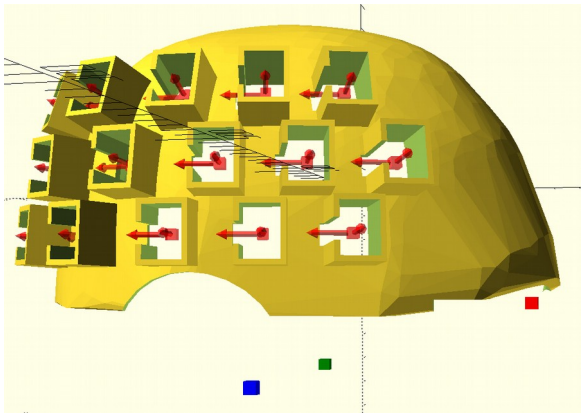


Figure 2. Sensor holders for two different measurement systems. On the bottom part is the sensor holder for the system of OPM magnetometers, and on the upper part for the SQUID system [15].

QuSpin Inc. and does not need a cooling system [14]. Since we have a limited number of these sensors, we have placed them only on the right side of the head, where we expect the greatest response, as shown on the bottom of Fig. 2. In our experiment we measured auditory evoked fields for a 1 kHz tone of duration 500ms, which were performed for over 500 stimulations. To acquire meaningful results, we need to follow quite a few steps. Results from the measurements gives us so called "Raw data", from which we have to extract many artifacts and noise. Then we average responses for individual stimulations. These steps can be performed with various computer tools like MNE [16], Brainstorm [17] and FieldTrip [18]. In our case, we used the latter.

C. Solving the inverse problem

As a result of all the steps in previous chapter, we obtained the averaged time series of the magnetic field B for all channels. Fig. 3 displays so called butterfly plot, where all channels are plotted. The external auditory stimulation was at $t=0$. We can clearly observe that the maximum response is at time around $t=100$ ms after the stimulation. The upper part of Fig. 4 shows an example of the measured values (B) at a specific time. Since the sensors of the SQUID system are distributed on a helmet shaped surface, see Fig. 2, we showed the magnetic fields as projection on a flat plane. We calculate the new locations in the projection as: $\Delta x = r_{i,j}\cos(\arctan(\phi))$ and $\Delta y = r_{i,j}\sin(\arctan(\phi))$, where $r_{i,j}$ represents the euclidean distance between i-th and the highest lying channel with index $j=118$. The angle is defined as $\phi=(y_i-y_j)/(x_i-x_j)$.

Next step is localization of source at the time when the sensors measured the biggest response. There are several ways to localize increased activity within the brain, when measuring with the MEG method. Most of them assume, that the net currents can be approximated as a current dipole, which give rise to a magnetic field. At this point we have to introduce a forward model. In our work we have used a model which calculates a magnetic field (B) outside a spherically symmetric volume conductor. If we want to use this model, we have to approximate the head with a best fitted sphere. In our case we fitted a sphere on the upper part of reconstructed head, that we presented earlier.

We calculated the magnetic field $\vec{B}$ in the sensor positioned $\vec{r}$ outside the sphere due to the current dipole with strength and orientation $\vec{p}$ and position $\vec{r_p}$ inside the sphere using the following equation derived by Sarvas [19]:

$$\vec{B}(\vec{r})=\frac{\mu_0}{4\pi F^2}[F(\vec{p}\times\vec{r_p})-(\vec{p}\times\vec{r_p}\cdot\vec{r})\nabla F], \qquad (1)$$

where $F=|\vec{a}|(|\vec{a}||\vec{a}|+\vec{a}\cdot\vec{r})$, $\vec{a}=\vec{r}-\vec{r_p}$, and

$$\nabla F=(\frac{F}{|\vec{a}|^2}+|\vec{a}|+|\vec{r}|)\vec{a}+(\frac{|\vec{a}|^2}{|\vec{a}|}+|\vec{a}|)\vec{r}. \qquad (2)$$

Note that the equation (1) is defined only for points outside the conducting sphere model.

The inverse problem, which represents finding the source for all the measurements of B at one specific time, is solved with performing a nonlinear least squares curve fitting using Levenberg–Marquardt algorithm [20]. In other words, this method searches for the optimal values of $\vec{r_p}$ and $\vec{p}$, where the difference between the measured values of B and the values calculated with the model (1) is the smallest. This method also needs a starting approximations for the searched variables. These approximations should be wisely picked, otherwise, the algorithm can find a local minimum instead of a global minimum.

III. Results and Discussion

A. SQUID system

As observed in Fig. 3 we can expect the biggest response after around 100 ms after stimulation. First we plotted a color map of values of the magnetic field (B) at time of greatest response after the subject received an auditory stimulation, for all 128 channels in the SQUID system in the upper part of Fig 4. From this picture we can observe two dipole-like field patterns, one on the left part and another on the right part of the SQUID system. For these values of magnetic field (B) we solved the inverse problem. As a result we obtained the locations and direction of two current dipoles. Next, we calculated the magnetic field for the same locations as the squid channels using the forward model (1). These fields are represented on the bottom of Fig. 4. Relative error (RE) defined as a root mean square (RMS) of difference between measured and calculated data divided by the RMS of measured data was 0.33 and corresponding correlation coefficient (CC) 0.94.

When comparing these two results presented on Fig. 4, we can clearly see that the values in both maps are very similar. Locations of the maxima and minima coincide. The center of the maximal measured field of the first

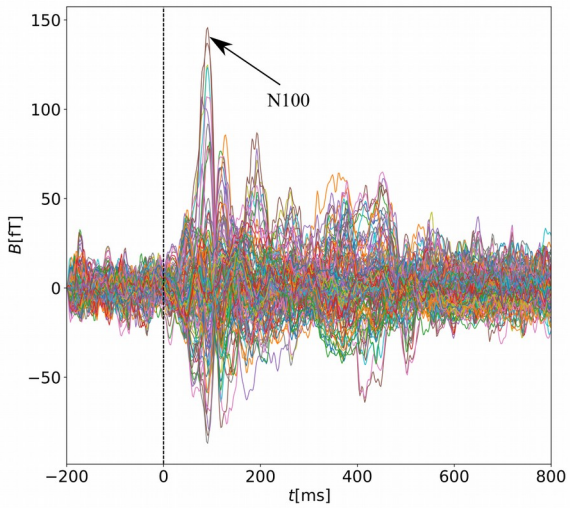


Figure 3. A so called "butterfly plot" for the averaged time series obtained with the SQUID system. Each curve, marked with the same color represents a time series of measured signal for a specific channel. At $t=0$ the measured subject/patient received a auditory stimulation, at around $t=100$ ms, we measure the maximum response (N100).

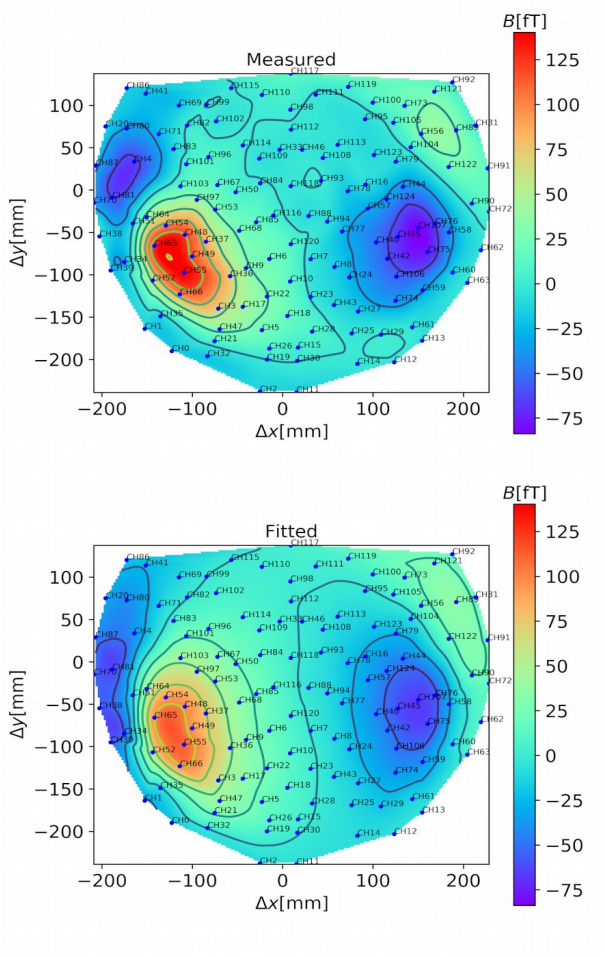


Figure 4. Color maps for values of the magnetic field (B) at each sensor for the time of maximal response after the subject received an auditory stimulation. The top part represents the measured values for an actual experiment measured with the SQUID system. The lower part represents the magnetic field calculated for two current dipoles obtained by solving the inverse problem of the measured magnetic field. The blue dots are locations of sensors.

dipole is at around $\Delta x = -120$ mm and $\Delta y = -80$ mm and the minimum at around $\Delta x = -170$ mm and $\Delta y = 20$ mm. On the fitted result the maximum and minimum are slightly shifted to the location at around $\Delta x = -120$ mm and $\Delta y = -70$ mm and the minimum at around $\Delta x = -190$ mm and $\Delta y = 0$ mm. For the second dipole, this shift is not so noticeable. The maximum is at around $\Delta x = 180$ mm and $\Delta y = 50$ mm and the minimum at $\Delta x = 150$ mm and $\Delta y = -50$ mm.

The locations of the fitted dipoles $(\vec{r}_p)$ obtained by solving the inverse problem for the values of the magnetic field (B) are shown on Fig. 5. Locations are presented on different viewing angles of the MRI scan. On these graphs the dipole is displayed with a red dot. On the left side of Fig. 5 projections of the first dipole are shown, on the right side projections of the second dipole are shown. The upper two graphs represent a sagittal viewing plane, the middle two an axial viewing plane and the lower two a coronal viewing plane. These results coincide with expectations, the calculated locations are near the center of the auditory cortex [21].

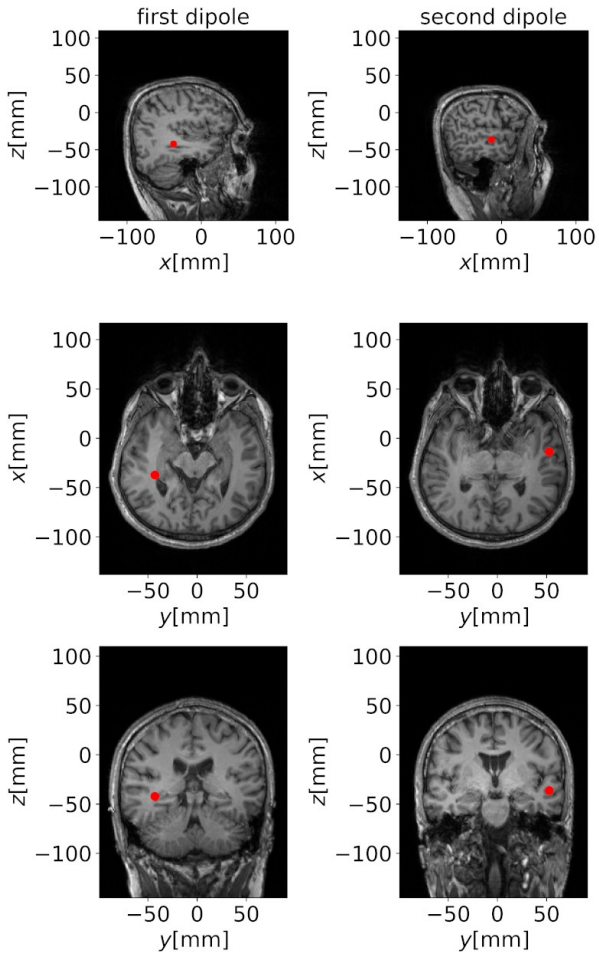


Figure 5. Locations of fitted dipoles presented for different viewing planes at the time of maximal response after the subject received an auditory stimulation. On the left side are the graphs for the first fitted dipole and on the right for the second fitted dipole. The upper two images show the sagittal view, the middle two the axial view and the lower two coronal view. The measurements were performed with the SQUID system.

B. OPM magnetometers

Next, we measured the response of the auditory stimulation with the system of 15 OPM magnetometers. The results of these measurements are presented on the upper two graphs in Fig. 6. The left graph represents the radial component of the magnetic field and the right graph the tangential component. For these values of (B) we solved the inverse problem as presented in previous chapter. As a result we obtained a location $(\vec{r}_p)$ and the dipole direction $(\vec{p})$ for one dipole. Next, we calculated the magnetic field for the same locations and orientations as the OPM magnetometers using the forward model (1). These fields are represented on the bottom of Fig. 6.

On the graph of the measured radial component, we can observe a minima of (B) on the middle and a maxima on the right side and on the graph of measured tangential component a minima of (B) on the right side and a maxima on the left side. If we compare the measured and fitted values we can see that these values do not completely overlap. Consequently, RE=0.37, CC=0.90 for

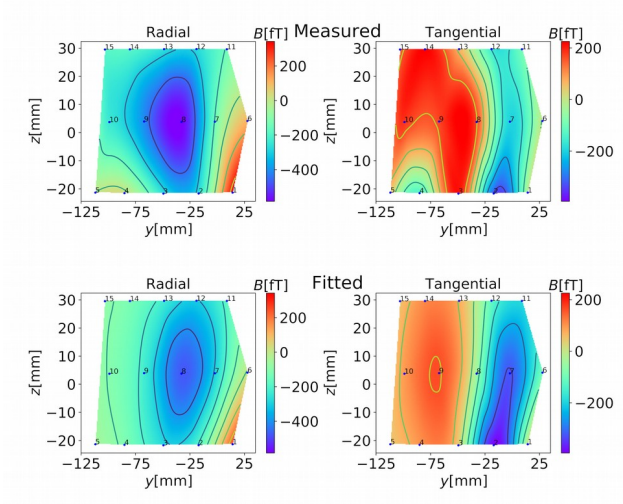


Figure 6. Color maps for values of the magnetic field (B) for radial component (left) and tangential component (right). Measurements are for the time of maximal response after the subject received an auditory stimulation. The top two graphs represent the measured values for an actual experiment measured with the OPM system. The lower part is the magnetic field calculated from the best fitting equivalent current dipole.

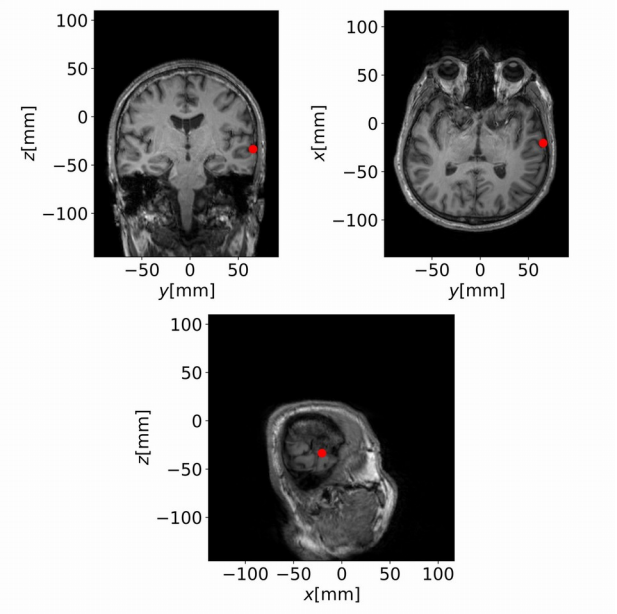


Figure 7. Locations of a fitted dipole presented for different viewing planes at the time of maximal response after the subject received an auditory stimulation. On the upper left is the coronal view, on the upper right the axial view and on the bottom the sagittal view. The measurements were performed with the OPM system.

radial, and RE=0.70, CC=0.79 for tangential components are worse than in the case of SQUID system, see Fig. 4 The locations of the fitted dipole ($\vec{r}_p$) obtained by solving the inverse problem for the values of the magnetic field (B) are shown on Fig. 7. The location of the fitted dipole are also close to the auditory cortex as in the case of SQUID system, see Fig. 5. These measurements with the OPM system are the first test results. This system still needs a lot of optimization, but the current results look very promising.

IV. Conclusion

In our work we were dealing with the basis of the neuroimaging technique called magnetoencephalography (MEG). We addressed the major advantages and drawbacks when measuring with the classic SQUID system. We then presented a new alternative system consisting of optically-pumped magnetometers (OPMs). For both systems we described how the measurements are made. An important role in the interpretation of MEG results is also the processing of MRI scans. We showed how we extracted from the MRI scan the outer surface of the head and individual layers of the cortex. These surfaces were also triangulated into a mesh, which will be very useful in our future work, when we will use realistically shaped head volume conductor model and apply the boundary element method (BEM) for calculating the magnetic field and the source localization [22]. To determine the locations of active regions inside the cortex, we solved the inverse problem using the dipole source model in the spherical volume conductor model [4,19]. Main results for the SQUID and the OPM measuring system were presented with color maps for measured and fitted values of the magnetic field. We also showed the locations of the fitted current dipoles on the MRI scans. We realized that with the SQUID system, the locations of the active regions coincide with our expectations. Despite the fact that the measured and calculated fields of the OPM system doesn't completely overlap, the location of the fitted current dipole is still in the region of the brain close to the auditory cortex. In order to confirm these conclusions, these methods will be in the future tested on a larger population. This system still needs improvements, particularly the number of channels was much lower compared to the SQUID system. This will also be a motivation for our further work. Since we are limited by the number of OPM magnetometers, we will explore how they need to be distributed to get as much information as possible.

Acknowledgment

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Detecting white spot lesions caused by teeth alignment treatment

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***Abstract*— When permanent orthodontic braces are removed dentists typically encounter the initial phase of tooth demineralization manifesting as white spot lesions (WSL) on the teeth s smooth surfaces. We developed a prototype for automatic segmentation of teeth and WSL, which may contribute to a more accurate and objective way of treatment monitoring. In the process of development, we used different image processing techniques and image segmentation paradigms. The developed prototype was evaluated on our own image database, built from the selected images of clinical examinations since an open annotated database is difficult to obtain. The prototype showed promising results with a lot of potential for improvements in future work.**

Keywords
computer vision, image processing, white lesions, image segmentation, region growing, segmentation with Otsu

I. INTRODUCTION

Computer technologies are increasingly used for medical purposes as they represent an important building block of modern health care [1]. Computer areas that are used to analyze medical data are in particular: computer vision, signal processing, and machine learning. The use of methods depends on the individual problem, the format and the amount of data that we have available. Automatic systems that operate on data obtained through clinical examinations enable us to help medical personnel, as the system can facilitate the detection process of anomalies in the data.

In this work, we will try to solve the problem that dentists face. The demineralization beginnings, which appear as WSL on the smooth surfaces of the teeth (Fig. 1) [2], often occur after the detachment of a fixed orthodontic appliance. After the treatment dentists must assess the size of the white spot at each examination and monitor the changes.

Orthodontic patients develop significantly more WSLs than nonorthodontic patients. If WSLs are left untreated, they may progress to produce carious cavitations, and may also present esthetic problems. Thus, the prevention, diagnosis, and treatment of WSLs are crucial to minimize tooth decay as well as tooth discoloration that could compromise the aesthetics of the smile [3].

Our goal is to develop a prototype system that will process, capture, and segment the regions of our interest from the captured RGB images obtained during the dental examination and evaluate the proportion of affected enamel. Thus we want to achieve a more objective system for monitoring the size of white spots and thus contribute to the development of modern healthcare.



Fig. 1. An example of white stains after orthodontic appliance removal

II. TOPIC OVERVIEW

When reviewing the related work, we found that there are not many articles directly related to detection of WSL. This is why we have expanded our view on the segmentation of medical and color images. A basic overview of various image processing and image segmentation techniques was drawn from [4], [5], providing a comprehensive overview of the subject, giving examples of use and the advantages and disadvantages of individual methods.

In the article [6], authors present an effective segmentation of the teeth with the watershed method and the morphological characteristics of teeth segmentation. In this article, the teeth recorded from the front are segmented. In the pre-processing step, they analyze the image in the RGB color space where they find that the difference in intensity between the tooth enamel and the gum is best expressed in the red channel. Thus, on the basis of the difference between the RGB image and the complement of the red channel, the region with tooth enamel is acquired. Then, using the three-cut method and morphological characteristics, they determine the potential region of interest. The potential region is divided into three parts due to the difference in illumination since the tissues that are perpendicular to the light source have a different contrast than those on the sides. This segments the parts with different illumination and consequently significantly improve the result.

The article [7] is not directly related to the problem that we are solving, but it uses many of the approaches that

we used in our implementation. First, analyze differences in histograms in the HSV color space, where we can observe how the histograms of the background and objects of interest differ. Before segmenting the image, they apply a 3×3 size averaging/mean filter to reduce noise. They use the Hue channel from the HSV color space. Since the channel H is defined as a circle (from $0°$ to $360°$), it is advisable to move the image values by a few degrees if our target region of the color at the turning point is between the maximum and the minimum value. For segmentation, the maximum entropy and adaptive thresholding were used. In the end, morphological operators are also used to fill the regions and remove smaller holes.

The image segmentation approach in [8] re-use the *Watershed* method. Most of the article is devoted to the pretreatment process. The segmentation was used by the light channel (*Value channel*) from the HSV color space. Over the selected channel, they apply a contrast correction CLAHE (Contrast Limited Adaptive Histogram Equalization), which works by correcting the contrast of the pixel using only the window of the adjacent pixels instead of using the entire image. By contrast correction method, the edges, which were previously less visible, appear. Then they use the Otsu correction and the Sobel filter, which emphasizes the transitions between contrasts, thus preparing the edges of the regions that will be filled in the segmentation process using the *Watershed* algorithm.

In the article [9], the HSI color space is used because it is easier to define the distance between adjacent colors than in the RGB color space. They use a couple of components (I, H) of the HSI color space for segmentation, which serve as an input to the clustering algorithm *k-median*, which is a version of *k-means* algorithm. For the distance measure, they use LAD (Least Absolute Deviation).

Because color and location information of an individual pixel point is sometimes not sufficient, we can obtain additional information, such as texture characteristics. In the article [10], they present how they have improved the process based on the *Mean-shift* algorithm [11] with texture data. To obtain these, the image was transformed using wavelet-transform and calculated the mean energy value. Then, these energy values were grouped into four classes and used as a new characteristic for describing image points.

In addition to low-level segmentation techniques, neural networks are also used. An example of such a work is [12], in which they use SOM (Self-organizing maps).

Our research involves the implementation of a prototype system that, through automatic image segmentation and other image processing techniques, segments the region of the teeth and affected parts with white stains on the smooth surfaces of the tooth enamel. For the purposes of the implementation, testing and evaluation of the system, we need a suitable database of images that we did not find on the web. Therefore, in cooperation with the medical faculty, we created our own database. When creating the database, we manually marked the areas of our interest, which serve as a reference for the evaluation. For the purpose of evaluating the system, we have developed a tool that allows us to compare the regions between reference marks and labels obtained with external systems. The Segmentation Comparison Tool uses various metrics that are used to analyze the performance of such algorithms. The goal of the implemented system is a prototype of a tool that dentists could use to monitor the size of the affected parts of the dental enamel during the course of treatment, as it gives objective and numerical facts about the condition.

III. Data acquisition

We used an intraoral Soprolife camera (Figure 2) to capture images. It is used as a device for the diagnosis of the prevalence of demineralization of dental enamel. The software package is also included with the tool - Sopro [13], which enables the user to keep records of patient examinations and add and edit the metadata of captured images. Thus, during the clinical examinations of patients, we took pictures of teeth, which had white spots present. Then, the images together with the metadata that were anonymized were exported and used for the construction of the database. The metadata that is exported with the images is dental location data, the date of the image creation, and some other data. When capturing images, we agreed that the teeth that are subject to review should always be at the center of the image. Thus, each captured image is at the center of the teeth that we want to analyze, together with the part of the gums and a smaller part of the adjacent teeth. By doing this we simplified the processing of images later because we are interested only in the teeth with the largest surface.



Fig. 2. Image capturing device – SOPROLIFE (*https://www.gerl-shop.de*)

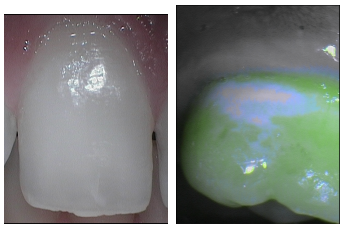

Fig. 3. Left: an example of an image captured by white light; Right: an example of an image captured by blue light

IV. Data Preparation

10 patients who were examined either once, twice or three times were used to collect about 150 pictures. We reviewed all the images manually and selected those that were of sufficient quality for further processing. The capture of good quality images with Soprolife presents a challenge since it

is necessary to set the camera's position very precisely, the dentist's hands must be calm, also the patient's oral cavity. Therefore, during the manual review, many images were rejected because they were too blurred and therefore useless.

We selected 30 images that seemed to be the most suitable and manually segmented them. For manual segmentation, we used the Gimp tool [14], with which we created additional two black and white images for each picture (Figure 4). The middle picture is a tooth mask that is a subject of interest. The right picture is a mask of white spots on the tooth of our interest. We did this for all 30 pictures.



Fig. 4. Left: original image; Center: tooth segment; Right: a segment of WSL

V. Pre-Processing Methods

The process of image segmentation depends on image pre-processing. In some cases, it represents the most important step. A wide range of methods can usually be used in the pre-processing, which usually greatly improves the results and contribute to more stable methods and more consistent results. Below we present some of the pre-processing methods used.

A. Filters

Filtering is a broad field of computer vision that covers a wide range of areas. It can be used for noise removal (smoothing), edge detection, pattern detection, extraction of features ... The filtering process involves the kernel and an input signal, which in our case represents a 2D digital image with one or more color channels. We can also represent the picture as a set of 2D matrices with discrete values. Each matrix represents its own color channel, and each matrix value represents the level of intensity at a specific pixel location point in the color channel. The nucleus can be represented as a 2D array, usually symmetric form and odd dimensions.

Image filters can be divided into two categories, non-linear and linear. An example of a non-linear filter is a *median filter*. The filter is non-linear because the output of the filter is not composed of a linear combination of input values. An example of a linear filter is a *mean filter*, for which we use convolution. The process of convolution can be represented as the weighted sum of the intensities of adjacent pixels. In the work we use filtering to remove noise in images and search for intensity transitions.

VI. System Implementation

In this section, we introduce the implementation of the system that we developed for the automatic segmentation of teeth and white stains. The solution was developed in the Python programming language using the OpenCV and SciPy libraries. With the segmentation process, we begin by first loading the input tooth image into the memory that is represented in the RGB color space. All input images should be recorded with the same dimensions so that the teeth are at the center of the image. Since this was not true for all the acquired images, some were hand-cropped later. Therefore, after we uploaded the image into memory, we changed its dimension to a size of 512×512. This was done in order to use the same parameters regardless of the dimension of the input image, without affecting the end result considerably. We captured two types of images. The first type is a standard color image, with no special features. The other type is images, illuminated with blue light at a wavelength of $450nm$.

A. Tooth Segmentation

Our primary goal is to obtain segments of teeth and white stains in order to assess the proportion of affected enamel. For this purpose, we segmented both tooth enamel and white stains. For the segmentation of teeth, we used the Otsu [15] threshold method (Figure 5). In the first step we eliminate the glare that appears on the smooth surfaces of the tooth enamel and the gums. For the localization of the glitter regions, we have used [16], [17]. The input image is converted to gray and normalized so that the values take the range between 0 and 1. According to the literature [17] a threshold value between 0.8 to 0.9 for the segmentation of regions with glare is suggested. Depending on the testing with different values, we selected threshold value of 0.8, as we obtained the best results.

So now we have a mask of regions that represent glare. The current state of the mask covers only parts of the picture where glare is the strongest, but in most cases does not cover the transition between the image and glare. If these passages are not removed, as a result, we get edges around the regions where there was a glare before. We can get rid of this by increasing the regions in the mask. We do this with the help of a morphological operator for the extension. For a structural element, we used a circle of 5 x 5.

In the article [17], the region covered by the mask is filled using Laplace interpolation. In our case, we used the algorithm inside the OpenCV library for interpolation purposes.The function that we used to fill parts with the presence of glare is called *Inpaint*. The *Inpaint* methods work by filling the missing pixel points with respect to their surroundings. OpenCV implements a method based on Navier-Stokes, and a method based on the *fast marching* [18] method.

We improved the contrast with the global stretch of the histogram, but we found that the results are not much better than the input images. That's why we used a histogram stretch which works locally only on a small window of the

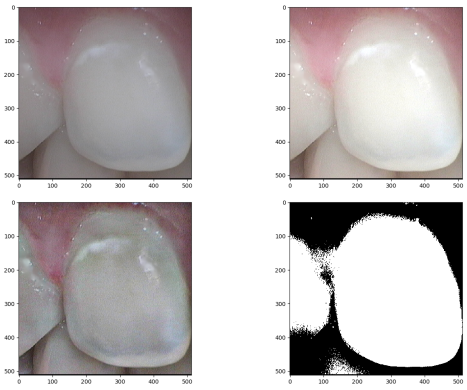

Fig. 5. First: input image; Second: global stretch of histogram; Third: CLAHE; Fourth: Otsu

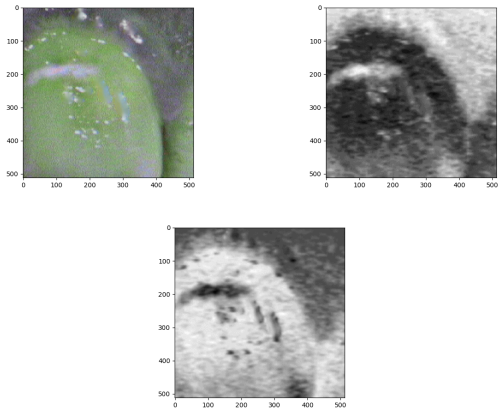

Fig. 6. Left: input image; Middle: channel A; Right: channel B

whole picture. For stretching of the histogram, we are using the CLAHE [19] method implemented within the OpenCV library. The window used is 32×32. The image 5 shows an example of an input image and a histogram stretching with both methods. In the last step of the pre-processing, we removed the noise using a Gaussian filter.

The first image in Figure 5, the segmentation contains some noise and segments of the adjacent teeth. Therefore, following the segmentation, the purification follows. First, we use a morphological operator *erosion* to eliminate possible minor connections between major regions of the segmentation. In this case, we use a structural element of the square shape (21×21). Then we find the related regions within the picture. We do this by calling the function *connectedComponentsWithStats* that is part of the OpenCV library. We used a 4-way connection for the connection type. Then we look for the largest segment and apply the opposite operator *diletation* to restore the original surface of the segment.

Given the assumption that the segmented tooth is located in the middle of the image and covering the larger part of the image, we can conclude that the largest connected region is the segmentation of the tooth. Now we have to use the opposite operator dilation to restore the original surface of the tooth.

During the analysis of the images, we found that white stains are always lighter in color than the surrounding, but this same color, which is a white spot, can also appear on other parts of the same tooth, which is a problem. When analyzing images captured by blue light, we found that candidates from regions with white spots can be segmented very easily according to the intensity of pixels in channel A or B of the CIELAB color space. As an example, we can look at the image 6. In the picture of channels A and B, we can see that the white stain completely stands out in intensity from the surrounding, which represents a healthy enamel.

In order to obtain the candidates of regions of white spots in the images taken without blue light, we implemented our own algorithm based on the growth of regions.The first step of the algorithm is finding the seed points, which will be located inside the white spots. To find candidates for points of white stains, we want to use a picture on which the sharp passages between enamel and white stains can best be seen. By experimenting we came to the conclusion that transitions are well seen on the gray picture. An example of such an image is the center image 7 (the image has inverted intensities).

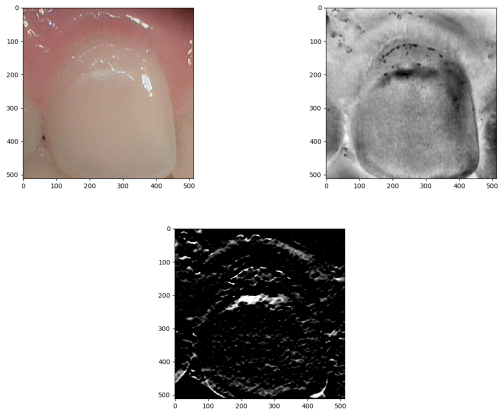

Fig. 7. Left: input image; Mid: gray image of the input image; Right: intensity difference after filtering

To obtain the approximate location of the WSL or larger white region, we used filtering with a 9×9 linear filter. The idea stems from edge-search approaches. For example, an extended Sobel filter. We find all the pixels that represent the above 5% intensities. Now we have a picture that consists of smaller regions that appear on the edges of the white stains. Since we need only a point for the region growth algorithm, we need to get at least one pixel location from each region, which will represent one of the starting points of the algorithm. This is done by using the OpenCV function *connectedComponents* separately for each associated region.

VII. Results

We used a collection of 30 images of teeth with WSL for testing. Of these, 10 images are covered with blue light and

TABLE I

TOOTH SEGMENTATION WITH THE OTSU METHOD

Image	F1	Prec	Sen	Spec
1	0.61	1.00	0.44	1.00
2	0.64	1.00	0.47	1.00
3	0.70	0.93	0.57	0.95
4	0.42	0.43	0.41	0.62
5	0.34	0.39	0.30	0.68
6	0.64	1.00	0.47	1.00
7	0.69	0.91	0.56	0.94
8	0.43	1.00	0.27	1.00
9	0.43	1.00	0.28	1.00
10	0.51	0.78	0.38	0.92
11	0.40	1.00	0.25	1.00
12	0.44	1.00	0.28	1.00
13	0.48	1.00	0.31	1.00
14	0.73	0.82	0.66	0.84
15	0.59	1.00	0.42	1.00

Image	F1	Prec	Sen	Spec
16	0.55	1.00	0.38	1.00
17	0.55	1.00	0.38	1.00
18	0.54	1.00	0.37	1.00
19	0.51	1.00	0.35	1.00
20	0.49	1.00	0.32	1.00
21	0.52	1.00	0.36	1.00
22	0.48	1.00	0.32	1.00
23	0.45	1.00	0.29	1.00
24	0.60	1.00	0.43	1.00
25	0.64	1.00	0.47	1.00
26	0.62	1.00	0.45	1.00
27	0.62	1.00	0.45	1.00
28	0.60	1.00	0.42	1.00
29	0.63	1.00	0.46	1.00
30	0.55	0.95	0.40	0.96
Avg	0.55	0.94	0.40	0.96

TABLE II

SEGMENTATION RESULTS OF WHITE STAINS (WSL)

Image	F1	Prec	Sen	Spec	T
1	0.79	0.77	0.82	1.00	n
2	0.92	0.98	0.87	1.00	b
3	0.81	0.84	0.79	0.99	b
4	0.19	0.12	0.45	0.90	n
5	0.19	0.12	0.45	0.92	n
6	0.93	0.91	0.96	1.00	b
7	0.81	0.80	0.83	0.99	b
8	0.24	0.15	0.53	0.89	n
9	0.49	0.41	0.62	0.95	n
10	0.62	0.85	0.49	0.99	n
11	0.30	0.89	0.18	0.99	n
12	0.62	0.97	0.46	1.00	n
13	0.51	0.43	0.62	0.93	n
14	0.29	0.22	0.43	0.94	n
15	0.37	0.33	0.43	0.98	n

Image	F1	Prec	Sen	Spec	T
16	0.60	0.69	0.53	0.99	n
17	0.60	0.76	0.50	0.99	n
18	0.48	0.72	0.36	0.99	n
19	0.47	0.31	0.95	0.92	n
20	0.60	0.63	0.57	0.97	n
21	0.49	0.54	0.44	0.98	n
22	0.00	0.00	0.00	0.96	n
23	0.52	0.47	0.58	0.95	n
24	0.79	0.70	0.90	0.98	b
25	0.74	0.74	0.74	1.00	b
26	0.73	0.83	0.65	1.00	b
27	0.77	0.80	0.73	0.98	b
28	0.81	0.75	0.88	0.98	b
29	0.54	0.58	0.58	0.97	b
30	0.54	0.58	0.58	0.97	n
Avg.	0.56	0.60	0.60	0.97	

20 plain images. Testing was performed on the Ubuntu 16.04 operating system with an Intel i7 4700HQ @ 3.40 GHz and 16 GB memory. The main goal of the work was the implementation of the prototype system for automatic assessment of the affected area of dental enamel with white stains. Since the problem has been divided into the segmentation of teeth and white stains, we will also present the results separately. A good prediction model should achieve high Recall and high Precision. A single measure, the F1-measure, is used to combine Recall and Precision. It is defined as the harmonic mean of Precision and Recall (a more general form of F1-measure is defined as a weighted harmonic mean of Precision and Recall). The values of Recall, Precision, and F1-measure are between 0 and 1; the higher, the better [20].

$$F_1 = 2 \times \frac{precision \times recal}{precision + recal}$$

As we can see in the table I, the specificity is almost always above 0.90, which means that our segmentation is almost entirely within the region of interest. If interpreted by the formula of specificity, then this means that we almost never return the background as part of the region of the tooth. The threshold methods are very fast, which can be confirmed in our case. The process of tooth segmentation with the Otsu method takes on average $2s$ ($2.06s \pm 0.54s$).

A. White Stain Segmentation Capacity

Table II contains the white spot segmentation results with the region growth method. In the segmentation we took into account information about the image type, the solution of the tooth segmentation and the localization of the glare areas. We segmented the white spots according to the type of image. The image type is represented in the table II in the T column. If the T column value is n then the picture is normal otherwise, it is illuminated by blue light b.

From the table II we can see that the performance is significantly better on the images illuminated by the blue light than in the ordinary pictures. On average, F is higher for 0.34.

VIII. FUTURE WORK

As we have seen from the results of the evaluation of the system, there is still a lot of room for improvements. One of the more important things that need to be improved if we want to continue to develop the system is to increase the database. In addition to low-level approaches, we could use and experiment with more advanced methods that require as many cases as possible, for example, deep neural networks. In addition to increasing the number of images, their quality and resolution should also be improved.

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EEG Based Imaging of Stroke Location, Extent and Progress of Recovery Using a GPU Architecture

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***Abstract* – This paper describes a new EEG-based imaging method that can depict the location and extent of stroke lesions similar to MRI scans. The ratio of delta and alpha band powers as well as a modified brain symmetry index is used with high-density EEG technology for generating topographical maps. Calculations are implemented on a GPU card achieving real-time processing speed making the method usable for continuous patient monitoring. The maps can help in verifying treatment effectiveness as well as measuring progress of recovery.**

Keywords - stroke; quantitative EEG; brain imaging; GPU; continuous monitoring

I. INTRODUCTION

Ischemic stroke is one of the major causes of death or permanent disability with increasing frequency of occurrence as the population in developed countries is aging. Timely treatment of stroke starts with an MRI and/ or CT scan to identify the location and extent of brain damage. After diagnosis, treatment starts and the condition of the patient is monitored by the medical staff based on external symptoms using standardized stroke scales (NIHSS, BI, etc.) [1], [2]. A second MRI scan might be performed on patient dispatch to confirm recovery status.

Unfortunately, complications can develop in the hospital, e.g. Delayed Cerebral Ischemia (DCI), which can only be discovered once symptoms worsen [3]. Also, efficiency of the treatment is difficult to assess without monitoring quantitative stroke metrics. These metrics could help in selecting the best treatment path, and be used as predictors for the level of recovery at the end of the rehabilitation period [4]–[7].

Continuous monitoring of patients and the use of mainly frequency-domain quantitative measures have already been suggested [7]–[10]. It is known that these metrics can detect stroke-related status changes well before symptoms develop [7]. The reported methods all rely on the calculation of a single metric from measurements using a standard 19-electrode clinical EEG system. We extend this approach by proposing the use of high-density EEG (128 or more channels) and topographical mapping of the metrics to show the location and extent of the stroke area. This representation also facilitates measurement of change as an indicator of the speed of recovery and outcome.

For achieving real-time computation of these metrics in high-density, high sampling frequency configurations, we implemented the method on a GPU architecture that can execute massively parallel algorithms with thousands of threads very efficiently.

The structure of the paper is the following. In Section II, we provide a brief overview of the quantitative EEG metrics typically used in stroke monitoring. In Section III, our improvement on the metrics to produce topographic information is described, then the details of the GPU implementations presented. Section IV shows the achieved results and finally, the paper ends with conclusions and future plans.

II. QEEG IN STROKE TREATMENT

The use of EEG in stroke diagnostics, treatment and rehabilitation has been researched since the 1980s [5], [11]. It is well known that stroke affects the activity in different frequency bands; delta and theta band intensity increases whereas alpha and beta band intensity decreases proportionately with the severity of the stroke [12]–[14]. A number of quantitative EEG measures (qEEG) based on frequency-domain information have been derived over the past few decades, such as different band powers, band power ratios, band variability, spectral edge frequency and different symmetry indexes [4]. These measures allow clinical specialist to precisely quantify EEG features and abnormalities as opposed to traditional qualitative waveform inspection. The Delta/Alpha power ratio (DAR) and the low frequency Brain Symmetry Index were found to be the most effective biomarkers of acute stroke [15] [16]. The DAR is defined as

$$\mathrm{DAR}=\frac{P_\delta}{P_\alpha}\quad , \tag{1}$$

where $P_\delta=\sum_{f=1}^{4} S^2(f)$, $P_\alpha=\sum_{f=8}^{12.5} S^2(f)$, $S(f)$ is the magnitude of the Fourier transform at frequency f (Hz).

The (standard) brain symmetry index (sBSI) [17] is defined as

$$\mathrm{sBSI}=\frac{1}{N}\sum^{K}\frac{1}{M}\Big|\sum^{M}\frac{R_{i,j}-L_{i,j}}{R_{i,j}+L_{i,j}}\Big| \quad , \tag{2}$$

where $R_{i,j}$ ($L_{i,j}$) are the Fourier coefficients belonging to frequency i = 1, …, K of the right (left) hemispheric bipolar lead derivations j = 1, 2, …, M. The revised standard BSI [18] uses the squared Fourier coefficients to increase sensitivity, and is expressed as:

$$\text{r-sBSI}(t) = \frac{1}{K}\sum_{\cdot}^{K}\left|\frac{R_n^{\cdot}(t)-L_n^{\cdot}(t)}{R_n^{\cdot}(t)+L_n^{\cdot}(t)}\right| \quad , \qquad (3)$$

where $R_n^{\cdot}(t)=\frac{1}{M}\sum_{ch=1}^{M}\alpha_n^2(ch,t)$, and $R_n^*(t)=\frac{1}{M}\sum_{\text{ch}=1}^{M}\alpha_n^2(\text{ch},t)$ $\alpha_n(ch,t)$ is the Fourier coefficient with index n of channel ch, evaluated at time t, corresponding to a particular epoch [t - T, t] with duration T. In the original article, T = 10 s.

A further variant, the *single channel pair averaged revised spatial Brain Symmetry Index* (pdBSI) is proposed in [19] that uses channel pair averages instead of global averages in calculating the symmetry index:

$$\text{pdBSI}=\frac{1}{NM}\sum^{M}\sum^{N}\left|\frac{R_{i,j}-L_{i,j}}{R_{\cdot}+L_{\cdot}}\right| \quad , \qquad (4)$$

where $R_{i,j}$ and $L_{i,j}$ are the FFT-based power spectral density values obtained from a right and, respectively, left channel of a homologous channel pair (i =1, 2, ..., M) at frequency j =1, 2, ..., N.

The advantage of these metrics is that they can be calculated in the clinical environment and when plotted as a curve used for monitoring the patient's status and recovery. DAR and BSI exceeding a threshold value indicates stroke well before symptoms develop, hence treatment can be started before irreversible neural tissue deterioration occurs [20].

III. Quantitative Stroke Imaging

The disadvantage of the above methods is that they provide a result either as a single global scalar value or a value changing as a function of time. There is no spatial information similar to what is available in CT or MRI scans. If we could provide 2D (or 3D) images containing spatial information based on EEG measurements, a more cost effective and patient-friendly monitoring method would become available.

Earlier attempts to creating such images are known [11], [21]. The shortcoming of these methods is that the resulting maps have very low resolution due to low number of electrodes in the 10-20 clinical EEG systems. A more recent study [22] examined the spatial sampling requirements for stroke localization and found that at least 64 electrodes should be used and 128 electrodes is recommended.

Our proposed method generates 2D topographical images of the Delta/Alpha ratio and a spatially-extended brain symmetry index by calculating these values for the electrodes of a 128-channel EEG layout, then using the electrode values, creating a high-resolution interpolated image as the final result.

A. Delta/Alpha Power Ratio

The rationale behind using the delta/alpha ratio (DAR) for topographic map generation is based on the fact that delta band intensity increase is caused by reduced blood flow [23] and this effect is confined to the stroke affected brain areas. On the other hand, higher frequency activity (alpha, beta, gamma) is attenuated in stroke patients, although in a less localized manner.

Averaging a high number electrodes for creating a single DAR value decreases the overall effect of high but localized delta power. We propose to calculate the DAR for each electrode and instead of averaging them, use the values to create a map by spherical spline interpolation [24]. Assuming a spherical head model for simplicity, for any given surface point E on the sphere, the potential U can be calculated as

$$U(E)=c_0+\sum^{N}c_i g\left(\cos\left(E,E_i\right)\right) \quad , \qquad (5)$$

$C(E)=\sum_{i=1}^{n}c_i h\left(cos(E,E_i)\right)$where E_i is the ith electrode on the surface of the sphere, and the c_is are the solution of the following equation:

$$\mathbf{GC}+Tc_0=Z \qquad (6)$$

where $\mathbf{T}'$=(1,1,…,1), $\mathbf{C}'$=(c_1, c_2, …, c_n), $\mathbf{Z}'$=(z_1, z_2,…, z_n) $\mathbf{T}'=(1,1,\ldots,1)$and $G=(g_{ij})=\left(g\left(\cos\left(E,E_i\right)\right)\right)$ $\mathbf{G}=(g_{ij})=\left(g\left(cos(E_i,E_j)\right)\right)$, where z_i is the potential measured at electrode E_i. In the proposed DAR map method, the potential is replaced with the delta/alpha ratios: z_i = DAR(i) = $P_{delta}(i)/P_{alpha}(i)$. The potential function $g(x)$ $g(x)$is defined as the sum of the following series:

$$g(x)=\frac{1}{4\pi}\sum^{\infty}\frac{(2n+1)}{m(\cdot\cdot+1)^m}P_n(x) \quad , \qquad (7)$$

where $P_n(x)$ is the nth degree Legendre polynomial and m is the stiffness parameter of the spline. The summation theoretically is infinite; in practice, n is sufficient to be between 15 and 50.

B. Brain Symmetry Index

Generating a symmetry map requires more modifications to the original BSI computing approaches. Similarly to the DAR map, the first step is to compute BSI values for each individual electrode. The symmetry ratio for an electrode r_i is defined as:

$$r_i=\sum^{N}\frac{R_{i,j}-L_{i,j}}{R_{\cdot}+L_{\cdot}} \quad , \qquad (8)$$

where i is the index of a give right-left electrode pair, and j is the frequency index, $1 < j < 25$. Since the sum is calculated without taking the absolute value, r_i preserves spatial information; if it is positive, the asymmetry

increased on the right, if negative, asymmetry increased on the left hemisphere. This indicates the location of the stroke lesion (consequence of the increased delta band power). The electrode values are subsequently modified to hold results only for the symmetry-increased areas using the following rules:

$$BSI_i^L = \begin{cases} -r_i & \text{if } r_i < 0 \\ 0 & \text{otherwise} \end{cases}$$
$$BSI_i^R = \begin{cases} r_i & \text{if } r_i > 0 \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

where BSI_i^L and BSI_i^R are the *BSI* values for the left and right hemisphere electrode, respectively. After substituting z_i with the appropriate *BSI* value $z_i = BSI_i^{L|R}$, the same spline interpolation as for DAR can be used to generate the symmetry map.

C. GPU Implementation

The reason for implementing the proposed method on GPU is performance that can help in reducing the execution time of the significant amount of calculations. Modern general-purpose GPUs are massively parallel execution engines with performance in the TFlops (10^{12} floating-point operations per second) range. For instance, the top-of-the range Nvidia Titan Xp GPU has 3840 cores and 12 GB memory, performance is 10 TFlops. This is several orders of magnitude higher than that of multi-core CPUs. Our implementation is developed in the CUDA-C programming environment. For a more detailed architectural and programming description of Nvidia GPUs, the reader is referred to the literature [25].

The calculation of the proposed metrics are based on the following sequence of operations:

Step 1: *Preprocessing: filtering and windowing*
Step 2: *FFT calculation*
Step 3: *PSD estimation*
Step 4: *qEEG metric calculations*

The remaining part of this section describes each step in detail including their computational and memory requirements, based on the following parameters: f_s = 2048Hz, 128 simultaneous EEG channels and 20s (or 128×20×2048 samples) long dataset. It is assumed that EEG data is arranged in a channels × samples matrix, where the rows represent the channels and columns the samples and samples are stored as 32-bit float values.

1) Preprocessing

Measurement data was filtered on the CPU side with a 674-tap FIR equiripple low-pass filter (Fpass = 42 Hz, Fstop = 48 Hz -60 dB) [26]. A custom kernel performs segment mean removal, segment windowing (Hamming window) and generating overlapped segments for the FFT computation step. The number of operations required for this step is $20\times2048\times128\times(674+1) \approx 3.5\times10^9$, the required memory is 2×20 MB.

2) FFT calculation

The Fourier transformation is performed with the Nvidia cuFFT library [27]. The library supports batch real-to-complex FFT which can be used for the simultaneous execution of *M* parallel FFTs, where *M* is the number of channels. The library must be initialized before executing the FFT by calling the `cufftPlanMany` function that configures that `num_channels` transforms must be performed in parallel.

```
int dim[3];
dim[0] = fs;
dim[1] = dim[2] = 0;
cufftPlanMany(&plan, 1, dim, 0, 0, 0,
       0, 0, 0, CUFFT_R2C, num_channels);
```

After the initialization, the transform is executed for one-second long signal segments with 50% overlap for a 20-second measurement with the following function call:

```
cufftExecR2C(plan, d_signal[i*K],
             d_fft[i*Q]);
```

where `i` is the index of the current signal segment, `K` and `Q` are the segment memory offsets for the input and output data, `d_fft` is the data structure for the transform output matrix stored in global memory. In our case, the sampling frequency `fs` was 2048Hz. The reason for using this sampling frequency is that this is the lowest available sampling rate in our Biosemi ActiveTwo EEG device. IN addition, we were also interested in the performance of the algorithms in this high frequency range, since similar frequency-domain analysis is performed in epilepsy diagnostics in which fast ripples (250-600Hz) of diagnostic value must be detected. A 2048-point FFT was used resulting in 1 Hz frequency resolution. The number of operations required for this step – assuming 1s FFT windows with no overlap – is $128\times20\times2048\times\log_2(2048) \approx 5.7\times10^7$, and the required additional memory for the complex Fourier coefficient output matrix is 20 MB.

3) PSD estimation

Calculating the power spectral density required the development of a custom CUDA kernel that implements Welch's estimation method by computing the squared magnitude of the FFT coefficients and averaging segment power spectra. The output variable `d_fft` is stored in channel order, segment after segment as illustrated in Fig. 1. Data is arranged in channel order 1-second long segments. Each thread in the `psd` CUDA kernel computes the power of one segment by computing the squared amplitude of the FFT coefficients, then averaging the segments S_i sample by sample s_j, where $i = 1,2,\ldots,20$ and $j = 1,2,\ldots,f_s$.

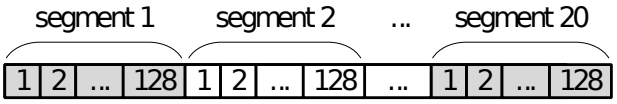

Figure 1. Layout of FFT coefficients in device memory. Small boxes represent 1-second signal segments of a given channel. Each segment holds $N=f_s$ number of data samples.

Averaging is implemented by local and global reduction. Each thread reads the sample value s_j of channel k, $k = 1,2,\ldots,128$, from segments S_i, $i = 1,2,\ldots,20$ accumulating the sum in a local variable then storing the final average $avg_{k,j}$ in global memory. The number of operations is $128\times20\times2048\times3 \approx 1.57\times10^7$, and the

required additional memory for the PSD output vector is 512 KB.

4) Calculation of the qEEG measures

The final step of the process is the calculation of the DAR ratios and the Brain Symmetry Indexes for each electrode. Since in stroke characterization, we are only interested in the frequency range of 1-45 Hz (δ, θ, α, β bands), only the first 64 entries of the PSD vector are used (64 is used to ensure number of threads are multiples of the warp size). A custom kernel with 128 × 64 threads are launched (thread block size = 64), in which each thread block computes the α, β, δ, etc. band powers of one channel. Band powers are computed by selective sum reduction using the new CUDA 9 `__shfl_down_sync` instruction that allows threads to access the registers of other threads within a thread block in a very efficient manner without using shared memory.

The parallel implementation of the symmetry index calculation relies on reduction operators. For each left and right electrode, the PSD values must be summed from 1 to 25 Hz. 32-thread blocks are launched in a grid of N blocks, where *N* is the number of electrodes, in our case 128. The threads in the block perform a sum-reduction relying again on the `__shfl_down_sync` instruction. Once the sums are calculated, the final electrode value is calculated using the rule given in (9).

The final step of the procedure is the topographical map generation. qEEG metrics are calculated for each electrode, the DAR and BSI maps can be generated using the above-mentioned spline interpolation technique. The details of the GPU implementation of this interpolation can be found in [28].

IV. RESULTS

In this section, we illustrate our current results using data from one stroke patient. Fig. 2 shows the MRI scan of the patient taken on the day of admission. Signs of a small left subcortical lacunar infarct is visible on the images. Closed-eye resting state EEG was measured 8 and 99 days after the stroke onset.

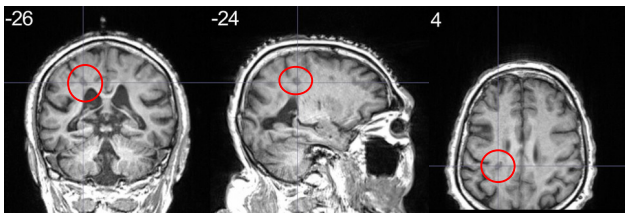

Figure 2. MRI scan of a stroke patient. Red circles indicate stroke lesion

Fig. 3 illustrates the DAR topography map produced from the electrode-level delta-alpha ratios using a 20-second long data sequence for the patient whose MRI in Fig. 2 shows clinically validated stroke lesion in the left parietal region. The left DAR map shows the day 8, whereas the right map shows the day 99 results. The correlation of the high intensity area on the left EEG map with the MRI is clear. The map correctly marks the location of the stroke. The intensity of the stroke area on the day 99 map is reduced to nearly zero, indicating the normalization of the delta and alpha frequency range activities in the patient's brain. This corresponds to the clinical NIHSS 0 score established 3 month after the stroke. The EEG data was carefully cleaned from artefacts prior to qEEG calculations to ensure the topography shows real power distribution features, not noise or other artificial phenomena.

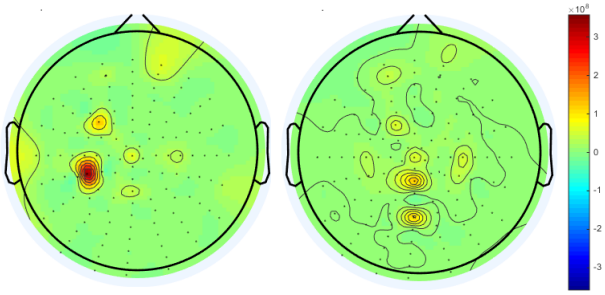

Figure 3. Delta/alpha power ratio map of the a patient measured 8 days (left) and 99 days (right) after stroke onset. Note the high-intensity area at the stroke location (left) that disappears after recovery (right).

Fig. 4 illustrates the brain symmetry map based on our proposed modification to the BSI calculation for the same patient, 8 and 99 days following the stroke incident. Note how the highlighted area (asymmetry increase) depicts the location and extent of the stroke on the left map. Similarly to Fig. 3, the right map shows improvement.

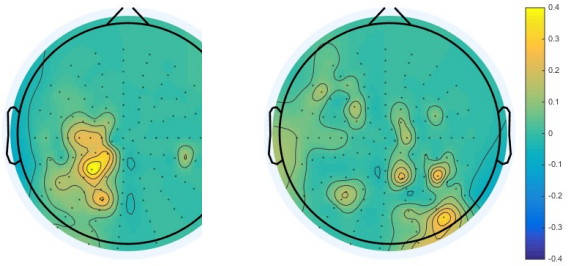

Figure 4. Symmetry map of the same patient on the day of stroke (left) and three months after the stroke (right). Note the high-intensity area at the stroke location (left) that disappears after recovery (right) and the map becomes more symmetric.

Fig. 5 illustrates the effect of using concurrent CUDA streams in calculation of the qEEG features for the 20-second data window. The Titan Xp GPU can support max. 32 concurrent kernels, hence using concurrent streams might result in better overlap of load/store and arithmetic operations. The use of at least 4 streams significantly reduces the overall execution time.

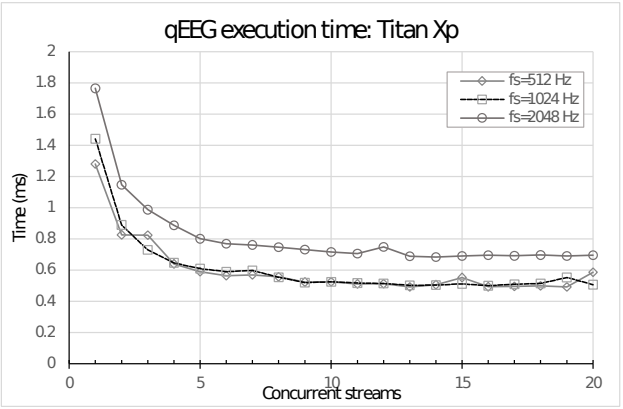

Figure 2. Execution time of the GPU qEEG calculation in function of the number of concurrent cuda streams and sampling frequency.

Execution time does not decrease beyond 6 concurrent streams. At this point the GPU chip is saturated, there are no more empty slots for further parallel instruction execution.

Finally, Table 1 lists the execution times measured on an entry-level and a top-of-the-range GPU compared to the NEURAL [29] qEEG features Matlab (CPU) implementation. Since this toolbox was not developed for performance benchmarking, the Matlab results are used here for indicative purpose only, to show the typical CPU execution times found in Matlab-based EEG data analysis for this task. The Matlab script used a single core for execution.

Execution times are given for computing the DAR and BSI measures from a 20-second dataset, using 128 channels and varying sampling frequency (512-2048 Hz). In the GPU case, the 512 Hz and 1024 Hz sampling frequencies were simulated by subsampling the dataset.

The results show that even with an entry level GPU card one can achieve two orders of magnitude faster execution when compared to a single-core Matlab implementation. A high-end GPU card, however, can achieve three orders of magnitude higher speed. Even if the CPU implementation can be optimized, the GPU implementations are expected to perform better.

TABLE I. GPU EXECUTION TIME (128 CHANNELS)

f_s (Hz)	Time (ms)		
	CPU Matlab	***Quadro K2000M***	***Titan Xp***
512	843.91	8.479	0.49
1024	1625.83	11.226	0.50
2048	4150.65	18.716	0.68

V. CONLUSION

A new imaging method was presented for creating 2D topographic stroke maps based on the delta/alpha power ratio and an improved brain symmetry index. The methods were implemented in a massively parallel fashion for NVIDIA GPUs which resulted in sub-millisecond execution times. In combination with MRI and CT scans, the EEG maps can be used to locate stroke lesions and monitor the amplitude and extent of changes during rehabilitation. The real-time capabilities might also allow the method to be used for monitoring during Carotid Endarterectomy [17], [30]–[33]. Further work is required to clinically validate the method as well as to fine-tune the algorithm, and investigate the possibilities of 3D imaging using realistic head models.

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Predicting the effectiveness of multi-drug cancer therapies

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Abstract - **Despite the ongoing development of new targeted cancer drugs, the survival rate of patients with aggressive forms of cancer like lung and pancreatic cancer is still poor. The main reason is the ability of cancer to develop resistance against cancer drugs. One strategy to overcome this resistance is to use cancer therapies with several drugs administered at the same time. This can increase our chances to kill cancer cells before they develop resistance. In order to investigate the effectiveness of such therapies, we let the in silico model of cancer Vini to calculate the most effective 2-drug therapies against non-small cell lung (NSCLC), small cell lung cancer (SCLC), and pancreatic cancer. Vini calculated the combination of vinorelbine with paclitaxel as the most effective against NSCLC, the combination of everolimus with doxorubicin as the most effective against SCLC, and the combination of everolimus with paclitaxel as the most effective against pancreatic cancer. As the existing clinical studies confirm Vini's calculations, it is justified to let Vini search for the combined cancer therapies with even more drugs. In order to further increase their effectiveness, the next research step will be the personalization of such therapies.**

Keywords – cancer resistance; effectiveness of cancer therapy; in silico model of cancer; multi-drug cancer therapies; personalized medicine

I. INTRODUCTION

Despite the steady progress with targeted cancer therapies [1], the average survival rate in some of the most aggressive forms of cancer is still very poor. According to American Cancer Society, the percentage of surviving patients within 5 years in stage IV of lung and pancreatic cancer equals 4% and 1%. One of the most important reasons for such a poor survival rate is the ability of cancer to acquire resistance to the certain cancer drugs via DNA damage repair, drug inactivation, drug target alteration, drug efflux, cell death inhibition, epithelial-mesenchymal transition, and cell heterogeneity [2]. Radiotherapy resistance is also common in certain types of cancer, for example in the lung [3] and pancreatic cancer [4]. Cancer can even gain resistance to any known drug, which is known as multi-drug resistance [5]. For this reason, it is of the utmost importance to find ways to suppress and overcome the ability of cancer to develop chemotherapy and radiotherapy resistance. There are various strategies for this, like inhibiting STAT3 signaling [6], or by targeting inhibitors of apoptosis proteins (IAPs) [7]. Another strategy are multi-drug cancer therapies, which aim to use several cancer drugs simultaneously [8]. The complexity of cancer biology [9] can impose a big challenge to such an approach, as interactions between drugs may intensify adverse events or even reduce their anti-cancer effects [10]. While drugs interaction software [11] can help to avoid drug combinations that will likely intensify adverse event, the same is not true if someone wants to avoid reducing anti-cancer effects instead of increasing them. At this moment the cancer system biology [12] seems the only method allowing us to estimate the antitumor efficacy of combined cancer drugs. In system biology, genes and proteins involved in cancer processes are represented with entities in databases, and the relations between them are described with networks and pathways [13]. There is a similarity between cancer networks and cancer pathways. However pathways are well defined and relatively simple structures, while networks are complex and noisy, but they likely contain novel information not contained in pathways. Deriving information from cancer networks and pathways can be performed with various in silico models of cancer, software tools working on proteomic, genomic and molecular levels [14]. Vini in silico model of cancer [15] uses KEGG cancer pathways [16]. Vini transforms these pathways into the matrices representing binding energies between the genes and proteins on the one hand, and drugs being investigated on the other side. Vini uses program for molecular docking Autodock Vina [17] which computes binding energies between genes/proteins of a certain cancer pathway and certain cancer drug. Then, Vini computes the second largest eigenvalue in magnitude (abbreviated SLEM) of this matrix [18]. The process is repeated for all cancer drugs under the investigation, and matrix with the highest SLEM points to the most effective drug against this cancer type. Vini is able to perform the same calculation for combinations with the arbitrary number of cancer drugs.

II. METHODS

The number of combinations with N drugs and without repetition is *N* factorial:

$$n = N! \tag{1}$$

If the order of drugs within combinations is important, the combinations are permutations. There are two types of permutations: with or without repetition. For example, the permutation of two cancer drugs A and B has four permutations with repetition: AB, BA, AA and BB. If the repetition is not allowed, there will be two permutations: AB and BA. **In the analysis of the effectiveness of multi-drug cancer therapies, of importance are permutations without repetition.** The number of permutations of *r* drugs within a set of *N* drugs provided that repetition is not allowed is:

$$n = \frac{N!}{(N-r)!} \tag{2}$$

The number of FDA approved cancer drugs in the period from the year 1949 until the year 2014 is 150 [19]. Thus, the total number of drug combinations is 150! which equals 5.713383956 E+262. However, in most cases, the maximum number of cancer drugs in the combination is up to 4. The reason for this limitation are possible interactions between drugs, that can lead to unwanted toxic effects and even to the decrease in the efficacy of cancer therapy. Table 1 provides the number of combinations with 2, 3, and 4 FDA approved cancer drugs:

Table 1: The number of n-drug combinations with FDA approved cancer drugs

n	number of combinations
2	22.350
3	3.307.800
4	486.246.600

The further limiting factor is that not all cancer drugs are approved for all cancer types. FDA approved 38 drugs for NSCLC, 7 for SCLC, and 15 for pancreatic cancer. Table 2 shows the number of combinations with these constraints:

Table 2: The number of n-drug combinations for NSCLC, SCLC, and pancreatic cancer.

n	NSCLC	SCLC	pancreatic cancer
2	1.406	42	210
3	50.616	210	2.730
4	1.771.560	840	32.760

We used the in silico model of cancer Vini for the analysis of the efficacy of multi-drug cancer therapies. Vini transforms the metabolic pathways of cancer into the matrices with matrix elements representing binding energies between the genes and proteins on one side and drugs being investigated on another side. Some matrix elements also represent interactions between proteins and genes. Then, Vini calculates SLEM values of these matrices to estimate the efficiency of existing cancer drugs, as well as to determine suitable candidates for new cancer drugs. In the case of the analysis of the efficacy of drug combinations, Vini first simulates the molecular docking of the first drug in the combination to genes in a certain cancer pathway. The results are complex molecular structures, each containing both gene fragments and drug fragments. After that, Vini simulates the molecular docking of the second drug in the combination to those complex structures. The process is repeated until the simulation of molecular docking of the last drug in the combination is performed. In multi drug analysis, these matrices contain only the binding energies between genes of specific cancer pathways and the drug combination. The reason for this is that the binding energies are much higher in a multi-drug environment, so we may neglect the interactions between genes. Vini model of cancer uses Autodock Vina software for calculating binding energies between receptors and drugs. Autodock Vina is able to simulate docking of receptors with many chemical cancer drugs. These drugs have relative small molecules. On the other side, Autodock Vina does not work well with protein based cancer drugs having large molecules and Dalton masses. These drugs are mainly monoclonal antibody cancer drugs (MABs), like bevacizumab, trastuzimab, ramucirumab, necitumumab, atezolizumab, durvalumab, and pembrolizumab, approved for NSCLC, and nivolumab, which is approved both for NSLC and SCLC. Therefore, the number of the approved drugs included in our analysis is reduced to 18 drugs for NSCLC, 7 drugs for SCLC, and 8 drugs for pancreatic cancer. Table 3 provides the list of these drugs:

Table 3: The list of cancer drugs approved for NSCLC, SCLC, and pancreatic cancer, and analyzed by Vini. Numbers are their indices used in the analysis.

NSCLC	SCLC	Pancreatic cancer
afatinib_ 0	doxorubicin_0	erlotinib 0
alectinib_1	etoposide_1	everolimus 1
brigatinib_2	etoposide-phosphate_2	fluorouracil 2
ceritinib_3	everolimus_3	floxuridine 3
crizotinib_4	mechlore-thamine_4	gemcitabine 4
dabrafenib_5	methotrexate_5	irinotecan 5
docetaxel_6	topotecan_6	mitomycin 6
erlotinib_7		paclitaxel 7
everolimus_8		
gefitinib_9		
gemcitabine_10		
mechlore-thamine_11		
methotrexate_12		
osimertinib_13		
paclitaxel_14		
pemetrexed_15		
trametinib_16		
vinorelbine_17		

Furthermore, given that the number of drugs covered by the analysis is reduced, the number of their combinations is also reduced, and is shown in table 4:

Table 4: The number of n-drug combinations against NSCLC, SCLC, and pancreatic cancer, analyzed in this essay.

	NSCLC	SCLC	Pancreatic cancer
2-drug Combinations	306	42	56
3-drug Combinations	4.896	210	336
4-drug Combinations	73.440	840	1.680

There are 72 genes in KEGG cancer pathway for SCLC, and 80 genes in KEGG cancer pathways for NSCLC and pancreatic cancer. The number of molecular simulations equals the number of genes in specific cancer pathway multiplied with the number of drug combinations. These numbers are given in table 5:

Table 5: The number of required molecular simulations

	NSCLC	SCLC	Pancreatic Cancer
single drug	1440	504	640
2-drug combinations	24.480	3.024	4.480
3-drug combinations	391.680	15.120	26.880
4-drug Combinations	5.875.200	60.480	134.400

During it's run Vini predicted the efficacy of 2-drug combinations.for all three types of cancer. However, as the results from 1-drug molecular simulations are input values for 2-drug molecular simulations, the total number of simulations equals the sum of all elements in the first two raws and is 34.568. Molecular simulations are computationally intensive. The time needed to perform molecular simulation and to compute binding energies between a certain gene and cancer drug on one processor core is typically several minutes. As the overall computational time is proportional with the number of molecular simulations, it means that even on a system with hundreds of processor cores, the simulation for all 3 and 4-drug combinations can last for a weeks. That is why we have limited our analysis to 2-drug combinations. Simulation lasted for approximativelly 72 hours and in average utilized 80 processor cores.

III. RESULTS

The efficacy of certain cancer drugs and their combinations (permutations without repeat) is evaluated by computing the Second Largest Eigenvalues in Magnitude (abbreviated SLEM) of the corresponding energy binding matrices. Higher SLEM values indicate the stronger anti-cancer drug activity. However, with two cancer drugs, e.g. drug A and drug B, their order does matter: The efficacy of AB and BA drug combinations must differ, and this is discussed in section IV, paragraph C. Therefore, it is reasonable to choose as the most effective the 2-drug combination with the highest sum of their SLEM values. This can be recast as the following optimization problem:

maximize (SLEM(AB) + SLEM(BA)) (3)
subject to: cancer type

SLEM values for single and 2-drug combinations against pancreatic and SCLC cancer drugs are given in tables 6 and 7. Due to the space constraints and relative large number of 2-drug combinations against NSLC, only SLEM values for single drugs are given in the table 8, and their effectiveness is discused hereafter.

As shown in table 6, single drug paclitaxel (ID 7) shows the highest activity with SLEM = 12.40 against pancreatic cancer. For 2-drug combinations order does matter. For example, the 2-drug combinations with the highest anti-cancer activity are everolimus with paclitaxel (SLEM_17 = 14.40) and paclitaxel with everolimus (SLEM_71 = 10.70). These two combinations also have the highest sum of SLEM values (SLEM_17 + SLEM_71 = 25.10). The 2-drug ombinations of everolimus with irinotecan (SLEM_15 = 14.40) and irinotecan with everolimus (SLEM_51 = 7.20) reached the second highest sum of SLEM values (SLEM_15 + SLEM_51 = 21.60):

Table 6: SLEM values for the cancer drugs against pancreatic cancer

ID	SLEM	ID	SLEM	ID	SLEM
0	7.50	20	1.00	51	7.20
1	11.70	21	1.00	52	7.20
2	5.00	23	1.00	53	7.30
3	6.90	24	1.00	54	7.30
4	7.40	25	1.00	56	7.20
5	11.20	26	1.00	57	7.20
6	7.60	27	1.00	60	3.50
7	12.40	30	2.20	61	3.60
01	3.70	31	2.20	62	3.50
02	3.70	32	2.20	63	3.50
03	3.70	34	2.20	64	3.50
04	3.70	35	2.20	65	3.50
05	3.70	36	2.20	67	3.50
06	3.60	37	2.20	70	10.70
07	3.70	40	2.10	71	10.70
10	14.40	41	2.20	72	10.70
12	14.40	42	2.10	73	10.70
13	14.50	43	2.20	74	10.70
14	14.40	45	2.10	75	10.70
15	14.40	46	2.20	76	10.70
16	14.50	47	2.10		
17	14.40	50	7.30		

SLEM values for approved drugs against SCLC and their 2-drug combinations are given in the table 7. Single drug everolimus (ID 3) shows the highest activity with SLEM = 11.70 against SCLC. The 2-drug combinations of everolimus with doxorubicin (SLEM_30 = 14.30) and doxorubicin with everolimus (SLEM_03 = 7.30) reached the highest sum of SLEM values (SLEM_30 + SLEM_03 = 21.60):

Table 7: SLEM values for the approved SCLC drugs and their 2-drug combinations.

ID	SLEM	ID	SLEM	ID	SLEM
0	9.80	15	6.00	43	0.80
1	9.80	16	6.00	45	0.90
2	9.80	20	6.00	46	0.80
3	11.70	21	5.90	50	3.80
4	3.90	23	6.00	51	3.70
5	8.30	24	6.00	52	3.70
6	9.70	25	5.90	53	3.70
01	7.30	26	5.90	54	3.70
02	7.30	30	14.30	56	3.70
03	7.30	31	14.30	60	5.70
04	7.30	32	14.30	61	5.70
05	7.30	34	14.30	62	5.70
06	7.30	35	14.30	63	5.70
10	6.00	36	14.30	64	5.70
12	6.00	40	0.80	65	5.70
13	6.00	41	0.80		
14	6.00	42	0.70		

SLEM values for the approved NSCLC drugs are given in table 8. Single drug paclitaxel (ID 14) shows the highest activity with SLEM = 12.40 against NSCLC. Among 306 (three hundred six) 2-drug combinations not shown here, the vinorelbine with paclitaxel (SLEM = 15.80) and paclitaxel with vinorelbine (SLEM = 10.70) combinations reached the highest overall SLEM score of 26.50.

Table 8: SLEM values for the approved NSCLC drugs

ID	SLEM	ID	SLEM	ID	SLEM
0	9.10	6	12.00	12	8.00
1	9.60	7	7.90	13	8.60
2	9.30	8	12.00	14	12.40
3	9.80	9	8.20	15	8.60
4	9.70	10	6.80	16	9.60
5	10.50	11	4.20	17	11.50

IV. DISCUSSION

A. The efficacy

The anti-cancer efficacy of combinations with two cancer drugs was the main criteria for the evaluation. The results obtained by using the in silico model of cancer Vini were evaluated by using the available clinical trials and studies.

NSCLC: The conclusion from study [23] is that although the combination of vinorelbine with paclitaxel mets it's response end points, increased toxicity makes this combination unsuitable for older patients. While QOL (Quality Of Life) improved over the study, the small sample hinders interpretation. Study [24] also confirmed that this combination is active in refractory NSCLC.

SCLC: The combination of everolimus with doxorubicin against SCLC was investigated in [25]. The conclusion from this study is that the combination produced cooperative antitumor effects.

Pancreatic cancer: We were not able to find any study exploring the efficacy of everolimus with paclitaxel against pancreatic cancer. In contrary, we found studies with this combination against several other types of cancer. For example, the study [26] found synergistic activity and acceptable toxicity of this combination against breast cancer, and the study [27] found this combination effective against large-cell neuroendocrine cancer and well tolerated. However, another study of the same combination against melanoma found no improved efficacy [28]. As it seems that the efficacy of this combination heavily depends on tumor type, we are not able to speculate about its possible activity against pancreatic cancer.

B. The toxicity

The interaction between drugs takes place not only within cancer cells but can happen in any other part of the body and produce unwanted toxic events. One way to investigate interactions between drugs is to use some common drug-drug interaction software [11]. In case relevant toxicity studies are missing, the possible adverse effects of any drug combination proposed from Vini must be investigated before clinical trial take place. One approach is to perform in silico evaluation of the toxicity. There are several in silico toxicity tools available, and a comprehensive review of methods is given in [21]. An example of such in silico toxicology tool is SwissAdme [22]. Finally, in case the toxicity of the combination with the highest anti-tumor activity exceeds the potential benefit, the next most effective combination must be considered.

C. The pharmacokinetics

Two SLEM results for the same combination of drugs may seem unusual at first glance. For example, the SLEM value of everolimus combination with paclitaxel is 14.40, while the combination of paclitaxel with everolimus has a SLEM value of 10.70. However, by realizing how Vini calculates the SLEM values of drug combinations, it becomes clear that this difference must exist. For example, in the case of everolimus in combination with paclitaxel, Vini first simulates the molecular docking of everolimus to the genes defined with cancer pathway. The results of these first simulations are complex molecular structures, with each structure containing fragments of a particular gene and everolimus. In the final step, Vini simulates molecular docking of paclitaxel to these complexes. In the case of paclitaxel combined with everolimus, Vini first performs molecular docking between genes and paclitaxel, and afterwards molecular docking between complexes and everolimus. Complexes and binding energies are different for both cases. Therefore, SLEM values of these matrices are different as well.

This asymmetry suggests that knowledge of the pharmacokinetics of individual drugs is of the utmost importance in the process of selecting the most effective combination. Combination that has the highest total SLEM value does not necessarily have to be the most effective. Some combinations with a lower total SLEM value, but with higher individual SLEM values, might produce better effects if drugs apply one at a time, at intervals.

D. The personalization of combinatorial cancer therapies

It is increasingly clear that there are molecularly distinct subtypes of various common cancers, with different therapeutic approaches required for each subtype [29]. A good example for this is breast cancer. According to the traditional classification, there are 4 various molecular types: ER-positive luminal-like, basal-like, ErbB2-positive and normal-like [30]. Even these subtypes are further divided into various biological subtypes [31]. Because of that, it is unlikely that combined therapies based on standard KEGG cancer pathways would be equally effective for all subtypes of a certain cancer type.

KEGG paths are graphs that are based on experimentally verified data. They show us how cancer processes take place at the molecular level, that is, at the level of the genes. In KEGG cancer pathways there is no quantitative information about possible gene expression or suppression. However, with high throughput techniques like DNA microarray scanning [32], the information about elevated genes can be gathered from patients' tissue and used as an additional input for KEGG cancer pathways. Vini may use in that way personalized KEGG cancer pathways in searching for more effective and personalized combinatorial cancer therapies. In other words, Vini may predict personalized combinatorial cancer therapies tailored to each patient individually.

III. CONCLUSION

The in silico model of cancer Vini predicted the most effective combinations of two drugs against NSCLC, SCLC, and pancreatic cancer. Available studies confirmed these predictions for NSCLC and SCLC. Since there are no available studies related to combined therapy with everolimus and paclitaxel against pancreatic cancer, the validity of this prediction remains open. By taking into account the above considerations, Vini is a tool of choice for predicting the efficacy of cancer therapies with two drugs. There are no barriers for using the Vini model in assessing the effectiveness of combined therapies with three, four, or even more drugs. Therefore, future efforts to continue our research towards the personalization of the combined cancer therapies are is justified.

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Management of Physiological Data Streams within Brain Disorder Rehabilitation

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***Abstract*—This paper developes a novel telemedicine solution for rehabilitation of balance disorders based on analysis and visualization of patient physiological data gathered by a set of sensors during the rehabilitation process. The training and physiological data sensing are based on two home-grown systems called Homebalance and Scope. The kernel functionality is implemented by the data stream management technology provided by the Esper system. Moreover, it supports training at homes integrated together and to specialized rehabilitation centers by the Dew/Cloud technology. A small core of early adopters is currently successfully conducting balance disorder rehabilitation according to methodology relying on the proposed approach.**

***Keywords*-brain damage rehabilitation, biofeedback, data stream, Esper, event processing language, Dew Computing**

I. Introduction

A. Motivation

In a broad class of modern applications, physiological data are captured by sensors, video cameras, and various Internet of Things resources. The data are then preprocessed, analyzed and visualized. It enables to study of functions and mechanisms, which work within humans and other living systems. These data are essentially continuous and, from the data-science point of view, are considered as time-series data and/or data streams, which introduce new challenges to the corresponding technologies. Addressing these challenges is important for Telemedicine allowing health care professionals to evaluate, diagnose and treat patients in remote locations using telecommunications technology. This paper proposes a solution of a specific domain application, which involves telemedicine features; this can be also a step towards the development of design patterns for a wider category of applications of this kind. Specifically, the paper deals with management of physiological data produced from body sensors of patients during their brain disorder rehabilitation sessions; it primarily focuses on treatment of balance disorders. Balance disorder of the central and peripheral system is a significant symptom that causes functional deficit in common activities. Patients after brain damage often face situations (e.g. using escalators, orientation in city traffic) that can be possibly dangerous or even impossible to manage. Consequently, balance training is one of the main focuses of brain disorder rehabilitation. Most modern balance training environments are interactive and built up on measuring instruments called force platforms (or force plates) that measure the ground reaction forces (their summary vector is often called as center of pressure) generated by a body standing on or moving across them, to quantify balance, gait and other parameters of biomechanics [1]. Methods based on virtual reality technology and biological feedback are appropriately supplementing conventional rehabilitation procedures.

From the technology point of view, our approach is built up on technologies involved in data science-based solutions and, additionally, several home-grown systems. The first one is called Homebalance (www.homebalance.cz - the system name expresses its important feature that it can be used in patients homes, in contrast to a plenty of such, typically very expensive, existing systems, designed for diagnosis and therapy of balance disorders). The second home-grown system is the Scope device (http://www.albertov.cz/#!vlv-lab/dqhko) intended to support research in biology, psychology, human research, etc. It finds use whenever there is an appropriate need during in-vivo experiments, continuous

and accurate sensing of biological and technical signals, such as electrocardiogram, electromyogram, skin resistance, respiration curve, temperature, humidity, pressure, physical activity, etc. Scope ensures this data collection and storage in such a way that all the collected data are synchronized in the same timeline. The paper outlines the whole implementation software architecture, describes the structure and semantics of the data considered, and presents the graphical outputs relevant to the functionality outlined above. The structure of the patients groups involved in the experiments and future research work issues are also discussed.

The kernel part of the software architecture, besides the Scope modules, is the Esper system, a language, compiler and runtime for complex event processing (CEP) and streaming analytics, available for Java as well as for .NET (http://esper.espertech.com/release-7.1.0/esper-reference/html/). It enables preprocessing of the multiple data streams produced by Scope on the fly and includes implementation of the physiological data stream analytic algorithms we proposed for the balance rehabilitation application. The architecture is designed as an open system it can be appropriately extended and adapted for other application domains. The ongoing Cloud/Dew computing paradigm [2] is considered as an ideal information infrastructure for implementation of the advanced telemedicine features involved in our approach.

B. Related Work

Similar objectives have been followed by other researchers [3]–[8]. Papers [6], [7] analyze the state of the art in balance rehabilitation systems supported by the virtual reality and biofeedback technologies, respectively. The WiiFit force platform [9] based rehabilitation systems and experience gained from the real application environments are discussed in [3]–[5], [8]. A game engine that involves advance characteristics needed to support rehabilitation at home is described in [10]; here, a rule-based component partially steers the therapeutic process.

Managing streaming data coming from end-user IoT devices with big quantities by Dew Computing is discussed in [11]. The Cloud/Dew paradigm in the context of breath gas analysis application is discussed in [12]. In [13] we addressed aspects of the evaluation of physiological data after a training session; now, dynamically, during the session.

Cloud design patterns as a prescriptive architecture guidance were elaborated and published by Microsoft [14]. We believe that there is also need to devote an appropriate effort for elaboration of such guideline for Dew/Cloud applications.

C. Paper Organization

The rest of the paper is organized as follows. Section II introduces our approach. The architecture prototype involving data stream capturing, analysis and visualization is discussed in Section III. The role and benefit of integration of a provenance system in the current solution in our future research is presented in Section IV. The current and assumed impact of this research in the future are discussed in Section V. Finally, we briefly summarize the achieved results in Section VI.

II. Our Approach Based on Biofeedback Data

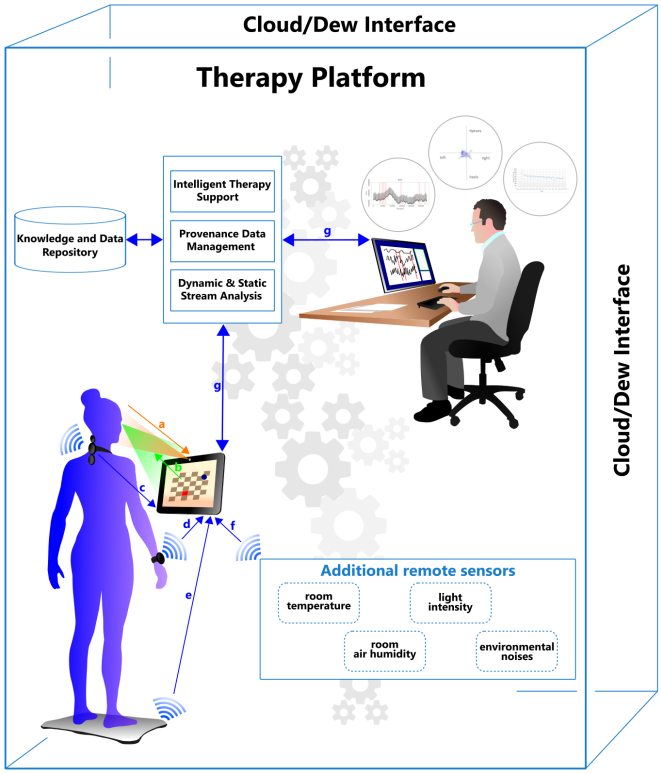

Figure 1. Balance training supported by biofeedback data and intelligent therapy assistance: a) patient face is observed by a camera (a post-analysis can identify e.g., specific emotions, concentration, etc.); b) patient gets audio-visual feedback; c) sensing neck muscle tension; d) measuring pulse frequency; e) data streams from balance force platform sensors; f) data streams from other observations, like room temperature, light intensity, room air humidity, environmental noises, etc.; g) data transfer and processing between patient and therapist areas. Based on [13].

Investigations in the above discussed research showed that the personalized application of the available systems during therapeutic processes requires careful choice of appropriate settings for large number of system parameters, values of which cannot be estimated purely from few simple measurements (e.g. weight and height of the patient). The system parameters must be modified w.r.t. to current patients state as well as to the set of multiple diseases the patient is suffering from. This is the first reason why a large search space should be considered when planning the type of therapeutic processes to be recommended for system parameter settings. The second issue is related to the fact that individual combination of therapeutic processes is recommended for each

patient and this combination influences the parameter values for individual processes. All this leads to combinatorial explosion that has to be faced. Our objective is to contribute to the solution of these challenges by an approach that includes biofeedback – and physiological parameters-based methods.

Figure 1 illustrates basic elements of biofeedback realization. The system parameter setting currently relies mainly on subjective observation of the status and behavior of the patient by the persons steering the therapy; this type of human expert supervision is time consuming, sub-optimal, and unproductive. The challenge and an ambitious research goal is to provide technical support for design of an optimal therapeutic process for each individual patient. A prerequisite for this approach is to collect enough training data that fully characterize the detailed advance of the patient during the rehabilitation processes and his/her therapies.

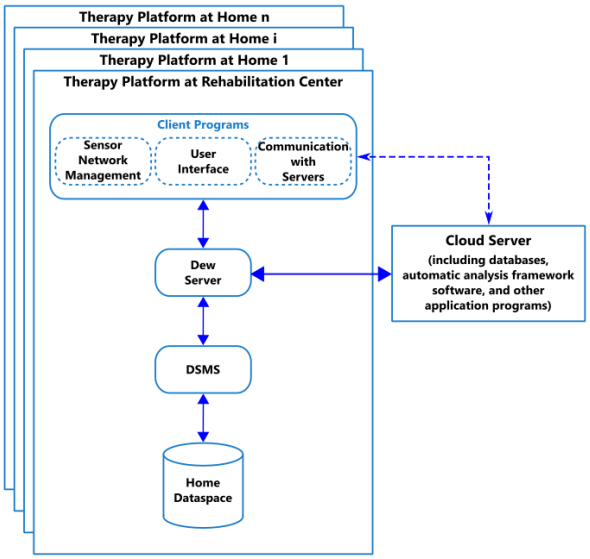

Figure 2. Cloud-Dew architecture for balance disorder training, where Dew is represented by the home infrastructure. Based on [15], [16].

As sketeched in Figure 1, the therapist is overloaded with the avalanche of data streaming from the sensors and at the same time he/she must be aware of the patient medical record data relevant for the therapy session. Moreover, he/she should promptly adapt the therapy parameters to dynamically react to the therapy process status he/she intuitively assumes from the observed data streams. To meet these challenges, we support him/her by the Intelligent Therapy Assistant that we proposed in [13]. Data streams flowing from the sensors are analyzed on the fly (dynamic stream analysis) or after the training (static analysis) using the state-of-the-art time-series analysis techniques. The collected data and knowledge discovered are archived in an appropriate Repository. Therapy workflow metadata are enriched by components allowing to apply appropriate provenance[1] techniques (http://veps.gridminer.org/) - these issues are discussed in Section IV.

The traditional model assuming rehabilitation conducted in highly-specified rehabilitation centers (clinics) that involves therapy pauses due to the high costs doesn't support this aim. Therefore, there are already efforts to provide therapy at homes equipped with appropriate technical resources, too. Our long-term goal is to create a network of cooperating nodes, where a node denotes a Cloud server associated with a rehabilitation center steering a set of home infrastructures. Each home system works autonomously, even if the Internet connection is not available at the moment, and in specific intervals exchanges collaborative information (analysis results, data mining models, etc. produced by the analytical processes) with the center involved in the Cloud. This Cloud-Dew concept is reflected in Figure 2. The Sensor Network Management steers the dataflow from sensors to the Home Dataspace managed by the Data Space Management System (DSMS) [17].

III. CAPTURING AND ANALYZING PHYSIOLOGICAL DATA STREAMS

A. Architecture

The Esper system (an output of a pioneering Standford research on data stream management) is the kernel part of our architecture prototype depicted in Figure 3. It operates on Events and the associated Time by prepared Queries that produce Results (Callbacks in the Esper terminology) visuaalized by GUI, which also allows to steer the functionality of the whole system by queries and parameter settings.

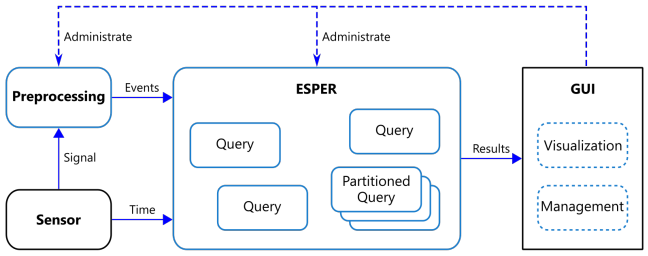

Figure 3. Data Sensing, Analysis, and Management: The Architecture Prototype (The kernel component originates in the Esper Documentation).

Sensors produce discrete signals (in 2 ms intervals in Scope), which are preprocessed and converted to Esper events operated on by queries specified in the Esper Event Processing Language (EPL). The events are

[1]Originally: the history or pedigree of a work of art, manuscript, rare book, etc.; in e-Science: information about workflow activities, data, and resources allowing reproducibility of scientific workflows.

Java or .NET objects. They can include simple or complex (structured) components (properties), e..g. *(SensorId, Sensed_Value, Time_Stamp)*.

As an example, Figure 4 shows visualized data streams sensed during a complete therapy session; they correspond to:

- Pulse Rate. This was derived from the electrocardiogram signals.
- GSR - galvanic skin response, measured by sensors attached to the fingers of the proband.
- EIMP - electrical impedance of the chest.

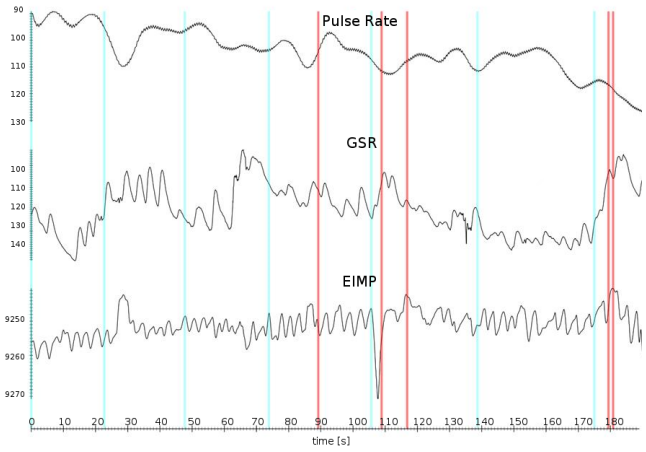

Figure 4. Visualization of selected features. GSR–galvanic skin reponse measured by sensors attached to the fingers of the proband (Low levels are considered to be a clear sign of stress.); EIMP–electrical impedance of the chest (breathing frequency estimation). The vertical red lines indicate occurrence of unexpected events from outside the training scenario that may affect the probands performance, the vertical blue lines indicate important time points in the testing scenario in this case, the time when the proband successfully completes a subgoal of the game scenario.

Complex Event Processing, or CEP, implemented by a CEP engine, is primarily an event processing concept that deals with the task of processing multiple events with the goal of identifying the meaningful events within the event stream (a time ordered sequence of events in time). CEP employs techniques such as detection of complex patterns of many events, event correlation and abstraction, event hierarchies, and relationships between events such as causality, membership, and timing, and event-driven processes (source: wikipedia.org). Similar to functions in a functional programming language, a CEP engine treats computation as the evaluation of streaming data. Streams in Esper have zero cost in terms of memory or processing. You could register millions of streams.

When time passes or an event arrives Esper evaluates only those queries that need to see such event or time. Esper analyzes EPL queries, performs query planning and utilizes data structures to avoid unneeded evaluation. EPL queries can be partitioned; have instances associated with a specific context, e.g. patient groups, specific time intervals, etc. In the picture above there are three unpartitioned queries and one partitioned query that has three partitions.

Esper has been highly optimized to handle very high throughput streams with very little latency between event receipt and output result posting. Advanced threading is one of the concepts that has been applied.

B. EPL Queries

The next subsection discusses various easily-understood EPL queries. The sample queries assume an event type by name *TemperatureSensor* that has the *temperature* property.

This EPL query selects all *TemperatureSensor* events.

*select * from TemperatureSensor*

Upon a new *temperature* event arriving, Esper passes the arriving event, unchanged and the same object reference, to callbacks. After that Esper effectively forgets the current event.

The following query looks for all *TemperatureSensor* events where the temperature is greater than 38:

*select * from TemperatureSensor (temperature > 38)*

This sample outputs the avarage temperature of all sensor events received from the start of the query:

select avg (temperature) from TemperatureSensor

There are many different flavors of data windows[2], which serve to limit the subset of events to analyze on the unbound stream of data. The next sample outputs the average temperature of all sensor events received within the last 1 minute:

select avg(temperature) from TemperatureSensor#time(1 min)

This statement outputs the avarage temperature of all sensor events that have a *temperature* of 40 or higher:

select avg(temperature)
from TemperatureSensor(temperature >= 40)

This query selects all *TemperatureSensor* events and instructs Esper to remember the last five events:

*select * from TemperatureSensor#length(5)*

This query outputs the average of the last five *TemperatureSensor* events:

select avg(temperature) from TemperatureSensor#length(5)

Esper offers the EPL pattern language, a versatile and expressive syntax for finding time and property relationships between events of many streams[3].

C. Graphical User Interface

The graphical user interface (GUI) allows users to interact with the system at two levels (in two functionality areas).

[2]A time window is a data window that extends the specified time interval into the past.

[3]All observed patient data have to be comprehensively evaluated and mutually compared. For example, if during rehabilitation unsufficient performance results (see the statokinesiogram discussion in Section V) and increased stress factors (increased pulse frequency and galvanic skin response changes) are being observed, decreasing of training difficulty would be a possible immediate solution choice.

- Administrator level. It includes a graphical tool for specification of syntactically a semantically correct EPL queries based on the metadata associated with sensors and data stream properties. Further, it enables to configure parameters of the preprocessing components.
- End-user level. It presents in a domain-specific way relevant data to therapeutists and other medical experts. These data include characteristic of physiological data streams - graphs and continuous visualization of analytical results. Further, it allows the end user to appropriately adapt therapy parameters.

IV. Integrating Provenance Support

Provenance is a key component of data science. It is metadata that describes the derivation history of any object in its development trajectory (capturing, preprocessing, analyzing, validating, etc.). Dealing with provenance is critical not only to provide evidence to the reliability and trustworthiness of the derived object but to support audit and trial of activities as well. So far, provenance has been widely explored in centralized architectures and in all different forms of distributed systems such as Grid (especially, in the U.K. e-Science program), Cloud, etc. To our best knowledge, it has not yet been addressed in the context of Cloud-Dew Computing.

We believe breakthrough contributions can be achieved by including the provenance paradigm into data-centric approach of the balance rehabilitation. The research challenges that we plan to address in our future research include

- How to steer the therapy to keep sustained improvements?
- How to objectively compare the real development of the patient status with the assumed or planned?
- Evaluation of the data produced under different conditions and interventions. This could help to propose optimal methods for different groups of patients with different brain damage level and development history.
- Investigate how to achieve reproducibility of successful treatments (discovery of such treatment processes).
- Investigate how, with the usage of data provenance methods and tools, the clinical pathways for the brain damage restoration domain can be improved and automated (standardized).

V. Research Impact

The typical training (rehabilitation) session using the Homebalance system and the Scope device used for capturing biofeedback and physiological data consists of three consecutive tasks that the probands are to perform: a simple chessboard scene described below, and two scenes (city street virtual scene, and water maze virtual scene) in 3D virtual environments discussed in the chapter we provided for [16]. There have already been reported several therapy successes achieved by applying the discussed approach. In

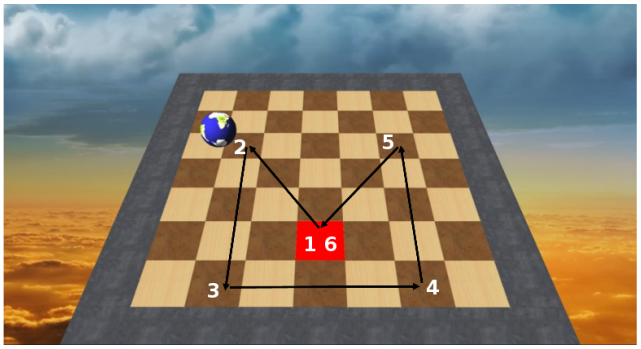

Figure 5. Chessboard scene: Trajectory of the required globe movement. The corresponding movement parameter setting and parameter taxonomy are described in [13]. The numbers, 1-6, denote board positions, the sequence of required movements, of the globe that correspond to the projections of shifting the center of gravity.

the 4-day case study, the patient with balance disorder after traumatic brain injury subjectively claims that he/she has bad stability at shifting/transferring weight to the heals. His/her training task is presented by the chessboard (Figure 5). The numbers *1* to *6* denote board positions (the sequence of required movements) of the globe that correspond to the projections of shifting the center of gravity.

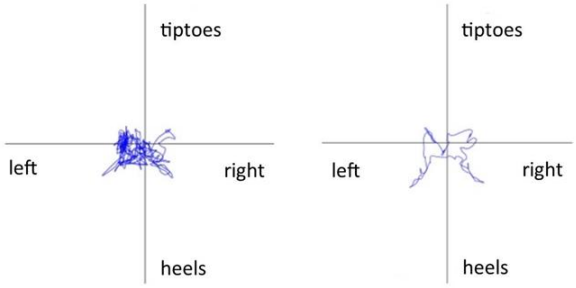

Figure 6. Statokinesiograms resulting from two therapy sessions showing the balance improvement of the addressed patient

In the 4th day, the trajectory has changed significantly and it is much straighter and shorter compared to that of the first day. Even maximum movement extent is larger and stress parameters are lower. The corresponding statokinesiogram[4] is shown in Figure 6 (right). This patient succeeded to achieve improvement in the heel standing very quickly and simultaneously his/her stress level was reduced. These facts support an assumption that at the beginning, there was a high anxiety caused by patient's lack of confidence and the resulting stress influenced the patient's performance, even though motoric deficitt was not so big that he/she could not master the given task to the end. The therapist shares this observation with the patient and supports his claim by

[4]A statokinesiogram depicts the movement of the center of pressure in an X-Y coordinate system.

calling the patient's attention to both statokinesiograms in Figure 6 that are carefully explained to the patient. This illustrative therapy is well understood by the patient who can clearly see his/her advance. This approach also increases motivation of the patient to continue in the rehabilitation process. In this way, visual feedback can significantly speed-up the improvement of the patient.

VI. Conclusions

This paper deals with management of physiological data produced from body sensors of patients during their balance disorder rehabilitation in the context of a novel rehabilitation concept, which is a significant addition to convential procedures, whose experience and best practices have steered the development of these technologies. Application of these technologies is accompanied by production of massive data volumes that overhelm the therapists involved in the rehabilitation, so the full potential of these data is not used. A potential solution is the development datacentric therapy approaches that we call as precision brain disorder rehabilitation, which use biofeedback data and physiological data collected by a sensor network and attempt to dynamically adapt the rehabilitation process to optimally meet intended goals.

Our future research plans include technical and medical aspects. Besides integration of provenance support mentioned in Section IV, data streams from the camera Kinect will be used for the 3D motion analysis. Further, concepts from the Cyber-Physical System research and development, especially, Internet of Things will enrich the architecture of our solution. The amount and kind of sensed data will be selected and appropriately visualized due to concrete characteristics of the patient. An extensive clinical study of rehabilitation results is conducted in several rehabilitation centers within a dedicated project. Among others, the aim is to provide classifications of the influence of each monitored parameter on balance and motion ability.

Acknowledgments

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PAPERS

NEW APPLICATIONS AND SERVICES

Targeted multichannel marketing campaign in Telecommunications

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***Abstract* - As mass media is overwhelmed with promotional content, regardless of campaign budget and media channels used, mass communication with customers brings less effective sales results than direct marketing. This study is made to present the effects of multichannel campaign throughout integrated direct communication with customers. Since new tariff plan campaign needed to be promoted, integration of several different direct communication channels is performed in order to reach target customer groups. Customer base was segmented by usage of tariff plans as well as by amount spent monthly within different tariff groups. Therefore, customer base was divided into groups that differed by usage characteristics. Marketing campaign was implemented throughout following direct communication channels: SMS with web link, web opinion poll form, call center and sales points. Customers received SMS with information about new campaign offer predefined for their usage level, with call to action by clicking on web link in SMS. When transferred to web form, customer were informed about special offer details and could leave their contact information in order to receive a call from call center and get even more information or activate new special offer. Form inputs were listed in file forms and transferred to a call center. Each customer was contacted and after offer acceptance, purchase ID was opened in sales application. When contract is signed on actual sale point, sales ID used in marketing campaign were matched with contract and marketing campaign effects were counted. 682 734 SMS were sent and 881 customers replied to a web form and left their contact information. After contacted from a call center, 315 customers signed a long term contracts, which represents 35.75% of contacted customer base or 0.046% of target customer base. Since customers who did not have long term contracts were targeted, and they were offered to accept a higher value offer for next 24 months, this percentage is found significant.**

Keywords - direct marketing; integrated multichannel campaign; telecommunications

I. INTRODUCTION

Telecommunications industry is a very fast moving. Number of technologies implemented in creating value for customers is increasing each day. Competitiveness of market rivals speed up time to market, and building loyal customer base is the key to success. Focus is not just on introducing new products, but also on quality of customer journey and experience.

Direct marketing builds accountability, feedback, and marketing profitability into the system. With the broadcast and promotional media, the marketer can never truly track how effective the campaigns are or determine where improvement lies. The results of broadcast and promotional activities are by definition interpretive and guesswork. Direct marketing, on the other hand, allows for a specific management of campaigns with almost immediately measurable results [1].

Consumers not only have a limited capacity to store information, they also have a limited capacity to process it. Information that is too complex or ambiguous is likely to be ignored. Advertisers must ensure that the information provided is understood by target group and the symbolism and imaginary used is relevant to the product [2].

This study shows exactly how customers` journeys led by company multichannel campaign resulted in better results than if customers made their decisions on their own, by analyzing all reachable information about product offers.

II. METODOLOGY

A. Campaign process and goals

In order to set up a successful campaign [3], the process model was determined and presented on Fig 1.



Figure 1. Campaign process model

Tracking the lifecycle segmentation model, in order to increase strong and loyal postpaid customer base, a new mobile tariff plan was introduced. It included three major customer segments: postpaid customers with expired contact due date, prepaid customers and new customers. Campaign goal was to attract these different customer segments to sign a long-term contract and choose tariff package with higher monthly fee that included more traffic allowed within package.

Marketing challenge was to find the best way to promote new tariff plan to each customer group. Earlier, simple mass media campaigns were conducted, and it was not possible to measure ROI by marketing channels. This time the goal was to define the best way to promote new tariff plans, while reducing advertising costs and even be able to measure promotional channel ROI.

B. Customer base segmentation

The involvement of innovative approaches is indispensable in order to achieve a positive business balance. One of these innovative approaches is the use of business intelligence in business processes. Syntagma "Business Intelligence" refers to a set of business processes, the technologies used in these processes, and information derived from these processes. Business intelligence can be a competitive advantage for companies that want to achieve profitability.

An important part of business intelligence involves the ETL process (extraction, transformation and loading) which represents the process of extracting data from source systems and bringing them into the data [4].

In order to target customers with right promotional message, segmentation was based on customers` monthly costs as well as contract type: prepaid or postpaid, as presented in Table 1.

TABLE I. CAMPAIGN TARGET GROUPS

Customer type	Customer base segment	KM	Group
Prepaid	Monthly spent low, no contract	A-B	1
	Monthly spent medium, no contract	C-D	2
	Monthly spent high, no contract	E-F	3
Postpaid	Tariff plans used, small, no contract due date	K,L,M,N	4
	Tariff plans used, medium, no contract due date	X,Y	5
	Tariff plans used, large, no contract due date	Z	6

The first step of segmentation was extraction of MSISDNs from customer databases. Part of extraction codes (queries) is shown on Fig. 2 – prepaid customer base and Fig. 3 – postpaid customer base.

After filtering exact MSISDNs that match campaign target groups, given postpaid lists were filtered again depending on some other statuses that excluded customers from being eligible for campaign, e.g. contracts closed regarding mobile device purchase – Fig. 4.

```
    AGR_TYPE is equal to / is in  M
AND Godina is equal to / is in  2018
AND Mjesec is equal to / is in  09
AND SUM(PRIHOD[kf]) / 100  is between  0 and 1
AND MSISDN  is not LIKE (pattern match) 3873%
AND Tarifni model is equal to / is in [redacted]
```

Figure 2. Extraction code used in prepaid customer base

```
select '387' || msisdn msisdn, (select naziv from ppaket where sifra = sifra_paketa) paket
  from ppretplatnik
  where
              (
                 sifra_paketa in (120,121,122,123,109,110,111,112,124,113,118,75,76)
              )
  and status = '1'
  and id not in (select pretplatnik_id from slgsm)
  order by sifra_paketa, msisdn
```

Figure 3. Extraction code used in postpaid customer base

```
select UOMCOMMON.FGET_PRODUCTOFFER_NAME(
UOMCOMMON.FGET_HEADOFFER_ID(id)) paket, c.userid, c.startdate,
(
select 'ASM' from [redacted]@gsm.telecom.ba where telefon = substr(c.area_code, 2, 8)
|| c.msisdn and add_months(datum, ugovorni_odnos) > sysdate and ugovorni_odnos > 1
) Asemblirana,
(
select 'AKC' from [redacted]@gsm.telecom.ba where telefon = substr(c.area_code, 2, 8)
|| c.msisdn and stop_date > sysdate
) Akcija
from ceventsource c
where stopdate is null and
'387' || substr(area_code, 2, 8) || msisdn in (
```

Figure 4. Filtering code used to exclude postpaid customers that are not eligible for the campaign

C. Communication process throughtout direct channels and platforms

Total number of unique MSISDNs was 682 734. After formatting and changing to .txt files, lists were inserted into messaging platforms for SMS and WAP push delivery, presented on Fig. 5 and Fig. 6.

SMS received customers in groups: 1, 2, 3 and 6. WAP push notification received customers in groups 4 and 5.

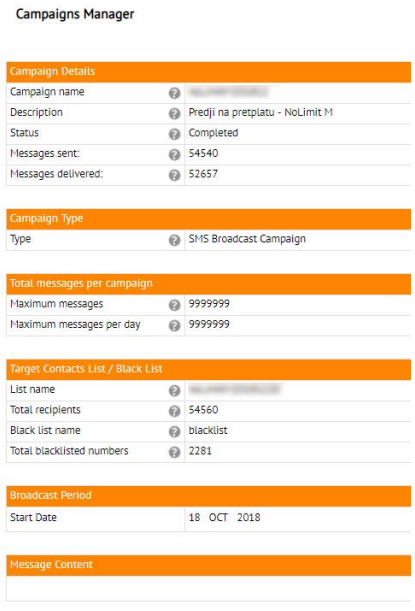

Figure 5. Bulk SMS campaign manager view

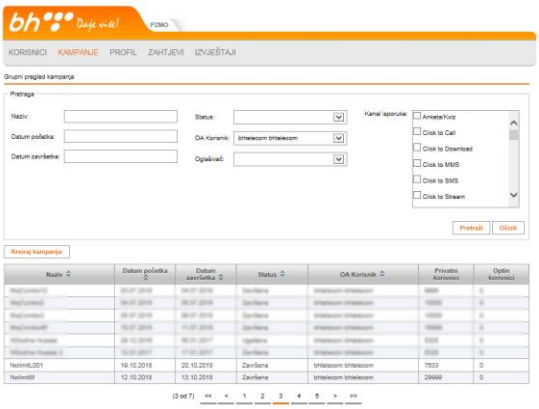

Figure 6. Mobile advertising platform campaign manager view

For each segment, customized SMS and WAP push content was created, with different shortened web link that led to detailed information about new campaign offer, predefined for users` specific usage levels. It is important to note that users who have set the interdiction on receiving SMS messages were omitted from the list.

When transferred to a web form, and informed about special offer details, customers could leave their contact information in order to receive a call from call center and get even more information or activate new special offer, presented on Fig. 7.

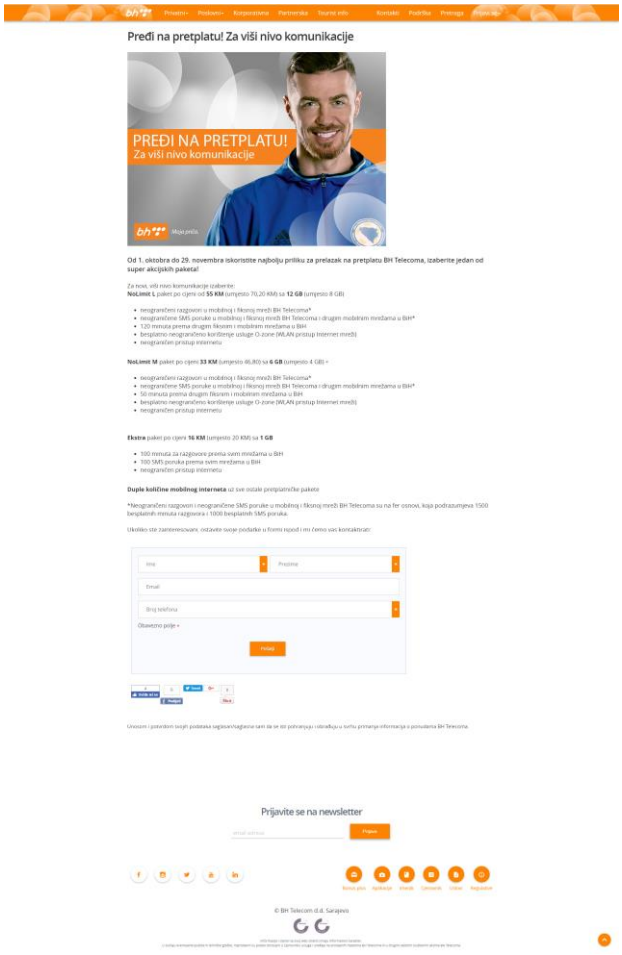

Figure 7. Web page were customers were redirected from SMS or WAP push messages

Feedback information that users left through web form were additionally cleaned in order to be ready for import into another platform that is used to distribute phone numbers to multiple BH Telecom call agents' lists. Data cleansing was performed through Access 2016, presented on Fig. 8.

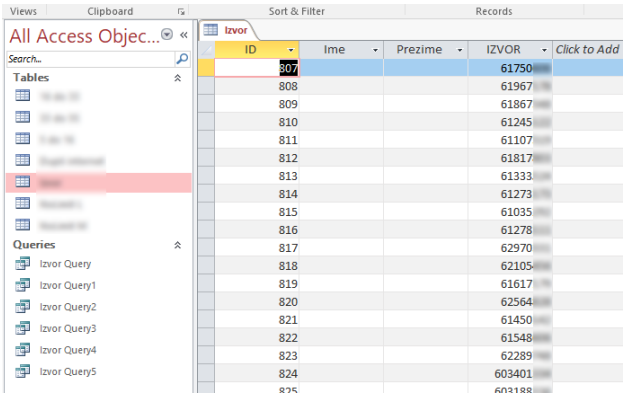

Figure 8. Data cleaning through Access 2016

After data were cleaned, MSISDNs were paired to users' information (name, surname, e-mail) so that the BH Telecom call agents can detect all other information about users before calling them, presented on Fig. 9.

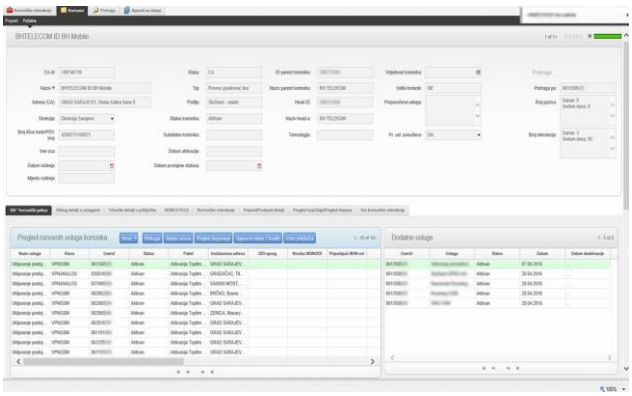

Figure 9. Customer care center application view

Web form users' information were collected on daily basis while campaign was active, and process of manipulation over them was repeated as mentioned above.

Once a customer was contacted by phone call from a call center, order ID was opened in sales application. When customer finally reaches physical sale point, contract number is matched with order ID and final campaign ROI can be measured.

III. RESULTS

A. *Interaction with customers*

Total number of messages sent was 682 734. Prepaid groups: 1, 2 and 3 received 619 706 SMS messages, which represents 90.77 % of total targeted customer base.

Postpaid customers in groups 4 and 5 received WAP push notification. Group 6 received SMS.

TABLE II. CUSTOMER INTERACTION RATES

Gr.	Number of messages	Number of clicks	CTR	Form submitted	% Form submitted / clicks
1	410 368	30 024	0.07	430	1.43
2	158 555	14 435	0.09	252	1.75
3	50 783	6 511	0.13	110	1.69
4	54 754	1 316	0.02	31	2.36
5	7 633	2 213	0.29	58	2.62
6	650	1	0.00	0	0.00

CTR is significantly higher in postpaid customers. Within both contract types, postpaid and prepaid, CTR and form submission rates are higher in groups with higher monthly spending, presented on Fig. 10 and Fig. 11.

The only exception is group 6 that did not react to SMS at all. This group represents postpaid customer base that have the largest tariff plan possible. Since campaign towards this group was focused on contact renewal in order to receive double mobile internet monthly traffic allowed, customers were not attracted to this type of offer.

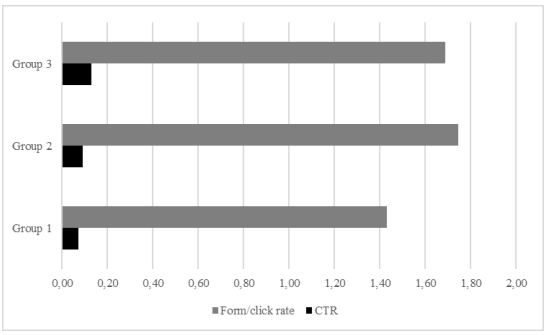

Figure 10. Customer interaction rates within prepaid segments

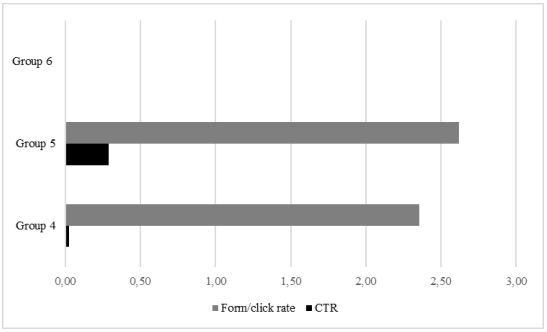

Figure 11. Customer interaction rates within postpaid segments

B. Final Campaign results

881 customers were contacted through call center (792 prepaid and 89 postpaid). 315 of them signed a new postpaid contract, which was the final campaign goal. 246 or 78% were long term contracts.

This statistics is presented in Table III and Fig. 12.

TABLE III. CONTRACTS SIGNED AS A DIRECT CAMPAIGN RESULT

Total new contracts closed	**315**
Postpaid - new long term contracts	53
Prepaid to postpaid migration - long term contracts	193
Prepaid to postpaid migration - no due date contracts	69

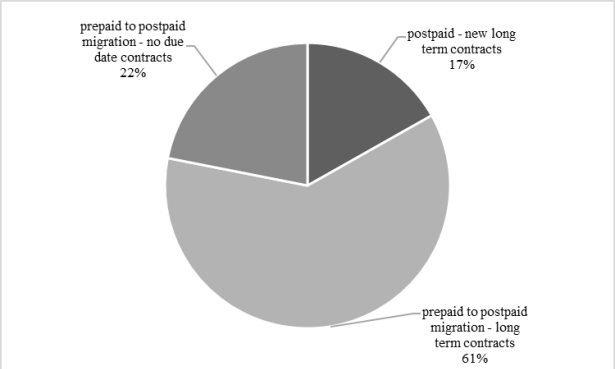

Figure 12. Shares of contracts signed by type

Postpaid customers reacted by closing contracts with 59.55% and prepaid with 33.08%, which is presented in Table IV.

TABLE IV. CAMPAIGN RESULTS BY CUSTOMER BASE TYPES

Campaign results	Customers contacted through call center	Contracts closed	% Contracts closed per call
Customer base	881	315	35.75
Postpaid	89	53	59.55
Prepaid	792	262	33.08

IV. DISCUSSION

Led by Gartner [5], brands that put in place user-level control of marketing data will reduce customer churn by 40 percent and increase lifetime value by 25 percent in 2023. Autonomous marketing systems will issue 55 percent of multichannel marketing messages based on marketer criteria and real-time consumer behavior, resulting in a 25 percent increase in response rates.

Since main campaign goal was to target and reach exact customer target base and motivate customers to migrate from prepaid to postpaid tariff model, or renew a postpaid contract by closing a new long-term contract, direct media multichannel campaign was conducted.

Multichannel campaign included following direct marketing channel types: SMS, WAP push notifications, predefined web content and forms, call center calls, and direct sale. Platforms that supported campaign process used are: billing databases, business intelligence - data mining and filtering, SMS messaging platform – SMS delivery, Mobile advertising platform – WAP push delivery and metrics, CMS and web applications – web content and forms, Google analytics – SMS link click

metrics, customer care applications – call center contacts, billing – contracts closed metrics.

Prepaid customers were attracted to campaign offer. CTR measured up to 13%, which resulted with 262 new contracts, or 33% of contacted prepaid customer base through call center.

Postpaid customers received WAP push notifications, and this group measured even higher CTR, up to 29%. Reasons for this high reaction rate was a good match of campaign offer and customer behavioral statistics. WAP push notification also enables delivery of visual image besides text message, which attracted customers to click even more. 59 new contracts were closed, which represents 59.55% of postpaid customer base contacted through call center.

V. CONLUSION

Having in mind that multiple systems, platforms, channels and intelligence were used, this campaign has all characteristics of targeted multichannel marketing campaign. Even if each platform lacked of some functionalities within themselves, by integrating more different platforms and intelligence in a controlled process, final result was a successful campaign with measurable ROI.

In comparison of CTR in web advertising [6], which resulted in average score in technology industries of 0.39% for 2018, and SMS and WAP push CTR that resulted in this campaign, it is clear that these direct communication channels have much greater ROI. Having in mind that telecom operators possess these platforms and costs per message are very low, these channels are the best way to reach mobile customer base.

If targeted correctly, together with attractive offer matched to customers' behavior and transmitted in promotional message, campaign success is guaranteed.

ACKNOWLEDGMENT

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New Perspectives for People with Special Needs According the Development of New Generation ICT Technologies

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***Abstract* - The paper considers the new possibilities that Fourth industrial revolution brings to everyday life and inclusion in the world of work for people with disabilities and the elderly (persons with special needs). Technological responses to the challenges of this involvement have been in the market for some time now. However, they are currently very limited to mostly static functions, so their application, though useful and necessary, is relatively limited. Cloud, M2M, IoT and especially 5G networks bring a new dimension and open new perspectives for developing applications tailored to the needs of such people. The paper provides an analysis of linkages between applications for people with special needs with upcoming technological possibilities and the perspective of such applications in the new ICT environment.**

Keywords - people with disabilities, older people; IoT; smart apps; independent life

I. INTRODUCTION

The development of Information and Communication Technology (ICT) and services based on them opens new opportunities and conditions for work and life in the contemporary society. Looking at the needs and the current possibilities of relying on ICTs for people with special needs, new services could considerably expand many perspectives for them, for their regular lives as well as for their greater involvement in the world of work. Persons with special needs generally include people with special needs due to their additional constraints, such as persons with disabilities or older persons, as well as people who are unable to harmonize their own exceptionally high abilities to their environment and remain vulnerable to the results of their work they can give. In this paper, this time, we will limit ourselves to people with disabilities and the elderly.

Fourth Industrial Revolution (4IR) enables remote location work, mobility, accessibility and communication reliability, personal security, etc. - all these are elements that are significantly increasing and greatly enhance the quality of life and work of people with disabilities and the elderly. In this way they are deeper and better in everyday life. The basics of these features are on apps. Most of these applications are designed for ordinary purpose, with or without some additional upgrade, while some are specially designed for people with special needs. The world of such applications, specially designed for people with special needs, has tremendous potential for further development because the parameters and the quality of the services on which they are based rise to the levels required for people with special needs. In fact, even beyond this, a whole new world of possibilities for developing such applications opens.

In this step, we intend to analyze the needs and opportunities of people with special needs in the light of ICT services and applications, as well as the perspectives of existing and the development of new applications that meet their needs.

II. CONDITIONS, POTENTIALS AND NEEDS

According to World Health Organization (WHO) report, in 2011 the contribution of people with disabilities in the total population was between 15 and 19 percent [1], [2]. Compared with 1970, this is an increase of about 50%. One reason for such an increase is certainly the aging population, where chronic illnesses cause disability in about two thirds of such patients. However, in the contemporary society, increasing the number of people with disabilities is particularly connected with the interaction of health and personal factors with factors and environmental conditions. This interaction creates barriers whose spectrum is large and wide, from narrow and specific to general and global. The development of ICT services has also enabled the development of ICT applications designed to alleviate these barriers [3]. Table I gives an estimate of opportunities for ICT applications to reduce these barriers. The barriers are presented as defined by the WHO report, and the potential for their reduction through ICT applications derives from the applications themselves through three elements - application potentials, complexity of potential solutions, perspectives of developed solutions. Application potentials appraise the extent to which ICT applications are generally appropriate to reduce the barrier itself. The complexity of the solution provides an assessment of the development and realization complexity of potential ICT solutions that could reduce certain barriers. The development perspectives give an estimate of how long such applications are sustainable. Whereby, this sustainability can be direct when it directly reduces the barrier itself, and / or indirectly, when applications for some other reason reduce the barrier. The table shows on which of these barriers to ICT applications have a greater or lesser potential impact.

TABLE I. ICT APPLICATIONS - BARRIERS IMPACT

		ICT		
Barrier		1	2	3
Inadequate policies and standards		S	N/A	S/I
Negative attitudes		M	N/A	S/I
Lack of provision of services	health care	S	XL	S/D
	assistive devices	XL	L	XL/D
	education	L	M	L/D
	welfare services	M	S	L/D/I
Problems with service delivery		S	S	S/I
Inadequate funding		M	S	L/D
Mobility		XL	L/XL	XL/D

1 - actual opportunities; 2 - solution complexity; 3 - development perspectives;

N/A – no impact; S – small; M – medium; L -large; XL very large; I – indirectly; D – directly

The assessment of the perspective is given by the breadth of the population, the possibilities of applicable solutions, complexity of solutions and technological development. There are also significant factors in their financing of development, production and support. However, the financing of 4IR services for people with disabilities is no longer separate and strictly targeted, and depending on the community's capabilities. ICT-based services for people with disabilities are very similar to the usual ICT services, in the worst case they are their derivatives. For example, an autonomous vehicle application can be applied in the same way to people with disabilities. In order for the smart parking application to become a targeted application for people with disabilities, only a small modification is necessary - specialization for accessibility parking spaces. The cost of such services can be significantly reduced by applying the principle of economies of scale and distribution economics (digital economy) simultaniously. By the principle of economy of scale a large quantity of a product ensures its financial viability. In this case, it is about the principle of universal service. This means that the same service is widely applied, not just for people with disabilities. Economy of distribution is a network-based economy where connectivity is the foundation of everything. This network orientation of services is the basis for their widespread use, as well as the basis for the development of additional features for people with disabilities. Optimizing the approach of economies of scale and digital economy brings two main benefites. Such a services become cheaper and financial affordability. On the other side, the development and maintenance of such services migrates from state and social institutions to private entrepreneurship. In addition, the services of education, vocational training and distance work can make persons with disabilities financially more independent.

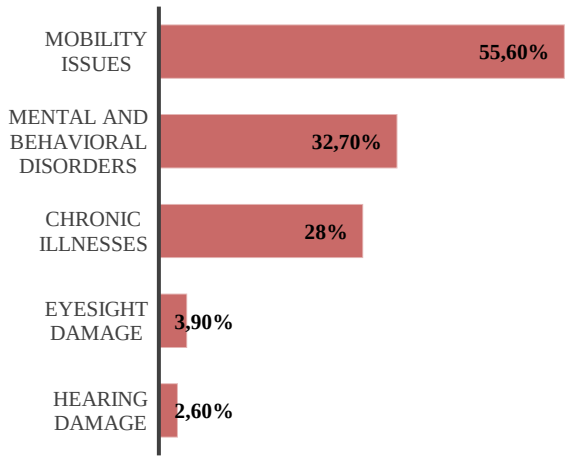

Figure 1. Distribution of difficulties by type in Croatia

The described obstacles arise from the difficulties experienced by persons with disabilities. These difficulties are observed through five basic groups, as shown in Figure 1. The picture shows also the distribution of the types of disabilities of persons with disabilities in the Republic of Croatia, as a percentage of the total number of persons with disabilities (N = 504 194), according to the nomenclature of Croatian Institute for Public Health on 10.02.2019. Given the total population, it is noticeable that the proportion of people with disabilities is around 12%, which is about 4% less than the WHO report. So we can conclude that the base of potential beneficiaries is actually bigger.

III. ICT SERVICES AND APPLICATIONS FOR PERSON WITH INVALIDITY

Observing at the needs of people with disabilities we can conclude which are the basic elements of specified services and how they affect them. These are data storage and data organization, monitoring and managing of processes, and communication. The amount of data is bigger and more specific. Data organization must be more efficient and support greater data access speed. Surveillance of the environment and life functions must be steady and accurate. Managing processes that support the life and work of people with disabilities must be safe. Communication must enable the transmission of large amounts of data, must be reliable and fast. ICT applications rely on the use of clouds in the segment of storage and organization data:

- Storage and organization of data,
- Monitoring algorithms,
- Management algorithms.

Communication based on the IoT concept has an integrating role. There are three types of IoT communication:

- Communicating things with people
- Communication between things
- Machine-to-machine communication (M2M)

Access to terminal devices provides M2M addressing and numbering system. M2M numbers and addresses are

often specially outlined in national numbering plans and in a different format to be sufficiently perspective for upcoming IoT services.

The infrastructure of the entire 4IR is the 5G network as a lever that drives massive scale and is crucial to a huge increase in opportunities for people with disabilities. In order for some services for disabled people to be realized through the appropriate application (or applications), the key element is that communication is fast, that communication can transfer a large amount of data at high speed and is reliable, all that the 5G network provides us (Table II.).

A. ICT services and apps for person with disability

When talking about services and applications for people with special needs, it should be noted that such services and applications already exist today. Likewise, the idea and concept are not new. Therefore, ICT services aimed at people with disabilities can be roughly divided into the following groups:

- Services that ensure independence within the home.
- Services that allow for independent movement (mobility).
- Services that overcome difficulties.

However, realization and implementation have not been sufficient to enable the population of people with disabilities to rely much more on such services and applications. Especially their development does not follow the growing needs of people with disabilities, increasing the number of such people themselves, and increasing the variety of their needs [4]. The underlying reason is in the fact that current ICT solutions can not satisfy these needs on some higher level, nor in one essential segment at the network (or global) level.

All the existing applications from these groups have a relatively low level of demands toward communication networks in all relevant segments - data rate, data volume, and communication reliability.

In mobility support a key role is in communication between things and interaction and communication with people. For these needs, today's ICT does not have the communication that would meet the need to transfer large amounts of data in very little time (high speeds) with very high reliability. Thereby mobility services also appear in the group of services that ensure independence within the home and in the group of services that allow for independent movement (mobility). There is a significant difference in the impact of ICT applications in these two service groups. For Services that ensure independence within the home, the quality and accessibility of services, in particular financial, are considerably increased. For services that allow for independent movement (mobility), self-movement without ICT applications are almost impossible.

TABLE II. COMPARISON OF 4G I 5G NETWORK

Download Speeds	4G real world	4G theoretical	5G real world	5G test environment
	20 Mbps average	300 Mbps	10-50 Gbps	1 Tbps
Latency	50 ms		1 ms	
Spectrum / Capacity	800 MHz		700 MHz	
	1.8 GHz			
	2.6 GHz		2.3 GHz	
			3.4 GHz	
			3.6-3.8 GHz	
			24 GHz and higher	

B. ICT applications useful for people with disabilities

ICT applications for mobility, although they are very demanding, have the greatest perspective for people with disabilities because they meet all the necessary conditions:

- The potential customer base is large and significant.
- Developing of IoT, Cloud, Big Data and 5G's technology base becomes wide accessible.
- Mobility is broadly present through other leading 4IR technologies too, such as robotics or autonomous vehicles.
- Their using is equally present both in the home and in the external environment.
- Their implementation and using for people with disabilities is universal because no special development is needed but just some modification or development of some additional opportunities.

Below are some examples of existing and planning ICT services and applications adapted to people with disabilities together with our visions.

Independent movement

Today, 55% of the world's population lives in the urban area, and by 2050 this percentage is expected to grow to 68%, where every eight inhabitant (and probably more) in the cities will be a person with some kind of disability [5]. Inclusive smart cities are a new approach and uses innovative technology that enables people with disabilities and old population to be included. From this, in 2017, the Smart Cities for All - SC4A initiative was launched [6]. The principles of universal design are applied by using and adapting other solutions for autonomous movement, especially autonomous vehicles. Applicability is also universal because the same application is used independently of location, time of day, and other time-spatial parameters. If the principle of universal design is respected from the beginning, costs are extremely small, as opposed to expensive investments in the accessibility of the existing infrastructure. The vision is to use all services through applications that will communicate with our environment through IoT. However, because of the complexity of such applications, they must have a complete ICT base and have an open concept of integration.

Smart City

The term "Smart City" represents a comprehensive system of services and the application of modern technologies aimed at providing a better life for citizens. Such a service system is based on IoT applications that include all three IoT

communications concepts, cloud computing as a database repository and a platform for performing monitoring algorithms, information and management of public services, the M2M address base, and the 5G transport base [7]. From the viewpoint of people with disabilities, such services are used directly, such as they are or with minor upgrades. Several examples: The "Air Pollution" service, without any modification, provides useful information to a person who has difficulties because of chronic illness [8]. "Perimeter access control" service can directly be used by a person with intellectual disability or person with Alzheimer's disease to keep within the scope of predefine mobility options [9]. The "Smart Lighting" service can directly use people with visual impairments and use the appropriate aids (white stick, special glasses) or sensor cards equipped with the sensor to turn on sound signaling if necessary, at the traffic lights [10]. In addition, by equipping auditory devices, such information could only be transmitted directly to the user.

An important aspect of universality of application is the possibility of individualization. The same application, people with motor disabilities with the help of smart aids (walkthroughs, canes, goggles, wheelchairs equipped with sensors or their "smart" applications) could use, with fewer adjustments.

Our vision of individualization in the smart city is smart traffic lights where pedestrians walking slower because of their difficulties can, with the help of such an application, extend the time of crossing (longer duration of green light). Further development of the same application can go in such a way that the traffic light recognizes the user's aids through audio-visual procedures, or intelligent traffic lights trough network receive information on the locations of people with mobility problems. The increasingly popular service - "Smart Parking", with the slightest adjustment, could be used by people with an accessibility sign to help them locate the appropriate parking space. These are services from the area of services that allow independent movement. However, significant relief is also provided by services from the bridging services group such as "e-Government".

Smart Public Transportation

Today's public transport is networked and thanks to this it is possible to provide information to passengers on information displays within the vehicle and on the stations.

Smart Public Transportation will have interactive touchscreen panels that displayed time, weather, news, toilet information, available seats in the carriage, help and assistance, connections for each station, famous landmarks at each stop, arrival/departure information for trains that serviced airports, local taxi information for each station when it was late, and details of emergency services. Each train would serve as an information kiosk—ensuring passengers always have information, wherever they are [11].

A wide array of applications, services, and technologies can connect a vehicle to other vehicles (V2V), to the infrastructure, and to its surroundings. A connected vehicle includes the different communication devices, which can be embedded or portable, present in the vehicle that enables in-car connectivity with other devices present in the same vehicle.

A connected vehicle also enables connection of the vehicle to external devices, networks, applications, and services. These applications can include anything and everything from traffic safety and efficiency, infotainment, parking assistance, roadside assistance, remote diagnostics, and telematics to autonomous self-driving vehicles and global positioning systems (GPS) [12].

Our vision is a smart public transport that is connected to a sensor that is carried by a disabled person; e.g. if the citizen through the application puts where he wants to disembark, he or she can get feedback while in the vehicle when is that station. The following suggestions would be that if the person with disabilities takes longer to enter or exit, with IoT the driver will be informed that at the next station is person with disabilities, also driver will receive the station where the passenger intends to go out. Thanks to this information, the public transport service can calculate how much a vehicle will be late and to reprogram the transport schedule, all that can be implement the ICT application.

Smart Parking

One of the major problems in cities is the lack of parking spaces. Smart parking is a wireless system that monitors the availability of parking spaces with the help of sensors embedded in the ground. The system is based on magnetic field technology and detects vehicles by measuring changes in the Earth's magnetic field caused by static vehicles or vehicles on the move. By applying ICT solutions, this information is distributed to servers, apps, displays and employees on the parking lot. It notes the exact time of each change in occupancy of the parking space [13]. The best application for Smart parking in 2017. (Smart Mobility Award 2017) is in use in Split, which gives insight into the availability of a parking space for vehicles with an accessibility sign. Not only can it easily be seen whether the parking lot has places for person with disabilities, but how much is the occupancy [14].

By modifying or upgrading, this application can become more applicable to people with disabilities. One of the major problems with using a parking lot for people with an accessibility sign is misuse: using an outdated tag or forged one. Our proposal is a modified accessibility sign that contains the sensor with the information about the validity of the sign (according to regulations the sign is valid for 5 years, and then a new sign is issued). With this modified sing the sensor at the parking place could provide information on the correct parking at the place for the disabled.

A card version already exists - EU Disability Card (EDC) has been launched in the EU by 8 members in 2016: Belgium, Cyprus, Estonia, Finland, Italy, Malta, Slovenia and Romania [15]. Similar cards were launched in the United Kingdom (Disability Card) and in France (Invalidity Card). With this card, for person with disabilities it’s easier to travel through the listed countries, access to cultural sights, using some services, etc. This card can easily be upgraded with smart parking functionality for person with disabilities.

Smart Home

A service group that ensures independence within the home is present today. For example, people with visual impairments and reduced mobility can issue voice commands

using existing technology such as Amazon Echo or Google Assistant Speaker. With this technology they can control lights, switches, and thermostats [16]. However, using ICT applications this service gets much greater importance.

The concept of a smart home has existed for some time on the market - managing devices through apps on a smartphone or through the dashboard. But by incorporating IoT, the whole concept has been raised to a higher, more accessible level [17]. With home user settings, each authorized application owner can manage home parameters from any location, such as gas shutdown, door lock etc. [18]. These were the problems that heavily burdened the older population and people with disabilities. By using the IoT application now they can independently, easily and reliably control it regardless of the location and time.

Smart Ring Bell and Lock

One of the great challenges of independent living for the elderly and the person with disabilities is to know who is at the front door, whether it is known or unknown person, and subsequently opening the door. In this smart system, you can define in advance what people can enter freely (via facial recognition) and which require the tenant's permission to enter [19]. Approval can be provided by the person with disabilities guardian. These two options: person recognition and unlocking an entrance door can be linked in one application.

Such applications can be solved locally, using only the device and software support the user has. However, the application of ICT solutions significantly simplifies system setup management. The main advantage is the possibility of remote control.

Smart Stick

Thanks to the various sensors in the smart city and the installation of a few sensors in a smart stick, the user can have information on his/her exact location, what is nearby, identify different obstacles (and alert the user to them) [20]. Figure 2 shows this scheme. Ultrasonic, hole, tactile sensors and RFID (radio frequency identification) ensure safe movement while whether, location, light and speed sensors ensure additional data about moving. Personal sensor gives additional data about person's health. If needed, the guardians of the person using such a stick have real-time location information. This is especially important in the case of people with dementia or Alzheimer's disease, as well as blind people.

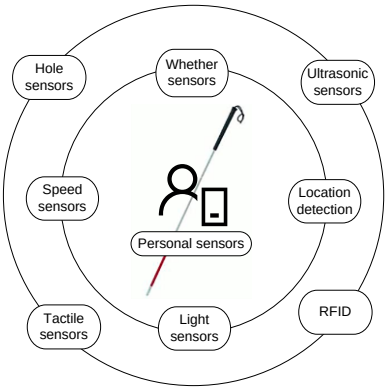

Figure 2. Smart Stick Scheme

Smart Glasses

For people who do not use a white stick but have considerable difficulty in sight, sensors can be fitted into the glasses frame and provide information to the user in the same way as in the case of a smart stick [21]. Smart glasses are connected to the IoT and can display messages on the glasses or notify the user using a microphone that can be connected to the headphones

Smart Wheelchair

The possibility of independent movement of persons in wheelchairs, without the help of another person, is of crucial importance for people with severe motor disabilities. A smart wheelchair is a power wheelchair to which computers, sensors, and assistive technology are attached [22]. By introducing the Smart Home applications, Smart Wheelchair gave the ability to move independently in a hospital or nursing home.

A step further is the possibility of independent movement outside of the closed and restricted area [23]. The logical solution is to install the appropriate sensors and applications that will allow movement in the smart environment (smart home, smart city) using IoT without any hindrance and according to the user's wishes [24]. Additionally, basic life parameters can be monitored, which can be sent to an appropriate server associated with health and other services as needed. Also, there is a possibility to avoid user's terminal equipment using M2M service. Figure 3 shows such a scheme of smart wheelchair.

Communication with Services (Police, Emergency Assistance, etc.)

In some situations, it is very difficult to communicate with people with disabilities. Some of the diagnoses are invisible at first glance, especially when it comes to mental illness, and public service staff may misunderstand the behavior of such persons (e.g. at Tourette's syndrome the person has motor tics such as blinking, touching other people, as well as verbal tics

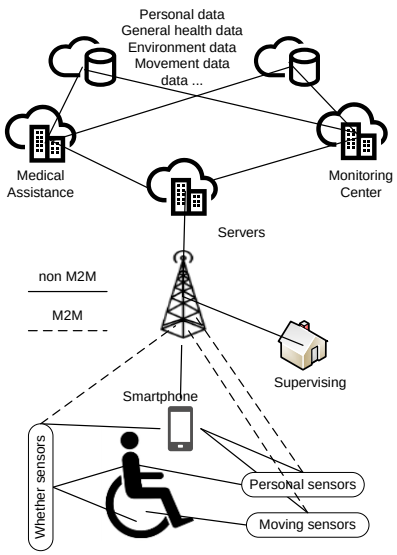

Figure 3. Smart Wheelchair Scheme

like shouting, bad language). Consequently, such persons may end up in jail or in a psychiatric facility. In the USA (Minnesota), an application is developed that allows families / guardians to enter the diagnosis and symptoms of escalation triggers. When a police officer or quartic guard is within a radius of 10 to 24 m from that person, that information is visible to him and he can approach him in the best way [25].

A set of ICT services can be divided into four main groups, considering the adaptability of the application to the needs of people with disabilities:

1. ICT Services that are applicable immediately
2. ICT Services that are applicable only under the condition of upgrades
3. ICT Services that are significantly better applicable under the condition of upgrades
4. ICT Services specializing in people with disabilities.

For each ICT application we can consider which group it might belong to. This also suggest the perspective of the application itself, primarily according to the principle of universal design, as a support application for people with disabilities. Table III. gives one such analysis, as an example of the procedure.

TABLE III. ICT SERVICE ASSESSMENT FOR PEOPLE WITH DISABILITIES

ICT application	group			
	1	2	3	4
Smart Parking	+		+	
Structural health				+
Noise Urban Maps	+			
Smartphone Detection	+			
Traffic Congestion	+		+	
Smart Lighting	+			
Forest Fire Detection	+			
Air Pollution	+			
Snow Level Monitoring	+			
Water Leakages		+		
Perimeter Access Control	+		+	
Radiation Levels				+
NFC Payment	+			
Intelligent Shopping Applications		+		
Smart Product Management				+
Item Location	+			
M2M Applications	+			
Indoor Air Quality				+
Temperature Monitoring	+		+	
Indoor Location	+		+	
Remote Control Appliances	+		+	
Art and Goods Preservation				+
Ultraviolet Radiation	+		+	

IV. CONCLUSION

Current trends of ICT development significantly expand area of human activity opportunities, both in regular life and in working relationships. New perspectives are opened for everyone, including for people with disabilities and elderly people. IoT and the benefits of the 5G network offer inexpensive high-speed solutions, where the factor of limitation is no more related to data volume. In this regard, by using services designed for people with special needs, it is possible to individualize almost the any particular service (e.g. public transport). However, enabling a better life in a home environment with the help of smart homes and associated services, we cannot reduce social interaction with people with special needs by pushing them into a smart environment on a local basis, as we lose the basic premise - inclusive and quality life in the community.

The authors will endeavour to encourage and continue research in their further work and activities to expanding boundaries of personal opportunities for people with special needs, to take away barriers for their normal life.

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Self-learning Prioritization of End-User Services to Eliminate Overload Situations

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***Abstract* – Telecommunication network providers employ various strategies to protect from and to mitigate overload situations caused by signaling storms to minimize end-user service loss. The common approach is the deployment of additional hardware above the engineered capacity combined with resource intensive operational recovery procedures. While signaling storms are relatively rare in its occurrence, they usually have serious consequences – loss of end-user service resulting in negative publicity and business damage. Adaptive overload management emphasizes end-user service as its primary goal in addition to the protection of a network function. The communication dialogs necessary to establish the end-user service are automatically detected and the involved requests are appropriately prioritized. Combining these two processes, the probability of service establishment and its eventual restoration is increased, which contributes to the reduction of overload situation as more end-users can receive its service. Self-learning request prioritization can reduce the time and complexity needed to restore service for all end-users during signaling storms. Through its automatic and self-learning operation it is suited for current and upcoming cloudified and 5G core networks.**

Keywords – overload; overload protection; robustness; signaling storm; adaptive prioritization; automatic network recovery; machine learning

I. INTRODUCTION

Telecommunication networks provide a variety of services to devices and applications that are consumed by end-users. End-user may be a human person using its (mobile) device to use internet-based services but also a software application or internet of things (IoT) device running without any human interaction. This experience is primarily a seamless one, the end-user is not aware of the technical details of the services, given the services are available. These services (voice, data, voice over LTE, voice over WIFI…) are delivered through a wide range of network functions (Fig. 1). For each service the communication may be different and may involve additional or less network functions (NF).

The approach of end-user service prioritization focuses on control plane network functions that hold the volatile end-user state information as well as semi-permanent subscription data necessary to provide the required services. Failure scenarios, like loss of (a portion of) end-user state information may trigger signaling storms within the network generating stress on network functions. Self-learning end-user service prioritization can, without significant investment into NF over-capacity and complex operational procedures, increase the service restoration rate and reduce the overall recovery time in overload situations.

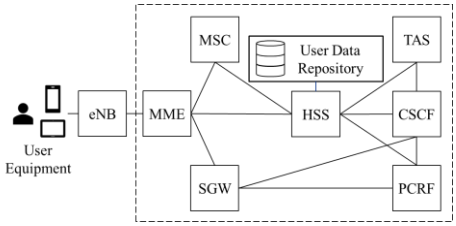

Figure 1. Interaction of network functions to deliver end-user service

II. THE CHALLENGE – SIGNALING STORMS

The telecommunication network is largely a multivendor environment. Different network functions from various vendors interact via standardized interfaces with each other. Decomposition into network functions supports and promotes innovation and competition. Vendors are competing to provide the best features, efficient resource utilization and carrier-grade availability. The downside of the decomposition is vendors focused attention on a specific network function ("silo" view). The network function itself is made highly available with its own approach to overload management (robustness) – primarily protecting itself against "misbehavior" of other NFs (vendors). Such effort is costly and uncoordinated between NFs. Considering a single NF in isolation may rationalize this strategy from vendors perspective, however from the telecommunication network operator point of view this is an unsatisfactory and an insufficient solution.

Telecommunication network operator's motivation and goal is to provide end-user service availability (and not a single NF availability in isolation) where all interacting network functions are included. This can be achieved only if the complete call flow (e.g. for device attach, service registration, session or service request) across the whole chain of different network functions is successfully executed (Fig. 2). Within a single end-user service call flow (e.g. device attach) certain NFs may be invoked multiple times.

Even if signaling storms are rare in its occurrence, they still happen more often that one would like to experience. NF overload protection is the foundation to master this kind of events. Overloaded network function performs individual decisions which requests will be processed, and which requests will be rejected (negative response). But as previously stated, all (call flow) requests across all network functions must succeed to provide service to the end-user. With NF silo overload decision behavior this can hardly be achieved, and service is provided either with low probability or not at all. It is just a coincidence whether end-user will obtain its service or not.

Common approach to mitigate negative consequences is to engineer network functions capacity for the worse possible scenario – deploying enough capacity to manage (the expected) traffic storms and thus avoid – if possible – overload conditions in the network in the first place. This approach has still the weakness that NF dimensioning is a theoretical exercise and the traffic in the network is not fully under network function control or under control of the planning personal. Rather it is driven by end-user devices, applications and failure modes of individual network functions (incl. faulty behavior). For this reason, additional operational procedures are developed to recover network with manually controlled procedures. Despite all the engineering efforts the risk remains, traffic storms are (still) possible and may emerge by factors higher than the planned NF over-capacity. The economic implications of such approach are significant – higher capital investment as well as increased ongoing operational costs.

III. PRIORITIZATION OF END-USER SERVICE

Carrier-grade network functions must provide overload protection on its external interfaces. A typical overload management would monitor selected performance indicators about its performance and utilization. If the utilization or key performance indicators (KPI) would cross predefined thresholds, the NF overload protection would be activated. Basic implementation would process as many incoming requests as it can successfully serve within a rolling time window while adhering to KPIs. The additional, randomly selected requests would be rejected with negative response.

The responsibility to recover from the negative responses is passed onto the NF client. The effect of this behavior is that:

- The NF client has very limited options and ability to recover (its capacity is also limited) and is likely to pass the failure back in the call flow chain.
- Rejection due to overload results in a service loss for end-user.
- Rejection of arbitrary requests decreases the prospects that an end-user will receive its service.
- Every rejection generates a retry process within the network which may eventually amplify the overload condition even further (end-users having service may be dropped off the network as well).

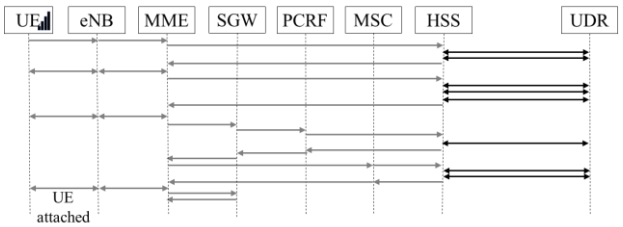

Figure 2. Exemplary attach call flow for UDR

An improvement to the situation can be achieved by supporting request priorities on network functions external interface. The NF client can, to a limited extent, indicate to NF service the priority of its request. NF service can make an informed decision to satisfy client priorities and reject lower priority requests initially during overload condition. This has impacts on NF clients that will need to implement the prioritization of its requests towards NF service fitting into the end-user call flow scenarios.

The generic principle of the end-user service prioritization is exemplary explained on a device network attach scenario. The Fig. 2 is providing such an illustrative example of a network attach call flow. We will focus on User Data Repository (UDR) network function [1] and its interaction with Home Subscriber Server (HSS). HSS is the NF client and UDR is the NF service. There are several key points that can be observed:

(a) The end-user service establishment requires several interactions to occur across multiple network functions.

(b) All these interactions must succeed to deliver the service to end-user.

(c) HSS NF is invoked several times in an end-user call flow (not necessarily triggered by the same NF) prior to service establishment.

HSS using UDR is a data less application. In general, it does not store states between multiple invocations of its external interface. HSS can adjust priorities for UDR requests within a single external invocation. The first UDR request with lower priority is followed by additional requests with increasing priority and finally the last request with relatively the highest priority. With staggered request priority within an HSS single external invocation, UDR being in overload, the first request with low priority would be more likely rejected than the requests with higher priority. This has the benefit that once the initial request (with lower priority) succeeds the next requests are more likely to succeed as well. Such behavior attempts to utilize the overloaded resources more efficiently and increases the probability of success for the particular HSS external interaction. However, overall end-user service establishment probability is not increased.

Enhancing the approach with end-user service prioritization requires HSS to prioritize UDR requests across multiple HSS external invocations (Fig. 3). The first HSS request in that call flow will have the lowest priority while the following requests towards UDR would be issued with increased priority. Likelihood of service establishment is increased under UDR overload conditions compared to the previous approach. The expected

consequence is reduced traffic and lowered resources consumption.

It is technically feasible, for a network function (e.g. HSS), to track internally end-to-end dialogs and determine appropriate request priorities. However, this is incomplete and complex:

- The prioritization is focused on single network function (e.g. HSS) impacting only a part of the end-user service delivery. The NF client may not be aware of other NF client's functionality which may cause additional interaction with the same NF service (e.g. UDR) which was not engineered in.
- The end-user call flow will vary based on network service and its characteristics itself and may not be constant (operators may enable, disable various features for groups of end-users).
- The NF (e.g. HSS) needs to store additional (highly volatile) internal state across interactions and thus introduce additional transient state information. Additional state information would eliminate data-less simplicity of NF client (i.e. necessary state replication across NF client instances).
- The prioritization depends heavily on deep engineering and implementation knowledge of the network function (which may change over time) and requires careful complex design consideration and on-premise configurability. Utilization of various NF client's features may alter the call flows and service invocations that must be considered in the implementation phase (increasing complexity and error probability).

The described approach can improve the situation at the costs of complexity. Self-learning end-user service prioritization provides a simpler and more generic approach.

A. End-user state information availability

Telecommunication network is providing the same services to a large group of end-users. The same (similar) communication patterns in the core network are repeated over and over. The information about provided service is represented as a state information that can be a registration state, attachment state or other kind of session state information. Initially, when a service is first-time requested by end-user, an initial state information must be created (registration or session data record). This operation is the most expensive one as it involves lot of interdependent communication across a variety of NFs (authentication, collecting service information, provisioned subscription data, applying policies…). The resource demands for initial end-user service establishment are very high. Once the service is established usually only smaller updates (e.g. service requests, location updates) are necessary to keep the service connected.

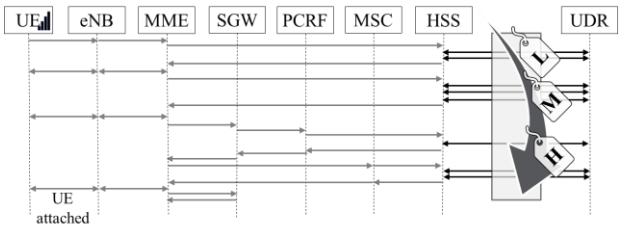

Figure 3. Exemplary attach call flow with UDR prioritization

There are many potential triggers of overload within the core network. However, majority is triggered by a failure scenario or application faults on the end-user devices. This may be a failure in radio network, failure in network connectivity, failure of network function instance or even a disaster situation (e.g. power outage, flood, construction work). Loss of or invalidation of the respective end-user state information within the network results in service interruption and end-user disconnection. End-users losing their service will attempt to re-establish the service as soon as possible. If many end-users are impacted there is a significant risk of overload to occur in the network.

The state information within the network represents the vulnerable resource that needs dedicated protection. In the exemplary scenario (Fig. 3) pressure is generated on semi-permanent (subscription information) data store (data needed to re-establish the service). The request priorities must be determined outside of the NF client and the prioritization of end-user service has to occur close to the NF service holding the state information (Fig. 4). Then it is possible to comprehend all interactions that are necessary to establish a service. This has the benefits of reducing the client complexity and increasing the flexibility in the deployment.

B. Enhancing prioritization with automatic learning

The amount of services provided by the network with its variations (service features) is limited. There are (large) groups of end-users using those services and the resulting communication patterns are following a very similar lifecycle – establish service (e.g. attach), update service information (e.g. service request) and dismantle service (e.g. detach). As these patterns repeat in the network, it is possible to analyze the traffic towards NF service and learn the interaction dialog patterns (end-user call flows) automatically in real-time directly from the network.

Fig. 5 is showing a logical diagram enhancing network function service overload management. All requests send towards the NF service would be analyzed and eventually modified. There are two main roles of such functionality:

(1) **Learning role** – scanning the incoming requests and learning end-user dialog sequences.

(2) **Prioritizing role** – labeling the requests with

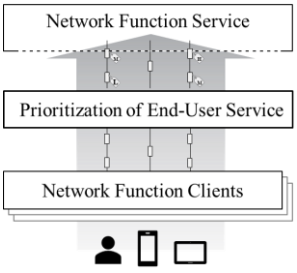

Figure 4. Logical diagram enhancing NF service overload protection

priority based on the learned end-user dialogs.

The first role (1) can be defined as the learning phase and is consisting of a sequence of activities:

- Request **sampling** – collecting request samples for analysis.
- **Extraction** of key features from the requests that are considered as important distinguishing factors. Using those factors end-user interaction dialogs are detected in the stream of requests.
- **Scoring** of the detected end-user dialogs and establishing end-user dialog patterns. Dialog patterns include the requests expected for end-user interaction including their priority based on the request position in the dialog sequence.
- The detected dialog patterns are then merged with existing known dialog patterns to continually **learn** active interaction patterns.

The learning phase is proceeding independently of the main traffic stream and their results can be periodically merged with the so far learned dialog patterns. Regular or constant learning phase will ensure that it can automatically adapt to possible changes in the network that may be caused by software updates or by new feature/service introductions. This functionality also significantly reduces the engineering efforts required for configuration of such functionality – it will simply be automatically configured for the needs in the network by itself.

The second role (2) of the service can be defined as the prioritization phase. In this phase each incoming request is **matched** against the active dialog patterns and if a match is found a **priority label** is attached to the request. The request with the priority is send to the NF service that uses this information in its overload protection mechanism. This way it will be ensured that the priority is in line with the end-user service delivery goals – the more progressed the end-user dialog (call flow) is the higher priority will be assigned.

C. Measurements

To validate the benefits and impacts of the end-user service prioritization the self-learning prioritization has been developed and tested in various scenarios. The setup consists of three components – a client, a prioritization service and the protected NF service. The client represents the end-users (UEs) demanding service and can simulate a

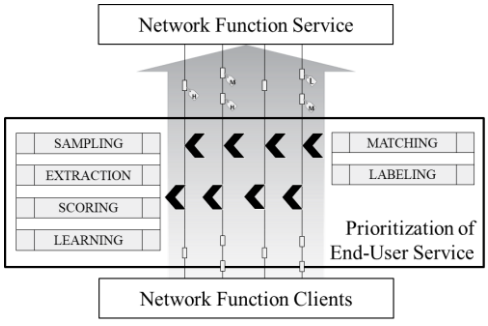

Figure 5. Logical diagram enhancing NF service overload protection

configurable number of end-users. The client sends all requests to prioritization service (without priorities). The prioritization service implements the end-user dialog detection mechanism (the learning) and the prioritization of the incoming requests which are forwarded towards the NF service for processing. NF service provides the protected network function service that is used by the client. It can support a priority driven overload protection and rejects the lower priority requests prior to higher priority requests (based on overload level).

The tests focused on comparing three specific scenarios with increasing number of end-users:

- Scenario (A) where NF service had enough capacity to process the peak traffic originated from signaling storm without NF service entering overload situation. This scenario was used to baseline maximum peak capacity.
- Scenario (B) where NF service has limited capacity and supports overload protection without priority consideration.
- Scenario (C) where NF service has limited capacity (as in previous scenario) implementing and using request priority to accept or reject requests in overload situation.

The initial situation for each test scenario is the same – loss of all end-user states (services) – all end-user services are disconnected. This represents the worst-case scenario where a traffic storm reaches the network function service requesting the service for all end-users nearly simultaneously. For scenarios with overload protection (with and without prioritization) the NF service (limited) capacity was exactly the same.

For an end-user to *attach* successfully to the network (service establishment) a sequence of requests must succeed on NF service. Once end-user is attached to the network a periodic *service request* is issued for each. If the *attach* use case fails it is aggressively retried after a small delay. If *service request* use case fails, the end-user loses its service and *attach* use case is initiated again. Each request to NF is accompanied by a timeout and its expiration leads to a use case failure with a subsequent retry starting again with *attach* use case. The *attach* use case produces factor 4 more requests than the *service request* use case.

The tests were executed with increasing number of end-users. Initial test with specific number of end-users was baselined at 100%. The number of end-users has been then increased by a factor up to 6 (600% of the initial number of end-users). Each test generated certain level of overload on the network function service (except the baseline scenario tests measuring the maximum peak capacity without overload).

For each number of end-users (from 100% to 600%) a baseline peak capacity was determined (scenario (A)). This is the capacity that is needed to be supported by NF service in order to avoid overload situation at all (i.e. to deploy additional hardware accommodating the expected signaling storms). This peak capacity is shown in Fig. 6 as gray bars on the right vertical axis. If the NF would have

to sustain the load from the 100% of end-users (initial number of end-users) without overload the NF would have to support 10x higher peak capacity (10 instances of the same NF service); for 6 times (600%) more end-users it would require even more than 30 times more capacity to avoid overload situation (compared to the limited capacity for scenarios (B) and (C)).

The Fig. 6 shows two curves (on a logarithmic scale – left axis) monitoring the average network *attach* success ratio representing successful service establishment – for overload protection with prioritization (black squares – scenario (C)) and without prioritization (dark gray triangles – scenario (B)). The value represents the likelihood that an attempt of end-user to *attach* to network will succeed. At the start of the test the ratio is lower and as the recovery progresses it is increasing. It can be observed that even with relatively low overload level the probability of network *attach* with end-user service prioritization is higher than without prioritization. This difference is even more significant with increasing overload on the NF service. End-user service prioritization on NF increases the probability of service establishment significantly under extreme overload situations. The side-effect of the increased probability is that the strength of the signaling storm is being faster reduced and less and less *attach* attempts are being retried which speeds up the recovery process.

It is important to note that the scenario without prioritization (B) has not recovered for 300% of end-users and more. Only a minimal portion of end-users received service which was subsequently lost (failed *service request*). The (simulated) network never recovered in these test scenarios.

The ratio of recovery duration is shown in Fig. 7. The chart is showing the recovery duration compared with baseline scenario (peak capacity available without overload). It can be observed that overload protection with end-user prioritization recovers faster. Not only that, overload protection with priorities is able to recover from significantly higher overload situations. This is especially caused by the increased *attach* probability, it can recover even 6 times more end-users with the same capacity (average probability of a successful end-user network *attach* with prioritization is still 0.55% compared to 0.0001% without prioritization).

Self-learning end-user service prioritization brings major benefits in managing signaling storms:

- It increases the probability that end-user service can be established or preserved during overload situations.
- The overall traffic is reduced faster as more users have service recovered. The duration of the overall recovery is shorter.
- Its automatic and self-learning nature can recover the service without manual intervention.
- It can recover from higher levels of overload.
- The deployment costs are reduced (lower peak capacity required).
- It provides a safety net for unexpected events in the network.

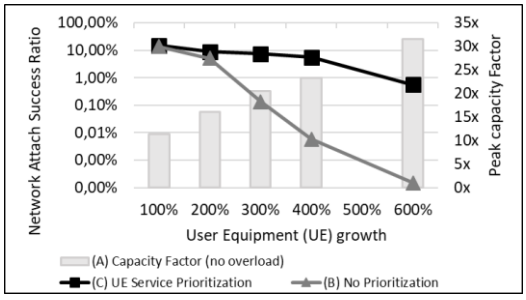

Figure 6. Network attach success ratio

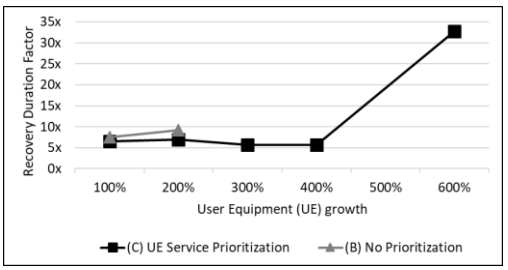

Figure 7. Recovery duration ratio of all UEs

IV. 5G CORE AND CLOUD

So far in our exemplary situation, the assumption has been that "somewhere" in the network end-user state is lost and a signaling storm is reaching UDR. UDR is the end-point that needs to deliver all the information that is needed to establish/restore services (UDR stores semi-permanent subscription and policy information that is the basis of majority of services in the network). But many of the current network functions also hold internal state information. For example, Mobile Management Entity (MME) holds registrations status, bearer information, IP Multimedia System (IMS) holds session information… The network functions are stateful and loss of any of this state may result in a signaling storm that impacts also all other network functions in the end to end call flow chain. State information and stateful network functions ideally require specific overload protection.

There are currently two significant developments in the telecommunication networks that are worth to analyze in terms of state information and the relevance of specific overload protection. The first area is related to network cloudification or Network Function Virtualization (NFV) of the core network. The second development is related to new 5G core network architecture and its service-based architecture.

A. Cloudification of network functions

NFV [2] is significantly changing the landscape of telecommunication networks. The cloudified network functions will have to adopt a different architecture – NFs must implement so called cloud native principles. Critical principle for NF cloudified architecture is the separation of state information from the NF business logic. The NF state information is being externalized and the network function itself is becoming stateless and thus simpler, easily scalable (elastic) and maintainable. Stateless

network functions can process any incoming request as the data can be queried and updated in real time. Externalized data need to be made highly available, scalable and include appropriate overload protection to minimize the likelihood of state information loss.

B. 5G Core

5G is introducing significant changes into the telecommunication core network. The standard leverages best practices from web scale companies and defines new interfaces. There are two main aspects relevant for managing state information – (1) disintegration of network function to separate data from business logic and (2) introduction of service-based architecture [3]. Disintegration of network functions is preferring stateless network functions with externalized state information. 5G defines [4] two data storage network functions that are available. Unified data repository (UDR) for storing structured data (e.g. subscriber profile, policy data, session information…) and unstructured data storage network function (UDSF) for storing unstructured private NF state information. Service based interfaces (SBI) [5] introduce a common interface basis for all network functions. All interfaces are based on the same protocol with different data information being exchanged. SBI is also introducing (an optional) request priority parameter that can be supported by network functions for overload management.

C. Data Layer

Based on the increasing needs for external data storage a data layer architecture has emerged. 5G service-based architecture [3] is introducing Unified Data Layer (UDL) that provides storage services for NFs, for semi-permanent (subscription, policy, context) information as well as for volatile user information (session data). In [6] the UDL has been refined into a Network Data Layer (NDL) with more detailed architecture and functional requirements. NDL combines the trends related to state/data externalization into a single network data layer. One of the NDL goals is increased stateful resiliency of network functions. The data layer is state-full and therefore its immediate ability to react to signaling storms (elasticity) is limited and it comes with significant costs (replication). Self-learning end-user service prioritization is a complement to the data layer. The end-user prioritization shall be overlaid (Fig. 8) on top of NDL external interfaces. NDL must support and respect request priorities on its external interface as part of NDL overload protection. This way, the state information would be appropriately protected even in overload – signaling storm – situations while state-less network functions can elastically adapt and accommodate to incoming traffic.

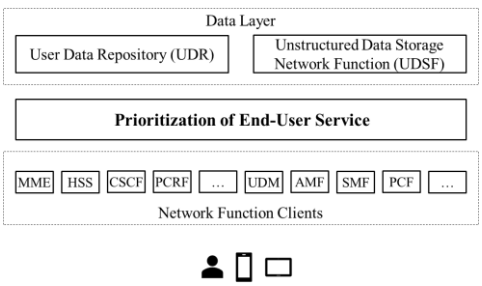

Figure 8. Enhancing data layer robustness in 4G and 5G networks

V. CONCLUSION

Telecommunication network operators expect that end-users will receive their service whenever they need and thus look for solutions how to improve the service delivery even in imperfect network conditions. Loss of (access to) state information leads to loss of end-user service and attempts to re-establish it as soon as possible. Signaling storms cannot be excluded in current and even in future networks. Introduction of new technology comes with unknowns and risks. The behavior of network functions and new 5G devices will need to be learned and tuned. Internet of Things (IoT) market is growing and it is expected still to significantly grow. IoT devices reveal different traffic patterns than consumer traffic patterns. The growing number of different devices raises the risk of uncontrolled traffic storms and makes traffic capacity planning unreliable.

There are many unknowns and the networks must be prepared for it. The implemented self-learning end-user service prioritization can significantly improve robustness of telecommunication network and help to manage signaling storms. It serves as a defense against the unexpected and recovers customer service even under high overload conditions automatically. It reduces engineering and implementation costs needed by vendors and operators through its self-learning and automatic operation. It permits to reduce the dimensioned peak capacity of network functions (thus the capital and operational expenses) while providing faster recovery times in overload situations. The approach fits very well into existing telecommunication networks as well as it matches with new 5G and cloudified networks.

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Mapping of QoS/QoE in 5G Networks

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***Abstract* — 5G technology will dramatically change the way of living. With a flexible combination of developing existing technology solutions and new radio concepts, and meeting the requirements for efficiency and scalability, the 5G network can respond to new user scenarios followed by a large increase in traffic and number of connected devices. This coming era of 5G network is demanding dynamic resource sharing and context sharing with seamless high speed connectivity everywhere. The challenge for operators is to understand and manage both the quality and performance of the services to fulfill on the technical quality of service (QoS) as well as on the quality of experience (QoE) level. Quality of experience is the subjective acceptability of the quality of a telecommunication service perceived by the user. This contrasts with quality of service, which concerns objective and technical metrics at network and application level. The identification of service-relevant QoE metrics and modeling of how these are affected by the different 5G QoS metrics is discussed in this paper. The impact of QoS parameters on QoE and the possible scenario of QoS/QoE mapping process are presented.**

Keywords – Fifth-generation 5G, Quality of Service QoS, Quality of Experience QoE, Key Performance Indicator KPI

I. INTRODUCTION

Customer-centricity is a novel paradigm which is shaping the evolution of the future telecommunications business. There is an urgent need to transform Communication Service Providers (CSPs) from network-centric to customer-centric businesses to accommodate increased customer expectations and competitive pressure. Customer expectations about the quality of service depend on the services they use [1]. Traditionally, performance monitoring based on existing standards has been focusing on technical Key Performance Indicators (KPIs). Quality of service for the wireless network is measured using KPIs. However, it is more important to focus directly on quality of experience. QoE refers to the provision of quality of service according to user's request. As one of the key driving forces of the future 5G network is the anticipated QoE. This will ensure consistency, transparency, personalization and differentiation in service delivery, some of top 5G topics.

Key performance indicators used by operators are average metrics that hide the real experience of users and are particular of a certain technology. KPIs today do not directly target the surveys of satisfaction. This is why the customer-centric paradigm that will characterize the 5G requires a redefinition of network indicators with a single measure of the user experience such as end user QoE. The distinguishing of service-relevant QoE metrics and modeling of how these are affected by the different 5G QoS metrics is very important. In this process both objective and subjective data must be considered for end user QoE.

In this paper, we discuss the identification of QoE metrics for services and modeling the ways in which they are subject to different 5G QoS metrics. In the first part we gave a brief overview of 5G KPIs, designed to assess the success of identified use cases. The second chapter summarizes the QoS and QoE interdependence and mapping characteristics. The impact of QoS parameters on QoE and the possible QoS/QoE mapping process scenario is presented. Finally, we point to some challenges that are possible on that path.

II. QUALITY OF SERVICE & QUALITY OF EXPERIENCE

A. *From KPIs to QoS*

Fifth-generation wireless is the latest iteration of cellular technology, engineered to greatly increase the speed and responsiveness of wireless networks. According to [2] 5G technological goals are: 1000 times greater mobile traffic, 10 to 100 times higher user speeds, 10 to 100 times more users, 10 times longer battery life at massive M2M communications, 5 times reduced E2E (End -to-End) delay.

In addition to improvements in speed, capacity and latency, 5G offers network management features, among them network slicing, which allows mobile operators to create multiple virtual networks within a single physical 5G network. This capability will enable wireless network connections to support specific uses or business cases and could be sold on an as-a-service basis. A self-driving car, for example, would require a network slice that offers extremely fast, low-latency connections so a vehicle could navigate in real time. A home appliance, however, could be connected via a lower-power, slower connection because high performance isn't crucial. The Internet of Things (IoT) could use secure, data-only connections.

5G concept consists of three generic services: Extreme Mobile Broadband Approach xMBB (Extreme Mobile Broadband), Massive Machine-Type Communication Mass Communication (mMTC) and Ultra Reliable Low-Latency Machine-Type Communication (uRLLC). These three generic services should be considered as the basic characteristics that cover the 5G user scenarios.

Key Performance Indicators which from the perspective of the end user take as the basis for assessing the performance of defined scenarios are: traffic volume density, experienced end-user throughput, latency, reliability, availability, retainability, energy efficiency and security [2], [3].

- Traffic volume density represents the total volume of user data that is transmitted to/from end user devices during a defined time divided by the area size covered by the radio nodes belonging to the RAN. It refers to the goal of supporting 1000 times more traffic volume compared to today's networks. This goal is the result of a large increase in the number of mobile devices, capacitive demanding applications and multimedia services.
- Experienced end-user throughput represents the average data flow that the end user's device reaches during the defined time. It targets the goal to support 10 to 100 times the typical user speed. This KPI depends on the environment, but also on the number of users and the amount of data they generate. It can be used as an indicator of user satisfaction.
- Latency refers to the goal to support 5 times less E2E delay than existing services, which is especially important for services requiring reliable connection in real time. Although all network entities are included in the E2E connection, delay enhancement is expected in the radio access network because of introduction of new functionalities.
- Reliability is a metric that describes the quality of radio connection that achieves a certain level of service. This KPI is important for all user scenarios. When reliability has a value below the expected QoE level, the service becomes unavailable to the user.
- Accessibility is the KPI which in the planned coverage area represents the measure of service availability to the end user.
- Retainability of the connection is a special aspect of availability and it is a measure of availability of the services during the time required by the end user. This KPI is important for all user scenarios and is important from the point of view of network optimization, which is especially apparent during the handover process between adjacent cells when users move between different frequency layers and/or access technologies.
- The energy efficiency is the KPI defined by the need to increase the capacity of resources to meet new requirements in terms of traffic load and therefore energy consumption.
- The security is the KPI defined by the need for extremely secure communication, and the protection of privacy and user integrity.
- The end user can be a person or device that communicates with other devices or people over their devices. Expected values of observed KPIs vary greatly depending on the observed user case. For each of 5G generic services, specific requirements for KPI values are typical, such as data rate for xMBB, number of devices for mMTC, and latency and reliability for uMTC, as it is shown in Fig. 1.

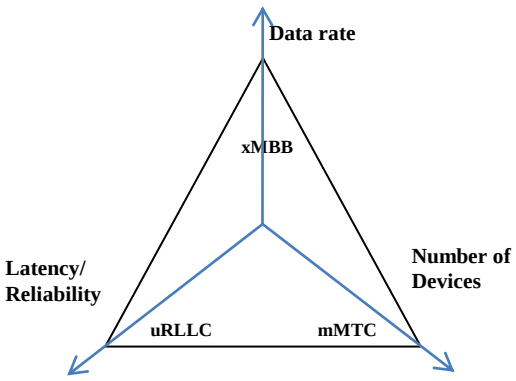

Figure 1. 5G generic services [4].

B. *From QoS to QoE*

QoE is the perception of users' services. International Telecommunication Union Telecommunication Standardization Sector ITU-T P.10/G.100 defines the QoE as "level of user's acceptance towards application and services is referred as QoE". QoE is a subjective measure and it is very difficult to measure it. Services provided with a very low level of QoE result in a disappointment of users, while on the other hand using maximum resources for all services will cause resource scattering. It is important to find a compromise on the above items. When QoE is achieved and approved by the user then to ensure a consistent QoE becomes more and more critical because user has great expectations based on previous experience.

In general, QoE is a non-parametric, nonlinear function of QoS where, if network optimization is based solely on QoS, it may not lead to optimal QoE. Defining an analytical relationship between technical aspects of QoS influencing QoE is not straightforward. This is because QoE is not directly captured by network measurements and random nature of human behavior. QoE is a qualitative measure of the level of satisfaction of the service and application and this metric must include factors relating to users, services and the environment. User related factor include user's perception and past experience. Environment related factors include the environment in which services providing framework is working. Moving from a QoS to QoE-centric network management and, in turn, from a network- to a customer-centric architecture would be a key differentiator and a step change from 4G to 5G networks.

The schematic relationship between QoS and QoE, which is divided into three zones, is given in Figure 2, [5].When the QoS disturbance is less than zone 1, QoE has a high value, and i.e. the user's appreciation is not affected. The QoE decreases, when the QoS disturbance reaches zone 2. Finally, when the QoS disturbance increases to zone 3, the QoE may fall, i.e. the user's appreciation will be highly affected and they may stop using the service altogether. Typically, when the QoS disturbance parameter increases, the QoE metric and user's

perception of quality decrease. QoS is not considered adequate for the thorough characterization of a product or service against to the most attractive QoE concept. QoS handles completely technical aspects regarding a service and does not incorporate any kind of human-related quality-affecting factors. This means that the same QoS level might not guarantee the same QoE level for two different users.

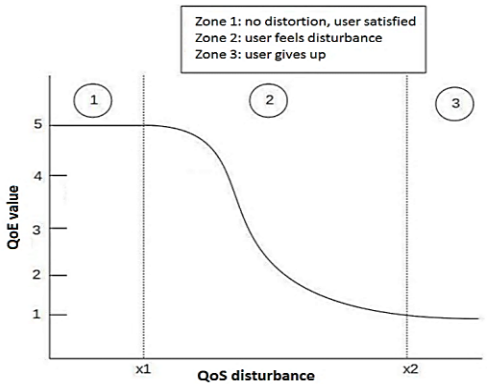

Figure 2. QoE vs. QoS [5].

The other factors that have also a significant impact on the finally perceived QoE as well are the context of use, the user-specific characteristics, the delivered content and the pricing of a service. In addition, there is no direct connection between technical factors and users' quality perception. For example, the constant improvement of one technical parameter does not linearly and infinitely improves user experience. Due to the existence of this gap, there was a need for mapping between QoS and QoE. However, this process proved to be demanding and complex, because it is influenced by numerous factors, both objective factors and the subjective perception of users.

The relationship between the KPIs and the QoE is highly non-linear and there is no any single mathematical function can describe this relationship with a satisfactory accuracy. So far, it seems that the non-linear, non-parametric regression trees or random forests are the best models in terms of prediction accuracy.

III. QoS/QoE Mapping

Different solutions for QoS have been proposed at a variety of layers in the Open System Interconnection (OSI) seven layers model. The two layers generally used for QoS are the application and network layers. The application layer includes services that are provided by the application in order to achieve the required QoS. Application layer QoS is concerned with parameters such as frame rate, resolution, colour, video and audio codec type, etc. QoS at the application layer is driven by human perception. On the other hand, network layer services are provided by devices such as switches and routers. The network layer considers parameters such as delay, jitter, and packet loss ratio, etc. Some of QoS parameters such as packet loss ratio, the total setup time of wireless connection and delivery bandwidth can be successfully mapped to QoE using perception-centric and stimulus-centric approaches [6].

It is important to investigate the end user-oriented QoE versus network-oriented QoS parameters. This motivates the need to gain insight into the principal ways in which the quantitative parts of QoE are affected by the network QoS parameters. It is possible to measure and quantify the QoE and subsequently derive a mapping correlating the QoS parameters with the measured QoE metrics. Thus, it is possible to build an effective QoE-aware QoS model.

5G network communications is intended to be context-based, whereby the user context can be a personal context, a context specific to the application, the environment, the device, and the network, [7]. Personal context refers to user-related information that can be added to providing personalized services such as user location, activity, emotions and the previous experience. An application-specific context specifies the required QoS to run these applications such as video streaming, web browsing, online games and cloud-based applications. Environment context refers to the conditions in which services are delivered as device's distance from access point, data traffic load and availability of alternative resources. Device specific context refers to remaining battery power, processor's capability and other device specification. Network specific context refers to the air link load, availability, reliability, throughput and spectrum sharing.

A. QoS/QoE mapping: possible scenario

5G should be a smart network, smart enough to deliver data transfer speeds to the user compared to their requirements, instead of providing maximum data transfer speeds all the time. Expected values of QoE and performance requirements vary greatly depending on the observed service type. There is no user scenario that can be viewed uniquely, but as a combination of different scenarios presented from the perspective of the end user.

For example, gaming or self-driving car scenarios require low latency, high data rates, low packet loss and high security in the second scenario. These requirements involve very high values of expected QoE. For selecting the most important KPIs for virtual reality office end users transmit large amounts of data at high speeds, where users can be located at different locations and have the impression "as if they are in the same room". If we consider the example of dense urban information society where at all locations at any time people communicate at high speeds with each other or with devices. However, some other service types do not have such rigid requirements, Table I.

There are two main quality assessment methodologies, namely subjective and objective assessment. The identification of service-relevant QoE metrics and modeling of how these are affected by the different QoS metrics is a key aspect. QoE metrics decompose individual user experience in different dimensions, which are perceivable and nameable on a service and context basis, and whose combination forms the subjective quality perceived by the user. Measuring and ensuring good QoE

of e.g. video applications is very subjective in nature. The most commonly used subjective method for quality measurement is the Mean Opinion Score (MOS).

TABLE I. COMPARISON OF QOE EXPECTATIONS AND PERFORMANCE REQUIREMENTS BY SERVICE TYPE

Service Type	Scenario	KPI	QoE Expectation
Gaming	1. Amazing fast 2. Super real-time and reliable connections	Latency ↘ Data Rate ↗ Packet Loss↘ Session Drop ↘	Very High
Massive deployment of sensors and actuators - home appliance	1. Great service in a crowd 2. Best experience follows you 3. Ubiquitous things communicating	Coverage ↗ Cost ↘ Energy Consumption ↘	High-Best Effort
Virtual office/Business services; Self-driving car	1. Amazing fast 2. Super real-time and reliable connections	Latency ↘ Data Rate ↗ Security ↗	Very High
Internet/ web browsing	1. Best experience follows you	Latency – tolerant Packet Loss – tolerant Experienced end-user throughput ↗	High-Best Effort

The objective approach is based on mathematical and/or comparative techniques that generate a quantitative measure of the service. In [5] is given a review of the approaches for measuring network service quality from a user perspective. They are classified into three categories, namely: testing user-perceived QoS (e.g. MOS), surveying subjective QoE (e.g. questionnaires) and modelling media quality (e.g. perceptual evaluation of speech quality). If we include in this model an objective QoE that is based on technical KPIs we get end user QoE, Fig. 3.

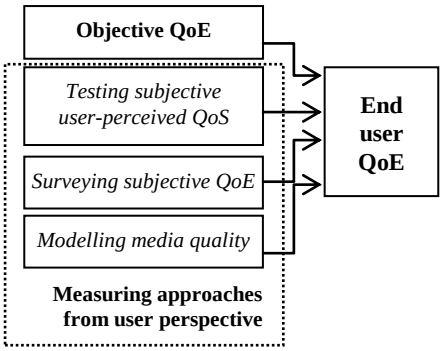

Figure 3. End user QoE.

Surveying subjective QoE metrics are aggregated based on survey results conducted on representative samples, allowing consistent performance monitoring over a shorter or longer period of time and performance comparison across all channels used by subscribers. There are a variety of strategies to choose the right type of metrics to help them choose what they will measure in interaction with their customers and how to develop their solutions for improvement, [9]. The most commonly used metrics by telecommunication operators are: CSAT (Customer Satisfaction) that is used as a direct measure of customer satisfaction; Customer Effort Score (CES) that is used as a measure that determines the effort involved in solving the user's problem and NPS (Net Promoter Score) that identifies promoters, then critics and passive users. This metric recognizes the users who recommend the company to others, which is the highest level of customer loyalty.

In [8] a high level view of the QoE/QoS mapping is presented. It is architecturally strongly related to the Software-Defined Mobile Network Controller. According to this concept the QoE/QoS mapping process can be modeled in two steps: first, the QoS metrics modulate the set of QoE metrics; second, the combination of these QoE metrics forms the end user QoE.

A simplified 5G KPIs-QoS-QoE mapping model based on approaches [5-8] can be presented in the following way: QoS data that are derived from basic set 5G KPIs, are translated to objective QoE. But end-to-end QoE is influenced by data received from user perspective (subjective user-perceived QoS, subjective surveying QoE and modelling media quality). The combination of all mentioned above the QoE metrics shapes the QoE of the end user, Fig. 4.

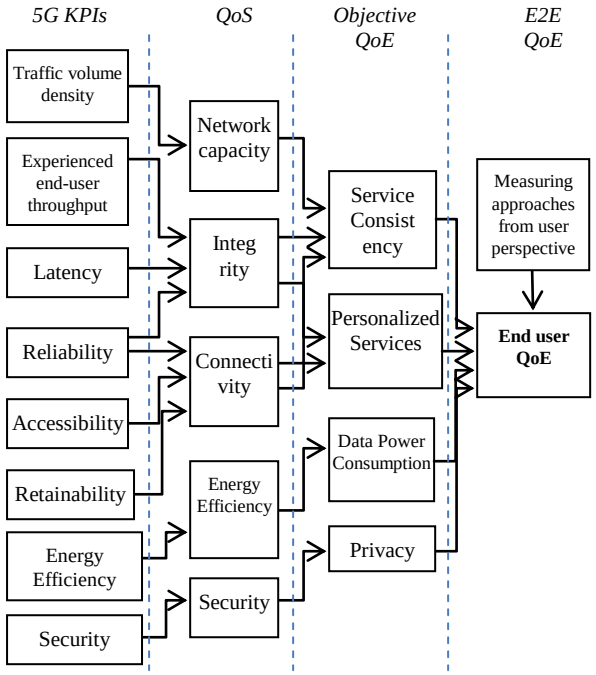

Figure 4. 5G KPIs–QoS-QoE mapping model.

IV. CHALLENGES

The main 5G challenges are related to data collection, selection of metrics, and analysis of results. The network is designed and built to adapt to customer rather than expecting customers to adapt to the network. This leads to the application of data analytics and machine learning in network operations, [10]. In order to refer the issue of interference and mobility management, the 5G comprehensive framework deals with a complete redesign of control and user functionality, as well as changes in infrastructure and user equipment. Operation and management of this 5G network must be simplified, including a new approach in which all focus is on the user

satisfaction. This requires advanced data analytics and the use of Big Data techniques to monitor the users' quality of experience by using network metrics that combine network and behavioral data. Big data and data analytics have an important role to play in this new paradigm of system operation and management. In order to derive the user QoE simultaneously, it is required to correlate location data with other context data, including bearer allocation, traffic pattern, day, hour, social behavior, contract details, etc. A classical computational approach is unable to manage such a huge volume, velocity, and variety of data. In [11] is described a new approach for the definition of KPI, which fits better with the future needs of the 5G in terms of network operation and maintenance.

It is well known that different customer segments will exhibit different behavior and perception on the services they received. For example, corporate users may require better voice QoE than consumer users, or users in a big city may have higher expectation on overall QoE than users in suburban areas. User requirements are also technologically dependent. Building a single QoE predictive model across the board may prove to be an effort in wasted due to the diverse user groups. However, more accurate models can usually be achieved if we stratify the data and build a model for each user group. The challenge then is how to perform the segmentation, [12].

Service Level Agreements (SLAs) between operators and end users as well as between operators and various Over the Top (OTT) providers need to be reconsidered because typical SLAs are described using QoS conditions, which do not imply a directly comparatively satisfactory QoE level for the operator's or the OTT provider's customers. Because of different stakeholders potentially involved throughout the end-to-end service provisioning chain, such as OTT providers, different mobile network operators or Internet Service Providers (ISPs), content providers, vendors, etc., the achieving end-to-end quality becomes a very challenging task in business terms. Customer experience management requires efforts across all communication layers and network domains, where different functions such as network access selection, resource allocation, QoS mapping, session establishment, and source coding need to be adaptable to the customer's QoE. Therefore, the shift from QoS-centric to QoE-centric networks is still emerging and an open research question.

V. CONCLUSION

In 5G, fulfilling customer demands creates many new challenges for the operator to address. Expected values of QoE and performance requirements vary greatly depending on the observed service type. The identification of service-relevant QoE metrics and modeling of how these are affected by the different QoS metrics is very important. Due to a lack of understanding of network dynamics, just using the business and network operation levels for data analytics is often inadequate to understand the root cause of customer problems. Data-driven modeling becomes very relevant as a future innovation enabler.

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Primjena agilnog pristupa u implementaciji promjena u procesima za realizaciju telekomunikacijskih usluga

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***Sažetak* – Za implementaciju potrebnih promjena u sustavima programske podrške koje telekomunikacijski operatori koriste za realizaciju svojih usluga u većini se slučajeva koristi model vodopada koji se sastoji od više slijednih faza prilikom implementacije promjena. Za razliku od modela vodopada, agilni pristup je puno fleksibilniji model gdje se implementacija potrebnih promjena odvija kroz više iteracija i na taj se način dolazi do konačnog rješenja. Da bi se omogućilo uspješno korištenje agilnog pristupa potrebno je osigurati preduvjete koji omogućavaju korištenje takve metode u razvoju složenih programskih rješenja koji zahtijevaju veliku preciznost i dokumentiranost i za čiji je razvoj potrebno izdvojiti značajne ljudske resurse i novčane troškove.**

Ključne riječi – sustavi programske podrške; telekomunikacije; agilni pristup

I. UVOD

Implementacija promjena u procesima i funkcionalnostima u sustavima programske podrške za realizaciju telekomunikacijskih usluga složeni je postupak koji zahtjeva uključenost velikog broja sudionika, preciznost i disciplinu u procesu pripreme zahtjeva, izrade procesne i funkcionalne specifikacije, izrade tehničke specifikacije, razvoja, testiranja i ažurnog dokumentiranja. Česti pristup koji se koristi kod telekomunikacijskih operatora je model vodopada koji uključuje više slijednih faza u razvoju programske podrške. Ovo je kruti model gdje je završetak svake faze uvjet za početak faze koja slijedi u ovom modelu. Ukoliko neka od faza razvoja nije dobro realizirana to ima direktni utjecaj na uspješnost faza koje slijede, a i na realizaciju kompletne promjene. To često donosi visoke troškove i značajna kašnjenja u razvoju. Agilni pristup uz korištenje scrum metodologije, za razliku od modela vodopada, uključuje rad malih timova koji u iterativnim postupcima rade na definiranju zahtjeva i razvoju softveru dio po dio i u svakoj iteraciji radi se nadogradnja rješenja dobivenog u prethodnoj iteraciji. Korištenjem agilnog pristupa dobiva se na fleksibilnosti i brzini razvoja te lakša prilagodba promjenjivim rješenjima i zahtjevima. Agilnim pristupom omogućava se i brža isporuka zahtjeva u manjim intervalima i omogućava se nadogradnja zahtjeva ili promjena u odnosu na rješenja prethodnih faza. Korištenje agilnog pristupa u razvoju sistemske programske podrške velik je izazov jer je potrebno pristup, čija je najveća snaga fleksibilnost i postepeni razvoj rješenja kroz iteracije, prilagoditi razvoju složene programske podrške gdje se zahtjeva velika preciznost i disciplina u razvoju rješenja te dobra dokumentiranost.

U radu je opisan postojeći model razvoja programske podrške u HT-u te dan prijedlog načina primjene agilnog pristupa u takvom razvoju programske podrške koja se koristi za procese realizacije usluga telekomunikacijskog operatora.

II. MODELI ZA RAZVOJ SOFTVERA

U ovom su poglavlju, između svih modela koji se koriste u tom području primjene, opisana dva modela za razvoj softvera. Model vodopada koji se većinom koristi za razvoj programske podrške telekomunikacijskih operatora i model agilnog pristupa uz korištenje scrum metodologije čija se primjena želi razmotriti i predložiti za razvoj programske podrške telekomunikacijskog operatora.

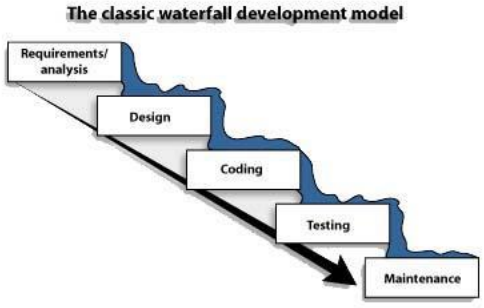
A. Model vodopada

Vodopadni model prikazuje disciplinirani napredak kroz sve faze projekta. Koraci razvoja u ovom modelu planski su definirani i ne preklapaju se, već slijede jedan iza drugoga. Sljedeća faza pritom ne bi smjela započeti dok prethodna nije završena[2].

Vodopadni model se sastoji od sljedećih faza (slika 1):

a) Prikupljanje zahtjeva/analiza
b) Dizajn
c) Razvoj
d) Testiranje
e) Implementacija

U stvarnosti je moguć povratak u prethodne faze, ali to iziskuje dodatne troškove i kašnjenje u realizaciji implementacije. Vodopadni model pogodan je za projekte koji imaju visoko razumljive zahtjeve s malom vjerojatnošću njihove promjene[2].

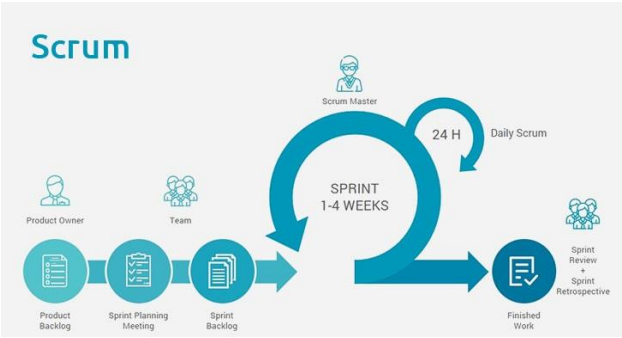


Slika 1: Model vodopada

B. Model agilnog pristupa uz scrum metodologiju

Po Scrum modelu projekt napreduje iterativno kroz sprintove. Model je opisan slikom 2. Na početku projekta definiran je Product backlog u kojem su na visokom nivou (bez detalja) popisane očekivane funkcionalnosti određenog proizvoda. Određuje se dio funkcionalnosti za pojedini sprint neposredno prije pokretanja sprinta, odnosno u fazi njegova planiranja. Skup tako detaljiziranih funkcionalnosti se naziva sprint backlog. Na osnovu procjene razvojnog tima planira se trajanje sprinta kako bi se omogućio razvoj svih funkcionalnosti iz sprint backloga. Svaki sprint bi trebao trajati dva do 4 tjedna (trajanje je fiksno i unaprijed definirano) tijekom kojih se kreira verzija proizvoda spremna za isporuku. Bitno je imati na umu da je sprint backlog nepromjenjiv, odnosno u njega se ne mogu dodavati nove funkcionalnosti kad je već započeo.

Produkt backlog je promjenjiv: ukoliko se uoče funkcionalnosti koje su potrebne, a nisu bile očite ili dovoljno jasne odmah na početku projekta, ili ako se u prilikom realizacije pojedinog sprinta ne mogu realizirati određene funkcionalnosti one se prebacuje u product backlog.



Slika 2: Agilni pristup uz scrum metodologiju

III. POSTOJEĆI PROCES RAZVOJA PROGRAMSKE PODRŠKE OSS SUSTAVA U HT-U

Model razvoja programske podrške u OSS sustavima potrebne za implementaciju novih usluga odvija se u HT-u kroz nekoliko osnovnih faza[3]:

A. Faza analize i izrade specifikacije

Prije izrade funkcionalne specifikacije za izradu programske podrške radi se na analizi poslovnih zahtjeva i definiranju poslovnih pravila potrebnih za uspješnu implementaciju poslovnih procesa. Funkcionalna specifikacija, osim poslovnih pravila, sadrži i modele poslovnog procesa. Modeli su koncipirani na način da se uspješno mogu koristiti za specificiranje potrebnih promjena u sustavima, analizu poslovnih procesa i dokumentiranje[4]. Takav koncept zahtijeva preciznost, dobru dokumentiranost i način prezentacije koji omogućava dobro razumijevanje svih uključenih u implementaciju programske podrške. Takav model razvoja zahtijeva specificiranje svih zahtjeva i ukoliko se ne obuhvate svi poslovni slučajevi uzrokuju se naknadna kašnjenje i naknadni povratak u fazu specifikacije. Zbog toga se koristi grafički način prikaza kao jedan od standardnog oblika prezentacije poslovnih procesa[4] i sintaksa jednog od standardnog alata za modeliranje (UML2 dijagram aktivnosti). Poslovni proces se prikazuje kroz više razina složenosti tako da se može koristiti u više prethodno spomenutih namjena.

B. Faza razvoja

Faza razvoja uključuje u sebi i dostavljanje zahtjeva za promjenom u IT koji u sebi sadrži specifikaciju[3]. Nakon usuglašavanja oko načina realizacije traženih promjena u sustavima podrške započinje dio realizacije kroz IT sustave.

C. Faza testiranja

Testiranje obuhvaća kompletni poslovni proces (sve sustave koji sudjeluju u fazi realizacije određene usluge) [3]. Ukoliko su rezultati testiranja dobri može se krenuti u fazu implementacije. Ukoliko nisu, potrebno je ispravljanje grešaka i ponovno testiranje.

D. Faza implementacije

Faza implementacije na strani poslovanja obuhvaća pripremu za realizaciju (obavještavanje korisnika IT sustava za podršku, upute i priprema potrebnih podataka za administriranje sustava). Nakon izvršene implementacije promjena u IT sustavima za podršku slijedi period praćenja samog rada sustava te potvrda ispravnog rada ili otklanjanje eventualno uočenih grešaka. [3]

Realizacija svake od nabrojanih faza u modelu razvoja preduvjet je početak slijedeće faze. Navedeni model odgovara tradicionalnom modelu vodopada. Postupak razvoja programske podrške na temelju ovog modela dugotrajan je i skup proces koji se u slučaju grešaka tijekom odvijanja jedne od faza modela dodatno produžuje i poskupljuje.

IV. PREDLOŽENI KONCEPT PRIMJENE AGILNOG PRISTUPA U RAZVOJU PROGRAMSKE PODRŠKE

Osnovni nedostaci postojećeg procesa razvoja programske podrške u HT-u, kao i kod tradicionalnih modela razvoja programske podrške, jesu:

A. Kruti model

Model onemogućava prijelaz u slijedeću fazu razvoja prije završetka prethodne faze što uzrokuje duže vrijeme i često kašnjenje u implementaciji potrebne programske podrške.

B. Greške u pojedinim fazama procesa

Greške nastale u pojedinoj fazi teško je pravodobno uočiti pa je često potreban povratak u prethodne faze procesa što znatno produljuje i poskupljuje proces razvoja programske podrške.

C. *Nesigurnost poslovnih zahtjeva*

Korisnici koji postavljaju poslovni zahtjev ponekad nisu do kraja sigurni u svoje zahtjeve ili zahtjevi nisu jasno i precizno definirani Ovakvi propusti se uglavnom uočavaju u slijednim fazama implementacije (npr. faza testiranja) i uslijed toga potrebna je promjena u poslovnim zahtjevima što zahtjeva povratak u prethodne faze procesa, promjene zahtjeva te dodatne troškove za implementaciju.

Postoje i dobre strane ovog procesa razvoja programske podrške, a najosnovnije su:

A. *Dobro planiranje*

Na početku procesa jasno se definirani opseg projekta, vremenski plan, troškovi i resursi. Zbog toga je moguće bolje upravljanje isporukom projekta i upravljanje troškovima i resursima.

B. *Dobra kontrola procesa*

Svi sudionici procesa znaju u kojoj se fazi nalazi proces i na taj način je lakše pratiti napredak razvoja programske podrške.

C. *Dobra dokumentiranost*

Kako se tu radi o implementaciji programske podrške koja upravlja složenom okolinom sustavima i složenim procesima dobra dokumentiranost jedna je od osnovnih preduvjeta za uspješnu implementaciju i kasnije uspješno održavanje programske podrške na produkciji.

Kako bi se sačuvale dobre strane postojećeg modela, a s druge strane iskoristile prednosti koje donosi agilni pristup, u razvoju programske podrške predlaže se model razvoja koji bi u svakoj iteraciji razvoja u sklopu agilnog pristupa sačuvao koncept modela vodopada.

To bi značilo da se s poslovne strane definira opseg i vremenski plan implementacije te izradi kompletna funkcionalna specifikacija koja uključuje i modeliranje poslovnih procesa, a implementacija se provodi kroz postepeni razvoj traženih poslovnih zahtjeva i procesa. Kroz svaku iteraciju bi se širio opseg implementirane programske podrške i ispravljali uočeni nedostaci u prethodno implementiranim promjenama. Kroz svaku iteraciju potrebno je i ažurirati funkcionalnu specifikaciju i dokumentaciju što uključuje i model poslovnog procesa. Vrlo je važno, unatoč fleksibilnosti i brzini koju donosi agilni pristup, osigurati kontrolu nad točnošću implementiranih promjena. Da bi se ovo omogućilo, poslovni zahtjevi, dokumentacija i modeli poslovnih procesa trebaju biti koncipirani na takav način da je moguće lako ažuriranje i razumljivost tražene i implementirane programske podrške. Predloženi model prikazan je slikom 3.

Postepenom implementacijom kroz iterativne postupke dolazi se prije do implementacije određenog dijela programske podrške što omogućava pravovremeno otkrivanje grešaka ili potrebu za promjenom poslovnog zahtjeva te se zbog toga ne uzrokuje kašnjenje i troškovi kao u tradicionalnom pristupu razvoja. Kroz svaki iterativni postupak moguće je definiranje pripadajućeg opsega promjena, potrebnih troškova i resursa. Moguće su promjene opsega poslova, utjecaja troškova i resursa.

Takav model razvoja programske podrške uspješno je primijenjen u HT-u u sklopu razvoja funkcionalnosti dogovora termina odlaska tehničara kod korisnika na realizaciju usluga. Na početku razvoja specificirane su sve potrebne promjene u sustavima za podršku i na temelju njih definiran opseg i troškovi traženih promjena. Nakon toga definirano je što će se realizirati u sklopu prve iteracije razvoja s time što su se razmatrali prioritet traženih promjena, prihvatljiv opseg promjena i troškovi. Nakon realiziranih promjena u prvoj iteraciji razvoja, krenulo se, kroz slijedeću iteraciju, na izradu nove funkcionalne specifikacije. Specifikacija je obuhvaćala promjene u programskoj podrški koje nisu ušle u prvu iteraciju te promjene za koje se zaključilo da su potrebne tijekom razvoja u prethodnoj iteraciji razvoja. Postojeća dokumentacija programske podrške za dogovor termina ažurirala se nakon svake iteracije.

Na ovaj način postignuta su, u odnosu na standardni način razvoja sistemske podrške u HT-u, poboljšanja u vidu brzine implementacije u sustavima te bržeg uočavanja grešaka ili nepotpunosti specificiranih promjena koje je potrebno implementirati u sustavima. Omogućeno je da se promjene koje su najbitnije za funkcionalnost dogovora termina implementiraju puno brže nego da se krenulo s implementacijom svih potrebnih promjena. Iskustvo kroz implementaciju u prethodnim iteracijama omogućilo je kvalitetniju specifikaciju traženih promjena u slijedećim iteracijama.

Važno je napomenuti kako je za uspješnu primjenu agilnog pristupa u razvoju ovako složene programske podrške potrebna podrška svih neposredno i posredno uključenih u ovakav proces. Od korisnika koji podnose poslovni zahtjev, poslovnih analitičara, IT stručnjaka koji rade na razvoju programske podrške, pa do samog managementa.

V. ZAKLJUČAK

Implementacija programske podrške za upravljanje procesima za realizaciju telekomunikacijskih usluga nije jednostavan i lagan proces. Stoga predloženi koncept nastoji iskoristiti dobre i primjenjive strane tradicionalnog i suvremenog modela u razvoju programske podrške bez obzira koristi li se na području telekom ili neke druge industrije. Preciznost i jasnoća poslovnih zahtjeva te dobra dokumentiranost tradicionalne metode razvoja nadopunjuje se s fleksibilnošću i brzinom razvoja manjih dijelova programske podrške koji se postepeno spajaju u konačnu cjelinu. Pojava grešaka i promjena poslovnih zahtjeva tijekom razvoja programske podrške kroz ovaj model nema toliki štetni utjecaj kao u tradicionalnim metodama razvoja. Na ovakav način osiguravaju se brze i manje isporuke, fleksibilnost i promjene u svakoj iteraciji, uklanjanje rizika s mogućnošću promjene prioriteta i opsega promjena u svakoj iteraciji. Primijenjena metoda ne osigurava kompletnu dokumentaciju u pojedinim fazama kao tradicionalni model, već na kraju procesa gdje su uključene sve promjene koje se implementiraju u sklopu svake od iteracija. Da bi se osigurali najbolji rezultati primjenom agilnog pristupa potrebna je odgovarajuća podrška unutar organizacije, disciplina u radu, stabilni i kompetentni timovi te sudjelovanje poslovnog i IT segmenta.

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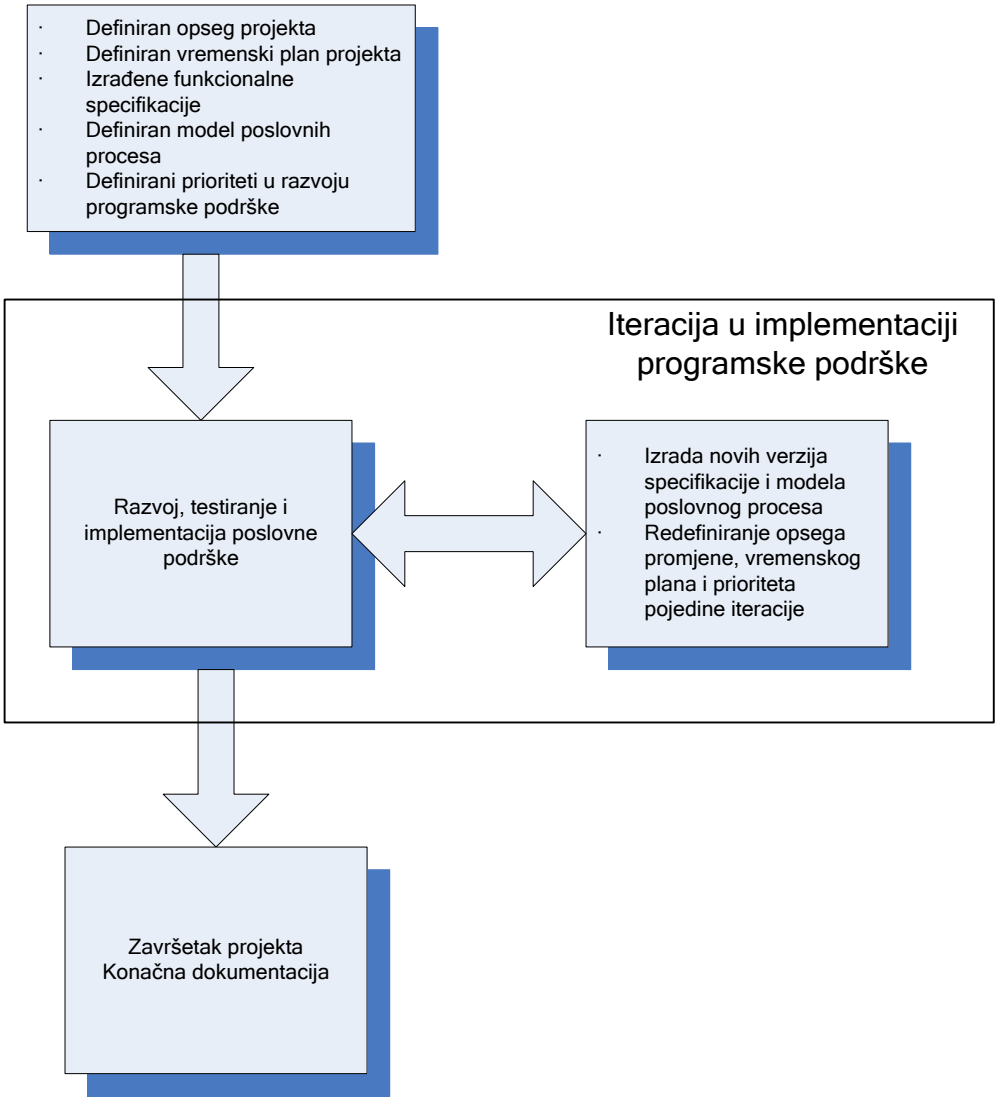

Slika 3: Predloženi model razvoja programske podrške

NETWORKS MANAGEMENT

Optimizing Traffic Routing in Different Network Environments Using the Concept of Software-Defined Networks

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***Abstract* - Routing process should encompass finding the best route through the network according to different criteria, with respect to the principle of load balancing, dynamic adaptation to current network conditions, special treatment of traffic based on QoS levels, as well as minimum energy consumption through energy-aware routing. The emergence of the IoT paradigm, 5G networks, increased number of real-time and mobile applications, as well as the increasingly complex requirements in terms of QoS, have put a grave task ahead of the researchers and the industry. Adaptive and efficient management of current network and traffic, and basis for making the networks resistant and ready for the inevitable changes in the foreseeable future, must be ensured. The idea of software-defined networks has offered a new architecture that seeks to overcome the disadvantages of classical network architectures. This approach has enabled direct programmability of the network, faster and simpler introduction of innovations, greater granularity of routing criteria, implementation of consistent and comprehensive policies, real-time response to changes, etc. This paper is a state-of-the-art overview of SDN traffic routing benefits in different network environments, as well as open issues and challenges to be addressed in future research.**

Keywords* - *SDN, network control, routing, data forwarding;

I. INTRODUCTION

The basic task of routing in computer networks is finding the path between the source and destination network node. However, routing should satisfy the required level of service taking into account the optimal use of network resources, all of which should work dynamically and in (near to) real-time. Understanding the routing process can be simplified through two basic sub-tasks. First is the forwarding sub-task that sends each packet from input port to the corresponding output port of the individual network device. The second sub-task is to determine the route by which packets travel on the path from source to destination node using different algorithms. In classic computer networks using standard IP routing protocols, both of these tasks are performed on the same device and are not clearly separated, thus causing many problems (such as increased configuration complexity, large routing related information overhead, inconsistent network polices, etc.) in modern network environments with increased and more complex requirements.

According to [1], more than a half of all failures happen during the maintenance are router-related. Also, research shows that router-related events are responsible for 16.5% of unplanned failures. They happen on 21% of all routers (87% on backbone, 7% on access routers). Routing related problems were up till now being addressed by adding new features to existing routing protocols, or creating new ones. However, due to the nature of classic network architecture and the way conventional routers work, such solutions increase the complexity of the network and take time for developing, testing, standardizing, and finally implementing on devices. Forwarding logic is placed on the low-level vendor specific devices, so deploying new ideas and capabilities is hard since there are no open standard interfaces. Making changes on-the-fly and satisfying dynamic network and user needs is practically impossible.

Software-defined networks (SDN) separate the forwarding tasks in the data plane and the job of determining routing rules in the control plane. This new network architecture enables unique network control with logically centralized approach, constant network parameters monitoring and dynamic routing adaptation, as well as open network switching devices for introducing innovations and new solutions without the existing barriers that classic network devices face. SDN centralizes and automates the processes of configuring network devices to route packets through the network, monitoring, troubleshooting and governing all aspects of network behavior.

SDN architecture consists of three planes (see Fig.1). The application plane lies at the top with services/application that reside on it, and communicate their requirements for specific network functions to the control plane via northbound interface using high-level languages. Below the application plane is a central place of network intelligence and the brain of SDN architecture - a control plane made of devices called controllers. They are in charge of translating application requests into specific forwarding rules and installing these rules through southbound interface to switching devices. These devices are located at the data level and are devoid of logic. They just "blindly" forward packets using instructions received from the controller. This network programming through controller-switch interface is achieved by using OpenFlow protocol [2]. Standardization of SDN and OpenFlow protocol (which has become de-facto standard for SDN) is

managed by ONF [3] (Open Networking Foundation). ONF is a user-driven organization dedicated to the promotion and adoption of SDN through open standards development.

The main contribution of this paper is reflected in the review of the advantages and opportunities that SDN routing yields in comparison to the current logic of forwarding based on IP routing protocols, analysis of the challenges facing the industry and the research community in the process of introducing these new network architectures, as well as presenting the SDN benefits used in some specific network environments.

II. THE PROCESS OF ROUTING PACKETS IN SDN NETWORKS

In order to direct a packet that enters the input port of a switching device, this device must have information on how to handle it. Switching devices in SDN networks are relatively simple. They are composed of a memory for storing records on how to direct a certain packet, and a processor that merely realizes the packet forwarding function and is absolutely free of routing logic. If there is a record in the switching device memory (which are called flow tables and are similar to the routing table in the classic IP routing devices) on how to route the incoming packet, the device will simply act upon it.

Each entry in the flow table consists of match fields, counters, and instructions on how to handle a packet that matches the corresponding record. In order to prioritize traffic flows and achieve faster matching rule search, entries are as organized in multiple flow tables as of OpenFlow version 1.1 [2]. For the purpose of greater granularity and finer flow control in SDN networks, packet routing can be based not only on the destination IP address, but on 38 different fields (including TCP source and destination port, VLAN, source and destination Ethernet MAC address, etc.) from packet headers. However, as previously stated, switching devices in SDN networks do not have their own logic and cannot make their own decisions. Therefore, if there is no record on how to direct the incoming package, the switching device will have to inform the controller via OpenFlow channel and ask for instructions on how to proceed.

Here we can identify several problems in the realization of routing at the data level. No matter how big, the switching device memory is not unlimited. According to OpenFlow standard routing can be realized using many criteria, so a large number of long routing records can exhaust the memory, burden the processor and take significant time while finding the appropriate forwarding rule for a specific packet. Therefore, it is necessary to make a compromise between the level of flow control we want to achieve on one hand, and memory capacity that is needed for particular network environment along with delay it causes on the other hand.

Additionally, if the switching device often receives new flows for which there are no records in the flow chart, the higher frequency of requests to the controller will burden the communication channel, the controller, and cause additional delay to create and install new rules.

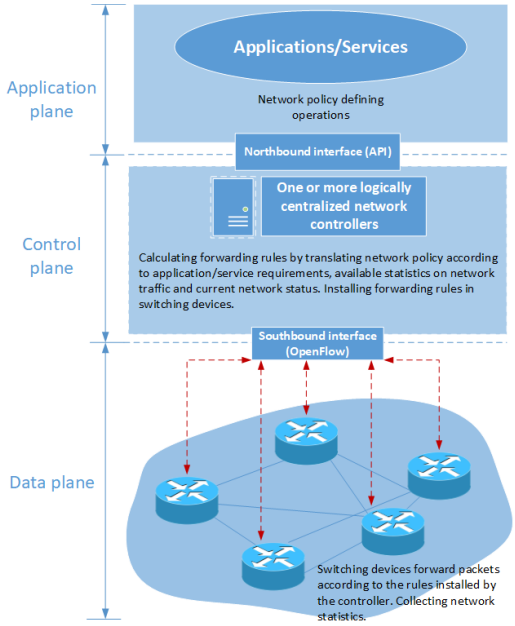

Figure 1. SDN centralized routing control architecture

A. *Routing related decision making in SDN*

Routing in SDN can be broadly categorized as routing based on individual flows or aggregated routing [4]. Each of these approaches is suitable for specific network environments. Routing based on flows implies that every individual flow is treated separately. For each flow there is a record in switching device flow table. This approach offers better detailed control and better management of individual flows, but also sets significant requirements to the switching device memory and to the controller that needs to calculate appropriate paths for these flows and install the forwarding rules in switching devices. Conversely, aggregated routing can handle a number of flows using one rule (using wildcard entries). This reduces earlier mentioned requirements, but at the cost of finer traffic control.

Considering the fact that the SDN enables dynamic (near to) real-time updating of routing rules according to the current network status, it is clear that the consequences of selecting one of the two aforementioned approaches are far-reaching. First, in order to know the current network status, the controller must obtain traffic statistics from network devices. Since each entry in the table has its own counter, it is clear that for larger number of entries, it will be necessary to collect and send to the controller proportionally more statistics related data. More data means more memory that needs to be reserved. Additionally, greater switching device-controller communication will additionally burden the OpenFlow channel used to exchange messages between these two types of devices. Furthermore, the process of updating forwarding rules for larger flow table will require proportionally more actions, more effort and will generate greater delay.

B. *Installing forwarding rules on switching devices*

There are two main approaches for installing forwarding rules on switching devices – reactive and

proactive [5]. Reactive approach means that the paths of individual flows are determined after the first packet of that flow arrives at certain switching device. Therefore, the network responds based on the request for installing, updating or deleting records over time. Using this approach ensures efficient and dynamic customization of the flow table. On the other hand, processing of each request on the fly entails additional delay in the network, creates overhead on the OpenFlow channel and burdens controller processor. Additionally, in the event of a link malfunction between controller and some switching device, this device will remain cut off because it cannot receive information on how to handle flows. A proactive approach involves the pre-calculation of routes by controllers and their installation before the arrival of appropriate traffic flow packets. This makes the switching device less dependent on the controller, because in the event of an error, it already has routes installed and does not have to communicate with controller. However, it requires smarter approach than just reacting to network events (global network knowledge, discovery, updates…).

A reactive and proactive approaches can also be used in case of failure recovery. When failure occurs, it is necessary to provide alternative paths for affected flows. If we use a reactive approach, the recovery is done by sending error information to the controller, which then calculates new paths and installs them in all relevant switching devices. In a proactive approach, backup paths are preinstalled. So, each primary path has a backup path that is activated if the primary path is unavailable. It is clear that proactive approach offers a faster recovery solution, less delay in establishing new paths, but literal implementation of this approach implies that the flow table should be twice as large (each flow has primary and back-up path).

Once again, it should be emphasized that the choice of the approach should be based on specific network demands. For example, the reactive approach goes well in the case of routing based on flows, while the proactive approach goes well in the case of using aggregated routing. Also, a combination of these approaches is possible and would allow flexibility for specific traffic that needs detailed control while still preserving low-latency forwarding for the rest of traffic.

C. Obtaining network status, calculating and updating routing rules

It has already been mentioned earlier that the controller, and control plane in general, is the brain of SDN network and the place where the most complex processes are taking place regarding the decision making for packet routing. The ultimate goal of control plane operations is dictated by services/applications from the application plane. SDN is, by its nature, a centralized network architecture and the logical question that arises is whether controller is also a central weak point of the system. This may involve multiple aspects such as security, scalability issues and robustness of the network [6], the ability of administrating different domains, etc. However, the organization of the control plane can be realized as distributed (logically or physically), hierarchical, as well as hybrid [7]. It is also clear that neither of these solutions represent ideal organizations of control plain and they each bring new issues to be dealt with. Such problems include modes and protocols of controller to controller interaction [8], synchronization of controllers and maintaining a global view on the network, topology learning process, responsibilities of individual controllers over certain parts of the network. Solving these problems is in direct relation and the key factor for the realization of the packet routing process and calculating optimal paths across the network in a dynamic way.

In order to successfully calculate the ideal routes according to application requirements controller needs to get information about ingress packets from switching devices. Moreover, to be able to do that dynamically, controller must continuously receive traffic statistics and network status data from the data plane, make calculations and install new rules to affected devices with minimum delay and maintaining consistency of the network policy [9]. Gathering statistics can be requested by the controller or push-based - sent by the switch (periodically or triggered by some defined event). Here we underline one more trade-off problem. Frequent and detailed network status collection and updating of routing rules will create more accurate insight to the current network status and better reaction to changes in traffic patterns. On the other hand, this approach will result in a proportionally large overhead. So, collecting statistics and updating forwarding rules is a trade-off between accuracy and overhead.

Most approaches of installing new packet forwarding routes have aimed to preserve consistency at packet level or at flow level. In either case, each packet/flow is exclusively processed either with an old or new installed rule. A newer approach is MABB (make&activate-before-break) [10] that tries to improve this principle by duplicating packets to travel through network between source and destination using both old and new route. When both copies of the same packet arrive to destination, the old rule is dropped from table. The approach respects policies of no loops and no black holes, reduces additional memory needed to keep old forwarding rules, and reduces time needed to keep those rules. However, transporting the same packet twice will cause increase usage of bandwidth. The effect it will have on overall network performance depends on frequency of topology and rule updates. Also, a mechanism for identifying duplicate packets on destination must be implemented.

D. Traffic load balancing

Respecting load balancing principles (stated in RFC 2291) in SDN networks can be brought to a higher level than it was in classic networks and turn it from static to dynamic real-time reacting mechanism. It is possible to evenly exploit the available network resources and alternative routes to same destination more efficiently thanks to a global view of the entire network and insight into network statistics. Practical implementation of load-balancing is not easy as it may seem at first glance because per-packet processing introduces additional problems for the operation of some standard Internet protocols. The problem was solved by the introduction of hash based per-flow processing (RFC 2292). However, this solution raised another issue. Some research have

shown that large flows (called "elephants") are few in Internet traffic, but their size seems to occupy a disproportionately large percentage of network traffic over a relatively long period of time. If such a stream or more are directed to the same alternative route, they will exhaust network resources, create bottlenecks and violate the principle of equal load.

Thanks to the architecture of SDN, it is possible to monitor and collect network data that can help detect such flows [11] and accordingly dynamically react with diversion to different paths. If one of the flows takes a bandwidth greater than the prescribed threshold, a new route is calculated and the instructions are installed in the forwarding devices. The detection of "elephant" flows can be performed on a network device or on an end host (application) level. However, one should be aware that detecting elephant flows at the switch level implies additional consumption of switch resources, as well as communication at the switch-controller level. On the other hand, detecting on end-host involves overhead at host and host-switch communication.

III. INTRODUCTION OF SDN BASED ROUTING IN SOME NETWORK ENVIRONMENTS

A. Hybrid SDN networks

There is much evidence in support of the claim that it is difficult to introduce a complete and "clean" SDN at ones. There are many problems for which mature and well proved solutions are not yet offered or have not been sufficiently tested in real network environments. In addition, significant investments in new equipment (openFlow enabled switches, controllers...) as well as education and training of technical personnel for the installation and maintenance of these equipment prevents many companies from introducing SDN at once. Operators need to gain confidence in functioning, capabilities and security of SDN networks. They have to be convinced in possibility of smooth transition to a new architecture so that this process does not cause negative consequences for end users. All of the above makes the existence of the middle phase in SDN introduction almost certain. This phase will be a new (and, according to prevailing opinion, temporarily) network environment as a bridge between classical architecture and SDN and is called a hybrid SDN [12]. The existence of a combined network has an impact on routing process. Interpreting the legacy routing protocols (OSFP, IS-IS, BGP…) and combining centralized SDN and decentralized classic architecture implies additional processing capacity utilization, and at the same time additional delay. However, there are examples of how using hybrid network can bring benefits in some networking environments.

As it was already mentioned previously, frequent requests to the controller for forwarding rules instructions can cause bottleneck on the switches-controller link and the inability of the controller to service and process all queries with its mainly large, but still limited capacity. During this period of frequent network traffic changes and frequent requests, it is possible to use standard distributed routing mechanisms, and in this way the controller will be unburdened for a certain period of time. This can be a great contribution to scaling concerns in case of large networks.

RCP [13] (Routing Control Platform) introduces solution for coordinate routing in large backbone networks and addresses iBGP scaling issue. It centrally collects information on AS topology and external routes, calculates and provides selected routes to regular iBGP for distribution. It is also possible to use SDN to reduce delays in packet forwarding between different autonomous systems. As BGP uses the information advertised by ISPs, in case they do not announce a particular network segment, it will not be used in the process of selecting the best route. This introduces additional unnecessary delay and affects the performance of routing. Authors in [14] offer a simple algorithm that enables to determine for which routes there are better alternatives even if some segments of the network are not announced in the standard routing signalization process. It helps in optimizing the path, thereby reducing the packet delay. By comparing the list of adjacent autonomous systems (AS) with routes to specific destinations, it is possible to see routes that contain the neighboring AS and this AS is not the next jump. SDN can be used as an effective mechanism for correcting these routes.

Example of keeping distribution of forwarding rules to data plane can be seen in DIFANE [15]. This concept introduces "Authority switches" that handle some of the network control tasks related to low-level rules and share them with all network switches. Fibbing [16] represents technique that relies on a distributed architecture of the current routing protocols, but controls the information centrally by injecting fake link state advertisements (LSAs) to construct a shared view of the topology. Fibbing creates false routing messages, legacy routing protocols transmit them through the network, router computes the routes and stores them in routing tables, and forwards the traffic according to those routes.

In hybrid networks with a mix of SDN and legacy devices at data level, Telekinesis [17] allows the controller to even manipulate legacy devices that do not support openFlow. A separate package is sent to a particular interface using the openFlow PacketOut function to update the entry in the forwarding by affecting the MAC learning process. Telekinesis increases the level of centrally controlled devices in the hybrid network. It also gives finer control in comparation to Fibbing as it operates on data link layer. However, in order to control an entry, given interface must be directly connected to an OpenFlow switch. Knowing that, the percentage of paths that can be controlled depends on the ratio of SDN and legacy devices, as well as their spatial distribution in the network.

The gradual introduction of SDN, taking into account network routing and traffic engineering, can be found in [18]. A particular focus is on providing a load-balancing mechanism for reducing congestion on links, as well as the assessment of trade-offs between invested funds in the SDN devices of the hybrid network and the benefits it brings in terms of network traffic routing.

Since many of the earlier work rely solely on bandwidth as the factor that drives traffic in hybrid SDN

networks, it is necessary to offer a solution for all QoS parameters [19]. Using data link layer protocols (STP and LBP) it is possible to detect topology and communicate with legacy switches, and using the SAQR (simulated annealing based QoS-aware routing) algorithm it is possible to adjust the weights of delay, loss rate and bandwidth requirements in a cost function to meet QoS requirements. The problem is that this approach involves working on a second layer, but not with devices such as third-layer switches or routers. Reference [20] proposes a new architecture for hybrid SDN QoS aware routing by segment and a new model called Smart-Alloc for allocating bandwidth in MPLS Traffic Engineering Diffserv Aware (DS-TE) network. It detects application SLA threshold, translates QoS requirements into an XML file, then detects legacy equipment constructor and turns XML to lines compatible with the legacy device. Verification of topology is performed, performance is monitored, bandwidth and paths are adapted according to traffic requirements. Testing on VoiP, Video, HTTP and ICMP traffic showed better video and voice quality, lower delay and jitter as well as reducing retransmission and increasing effective retransmission of lost and damaged packets.

B. Routing as a Service

Predecessor of SDN, RCP [13] proposes to separate the routing logic from the forwarding device, but is concerned with routing within autonomous systems. So end-to-end routing control is not considered, which is of utmost importance to guarantee the level of service. Routing as a Service (RAS) [21] is a solution for network environments where packet travels over different autonomous systems. The idea was that "third party" "negotiates" with ASs on one hand and users on the other, in order to avoid direct negotiations. The "third party" concept implies a complete network view that will enable better management and greater overall network capabilities. Such an architecture could facilitate route selection, guarantee end-to-end QoS routing, block unwanted traffic closer to the source unburdening the network from additional harmful load and more efficiently preventing attacks, avoiding packet traversing through unwanted autonomous systems etc. Classic BGP protocol for inter-AS routing was not able to achieve this.

C. Information-centric Networking

With big changes taking place on the Internet, first and foremost, the huge and rapidly growing amount of traffic transmitted through networks, a new idea emerged that diverts attention from host-centric paradigms and end-to-end principles. Information-Centric Networking (ICN) proposes network environment which rather focuses attention on content, information or data. It relies on the replication and caching of frequently used content in the network so that it can be delivered as quickly and effectively as possible to other interested parties. For this kind of content delivery, an efficient routing scheme is required. Reference [22] suggest a schema that uses SDN capabilities for content-aware routing in large production networks in conjunction with the Community Division (RISC) for severing topology in different communities. SDN allows vertical decupling into the data plane containing "Communities" and "Information Centers" and a control plane containing SDN controllers that enable the implementation of the routing mechanism for intra-community routing based on the same "Community" information and inter-community routing based on social relations among "Communities". The limitations of the proposed routing method are reflected in disregarding the "Content Router" mobility in the dynamic implementation of the network, and the fact that the increase in the amount of information in an "Information Center" over a certain limit affects significantly the efficiency of the routing.

D. 5G, IoT, VANET

One of the ONF six subgroups includes Mobile Networks. It defines extensions to OpenFlow to support abstractions needed in mobile networks and, in particular, works to identify opportunities in 5G networks in support of standard development related to SDN. In order to achieve the set high data rates goals in 5G, it will be needed to have successful interoperability in the heterogeneous wireless network environment [23]. SDN can help in efficient traffic management, i.e. by monitoring and assigning the appropriate bandwidth.

In addition to the 5G network, one of the current hot topics is Internet of Things (IoT). According to statistics [24], number of connected devices will exceed 75 billion in 2025. Such a large number of devices will surely increase the generated and transported amount of traffic by several hundred percent. Greater traffic means more complex management and routing from the place of generation (e.g. various types of sensors) to the destination. Usage of programmability is highly anticipated, and centralized control for IoT management and integration with SDN is required [25].

VANET networks strive to create a communication platform that will serve to intelligent transport systems and provide adequate real-time travel information. The goal is to create a smart transport network that will enable applications for emergency vehicles, respond to incident situations, inform drivers and passengers, etc. This puts new demands on traffic routing process in a complex and extremely dynamic environment. Furthermore, greater use of electrical vehicles will impose greater challenges in terms of energy efficient routing to minimize vehicle battery consumption. In this sense, EEMSFV - Energy Efficient Multicast routing protocol [26] has already been presented. EEMSFV is leveraging SDN along with Fog computing for VANET networks including deadline and bandwidth constraints.

IV. SOME FUTURE RESEARCH CHALENGES

Although SDN is a logically centralized architecture, it can be physically distributed, which means that modes and communication protocols are needed between controllers to ensure adequate network status data which is crucial for making correct routing decisions. Although there is some research on this topic, more attention should be focused to this problem because the inadequate synchronization of distributed controllers means losing the central view of the network and network control. Consequently, this would also mean failure to implement one of the basic concepts

on which SDN networks are based. In order to achieve up-to-date dynamic routing, it is necessary to address problem of optimal frequency of statistics collecting as well as an adequate strategy for changing the network routing configuration in accordance with the current state of the network and traffic patterns. Key parameters that need to be considered regarding this are increased signaling traffic, additional delay and impact on other QoS service parameters, limitations on flow table memory, controller load, network policy consistency. In terms of energy-efficient routing, especially in the case of resource and energy limited IoT devices and electrical vehicles, it is necessary to keep in mind that control traffic needed for SDN routing architecture, besides consuming bandwidth and degrading spectral efficiency of devices, places a significant burden on batteries as a source of energy. Although apparently there is a potentially bright future for the SDN, it will still not be introduced at once, in all segments of the network and in all network environments. It is necessary to develop clear strategies and recommendations, and conduct testing to find out the best ways and best pace of gradual introduction of SDN to different classic network environments. All this in order to achieve, as much as possible, the coexistence of SDN centralized routing and the legacy routing protocols.

V. CONLUSION

This paper presents a review of routing concepts using SDN network paradigm principles. We examined aspects of routing relevant for different types of networks environment according to their organization, topology, characteristics and traffic patterns. The necessary prerequisites for achieving a centralized decision-making process are considered, respecting the basic ideas of SDN, taking into account constraints such as scalability, delay, limited memory, processor and other network and device resources. Special attention has been paid to the gradual introduction of SDN in hybrid network environments, as well as on the application with other emerging concepts (5g, IoT…) and their synergy with SDN routing logic. The benefits that SDN brings in terms of routing traffic for modern networks are certainly great, but in order to exploit their full potential, much more attention needs to be paid to existing challenges and open issues.

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An analysis of reconvergence delay when using BGP-LS/PCEP as southbound protocols

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***Abstract* – Aim of this paper is to explore latency in reconvergence after link failure when using BGP-LS/PCEP as southbound protocols in IP/MPLS network with centralized controller. Controller in network is PCE element in charge of Traffic Engineering management. Scenario in this paper describes an IP/MPLS network with four routers, fours links and four tunnels passing through multiple links. In case of a link failure, affected tunnels must be rerouted to alternative links evenly distributing traffic across the links. Therefore, it is necessary to have a central controller that will have a complete knowledge of the network in order to evenly and efficiently redistribute traffic. Our IP/MPLS network contains multi-vendor devices and do not support OpenFlow protocol hence as a southbound protocols standardized BGP-LS and PCEP are used. BGP in general is designed as a very slow protocol. Additional, BGP-LS has to wait for the internal routing protocol on the routers to update the Traffic Engineering Database before the BGP-LS signals change event to its peers. Therefore, we will explore some possibilities of reducing the latency in reconvergence after link failure.**

Keywords – IP/MPLS, SDN, BGP-LS, PCEP

I. INTRODUCTION

Figure 1 shows the IP/MPLS network with routers R1, R2, R3 and R4. They are connected with links L1, L2, L3 and L4 with capacities C1, C2, C3 and C4 respectively. Capacities C1 and C4 are lower than C2 and C3. The MPLS Traffic Engineering is implemented on the devices. The traffic between R1-R2 goes through the tunnel T1 (presented with blue line), R1-R3 goes through the tunnel T2 (presented with purple line), the traffic between R1-R4 goes through the tunnel R3 (presented with green line), and the traffic between R2 and R3 goes through the tunnel T4 (presented with red line). In the Figure 2 case of a L2 link failure is presented. Affected tunnels will be rerouted through other links (L1 and L4). After L2 failure congestion can occur on active links L1 and L4 with capacities C1 and C4, although under normal conditions these links capacitively meet traffic needs. On the other hand, link L3 remains insufficiently used. In order to avoid this scenario, congestion in network tunnels should be detected and, if necessary, automatically reroute tunnels to other alternative links (for example blue tunnel), and load balance the traffic. Figure 3 represents the dynamic establishment of a blue tunnel from R1 to R2 over R5 and R4. Elements in the network have independently discovered new path through the network over links that have enough capacity, L5 and L6 with

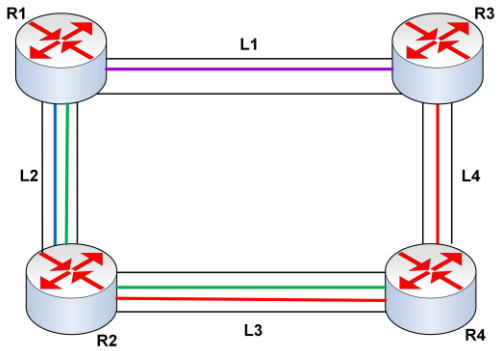

Figure 1 IP/MPLS network

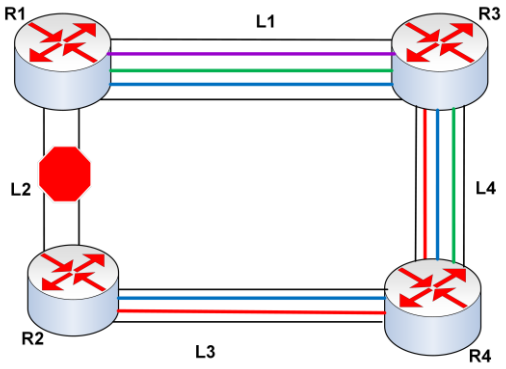

Figure 2 Link failure in IP/MPLS network

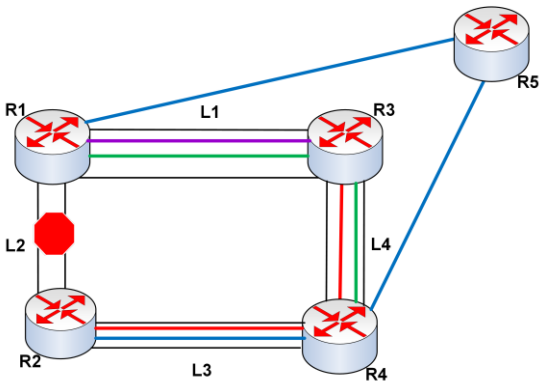

Figure 3 Dynamic establishment of tunnel in IP/MPLS

capacities C5 and C6. In this way, links L1 and L4 are not congested.

In order to monitor network congestion and automatically create additional tunnels through alternative links, it is necessary to have an element that will a) monitor link conditions, b) know the complete topology of the network in order to select possible alternative links c) create additional tunnels 4) perform efficient load balancing of traffic 5) have minimal delay and packet loss. For this purpose, a centralized SDN controller can be used. Centralized SDN controller will have complete network topology information, can monitor congestion conditions and create additional tunnels. However, SDN as a new technology, although it promises a lot, still contains many unresolved issues, giving service providers a certain amount of technical and economic uncertainty in the application of Full SDN in networks. Instead, SDN technology should be applied gradually, and use existing protocols that are only slightly upgraded. In addition, in ISP networks are installed devices from different vendors, hence central controller and network devices must communicate through protocols that are supported by all vendors. Also, one of the main questions is latency, or time needed from the moment of a link falure to a full convergence of traffic. It is very important that all necessary information is exchanged at a very high speed (preferably in real time) so that the packet loss does not occur due to excessive congestion of the link. In summary, necessary requirements are: 1) Rapid traffic rerouting due to link failure 2) Measurement of new state on links 3) In case of congestion, creation of additional tunnels via alternative links 4) Load balancing of traffic with the aim of unloading the congested links 5) The process of creating additional tunnels and load balancing should occur with a minimum delay 6) The ISP provider would have to be able to apply this solution on all devices regardless of the equipment manufacturer with minimum investments. In section II overview of all protocols and technologies used in scenario will be presented. In section III our approach and design of IP/MPLS network is presented.

II. USED TECHNOLOGIES AND PROTOCOL OVERVIEW

In this section a short overview of IP/MPLS, SDN, BGP-LS and PCEP will be presented.

A. IP/MPLS

IP protocol is the protocol with a task of delivering packets from source host to the destination host based on the IP addresses in packet headers. By using MPLS with IP possibilities of transported services can be extended. MPLS is a network technology that uses labels attached to packet to forward them through the network. The idea of MPLS is to label ingress packets based on their destionation address and switch all the traffic over a common infrastructure. One of the early reasons for MPLS was the need for speed. Switching packets solely based on examining IP addresses in header was considered to be slower than switching labeled packets by looking up just the label on top of a packet. In MPLS, first label is imposed on the ingress router and the label belongs to one label switch path - LSP. The ingress LSP imposes one or more labels in the packet. The intermediate LSPs swap the incoming label with another label and transmit the packet on the outgoing link. The egress LSR of the LSP takes off the label of this LSP and forward the packet. All labels are local and Label Distribution Protocol – LDP is protocol used for carring the label bindings in the MPLS network. Also, label information can be carried with BGP and RSVP protocol in case of MPLS Traffic Engineering. The basic idea behind traffic engineering is to optimally use network infrastructure. With traffic engineering implemented in the MPLS network, traffic that is destined for a particular prefix or with a particular quality of service flow from point A to point B along a path can be different from the least-cost path computed by the dynamic routing protocol. The result is that the traffic can be spread more evenly over the available links in the network and make more use of underutilized links in the network. [1] MPLS traffic-engineered LSP is called MPLS TE tunnel. A TE tunnel is unidirectional and must be signaled with RSVP protocol.

B. SDN

A router is typically segmented into three planes. The control plane is the brain of the router and is responsible for maintaining connections and exchanging protocol information with other router or network devices. The data plane or the forwarding plane is responsible for the switching of packets through the router. The management plane manages a device through its connection to the network. Software Defined Networking (SDN) is an architecture which decouples control plane and data plane achieving flexible and intelligent networks. SDN has been defined by Open Networking Forum [2] as an merging architecture that is dynamic, manageable, cost-effective, and adaptable, making it ideal for the high-bandwidth, dynamic nature of today's applications. This architecture decouples the network control and forwarding functions enabling the network control to become directly programmable and the underlying infrastructure to be abstracted for applications and network services. OpenFlow protocol is a foundational element for building SDN solutions, but in parallel with the continual development of OpenFlow, other industry forums such as IETF have also been developing similar concepts such as PCEP, BGP Flowspec, NETCONF/YANG/OpenConfig, I2RS, and ForCES. [3] SDN architecture consists of three layers: infrastructure, control and application. The infrastructure layer comprises network elements, which expose their capabilities toward the control layer via interfaces southbound from the controller for example OpenFlow, PCEP or NetConf. The SDN applications exist in the application layer, and communicate their network requirements toward the controller plane via northbound interfaces, often called NBIs. In the middle, the SDN controller translates the applications' requirements and exerts low-level control over the network elements, while providing relevant information up to the SDN applications. [4]

BGP is defined as a standardized exterior gateway protocol designed to exchange routing and reachability information between autonomous systems (ASs). [5] BGP is a protocol that has better scaling properties because it can distribute millions of entries (for example, VPN prefixes). Another benefit of BGP is that it uses type, length, value (TLV) tuples and network layer reachability information (NLRI) that provide seemingly endless extensibility without the need for the underlying protocol to be altered.

BGP Link-State (BGP-LS), also known as BGP for Traffic Engineering or BGP-TE, is a new BGP address family. BGP-LS is an extension to BGP that allows it to carry link-state information. [6] This link state information is acquired from the interior gateway protocol - IGP as is normally done with other state information, but in this case from the area's traffic engineering database (TED). It has been described a mechanism [7] by which link-state and TE information can be collected from networks and shared with external components using the BGP routing protocol. This is achieved using a new BGP Network Layer Reachability Information (NLRI) encoding format. To advertise the TED into BGP-LS, entries in the TED are converted in the form of routes. These converted routes are then installed by the TED on behalf of the corresponding IGP, into a user-visible routing table. After that, BGP-speakers or Route Reflectors with all the routes in the network start a BGP-peer session with an external component and forward all necessary data. [5]

C. PCE Environment

There are three main components of the PCE environment: a PCE server, a PCE client (PCC), and the PCE Protocol. Path Computation Element Communication Protocol (PCEP) [8] is a protocol for communications between a Path Computation Client (PCC) and a Path Computation Element PCE, or between two PCEs. PCE [9] is defined as an entity or application that can be located within a network node or component and is capable of computing a network path or route based on a network graph, and of applying computational constraints during the computation. Such interactions include path computation requests, replies and notifications of specific states related to the use of a PCE in the context of MPLS. [9] also describes architecture and various types of PCE. PCE allows a network operator to delegate control of LSPs to centralized controller. The PCE server provides three fundamental services: path computation, state maintenance, and infrastructure and protocol support. The PCE server uses the PCE Protocol in order to convey this information to network elements or PCCs. [6]

D. BGP-LS and PCEP as a southbound protocol in SDN

BGP-LS and PCEP work together as a southbound protocols in SDN. On the one hand, BGP-LS provides TED (Traffic Engineering Database) information on topology and link conditions (for example availability of devices, bandwidth, cost, existing LSPs, TE metrics, etc.), while PCEP communicates between PCE and PCC. PCE is an element that can be applied to a central controller and calculates an optimal path, and PCCs are the clients or devices that apply these budgets. The PCE can be stateless, which means it does not store data on existing LSPs, so it only uses a TED database for the budget, and it can be statefull, which means that it preserves data on pre-established LSPs, so for the budget it uses TED and LSPDB. Survey paper [10] presented state-of-the-art on PCE architecture. The state-of-the-art PCE can be active and passive, and the state-of-the-art PCE is of great interest to us since it is able to initiate LSPs without the need for a PCC's prior request for creating a LSP. In this case, the PCE has full control over the network and creates LSPs itself. What is important to note for PCEP is that PCEP supports load-balancing. PCCs and PCEs are in constant communication and usually share two types of messages: PCRpt (a report on the status of LSP sent by PCC) and PCupd (updates sent by PCE). After the PCC has made a certain update, it again notifies the PCRpt PCRP that the update has been successfully executed (for example LSP is UP). In this way, the TED database is used by the PCE. Thus, PCE with information from TED, LSPDB and PCC reports has a centralized view of the entire network, and is able to calculate optimal paths, create additional LSPs, and perform load balancing.

III. RELATED WORK

In [11] authors presented research where aim is using the notion of SDN in creating and managing a Dynamic MPLS tunnel in OSPF networks. In [12] congestion-aware link failure recovery in Hybrid SDN Networks is presented. The aim of [12] is to avoid potential congestion in the post-recovery network by choosing proper backup paths. Mendiola and et al in [13] explored the impact of SDN to Traffic Engineering using Path Computation Element (PCE) based architecture. In [14] authors were exploring how to truly enable Multi-Layer Traffic Engineering Optimization. For optimization, they were using PCE to solve the path computation problem in complex environment. Two mechanisms of optimization were studied: 1) In case of IP/MPLS, BGP-LS was used to distribute Link-State and TE Information 2) In case of WDM converged with OTN, data is exchanged in RESTful interface with JSON encoding. In [15] authors presented SDN-based WAN optimization with BGP-LS/PCEP implementation in multi-domain MPLS networks. In [16] authors explored the problem of the effectiveness of PCE-based computation of inter-domain paths because of limited visibility of Traffic Engineering information which is usually restricted to a single domain. In [17] using OpenDaylight controller is presented. In [18] proactive hierarchical PCE based on BGP-LS for Elastic Optical Networks is presented. In the HPCE architecture a single parent PCE (pPCE) is responsible for a inter-domain path computations, while in each domain a local child PCE (cPCE) performs intra-domain path computations. In [19] and [20] demostrations of H-PCE with BGP-LS are presented.

IV. OUR APPROACH

In this section we will describe our approach, and in what ways it resolves all of the stated problems and requirements that need to be fulfilled. Our IP / MPLS network consists of devices from different vendors. Traffic Engineering is enabled on devices. In order to enable the best use of the network (links and tunnels), the IP/MPLS network communicates with a central SDN controller with an insight into the entire network. In this model, as the southbound protocol is not used OpenFlow, the SDN controller communicates with the IP/MPLS network via BGP-LS and PCEP. BGP-LS and PCEP are are standardized so two problems are solwed: 1) The ISP does not have to invest in new devices that support OpenFlow, but only upgrades already existing protocols on existing devices. 2) BGP-LS and PCEP protocols are supported by all vendors. In addition, PCEP supports load-balancing, which was one of the conditions that the model should satisfy. The controller can be programmed to monitor the state of the network or the LSP, and if the amount of traffic exceeds a certain treshold, for example 90%, the LSP automatically creates and performs load balancing between the old and the new LSP. An increase in traffic can indicate the consequence of a link failure after which traffic has been redirected to existing links and thus burdened them even more. Also, after the link is restored, the controller may send an update to delete the temporary tunnel. This would allow optimal dynamic traffic-engineering to fulfill all the goals set at the beginning. However, it remains a problem of time that will run from the moment of link failure until the moment of optimal dynamic routing is established. After link failure, with the help of fast-rerouting traffic, the traffic will be relatively quickly rerouted to another link. However, this information about link failure and congestion of alternative links should come to the PCE. After that, the PCE must run the algorithm to calculate the best path in the new state of the network and send instructions to all affected PCCs. It is very important that all of this information is exchanged at a very high speed (preferably in real time) so that there is no loss of packets due to excessive congestion of the link. However, when using the BGP-LS / PCEP protocol, it is questionable how quickly BGP-LS updates TED. If a change occurs in the network, IGP registers that change, and re-distributes new routes to BGP. BGP is an Internet protocol that is designed as a slow protocol. Since it is applied in large Internet networks where very often a short-term fallout of links is very often, it is designed as a slow protocol to not register any short-term outages. This is the advantage of BGP on the one hand, however, it is necessary to act quickly to prevent congestion in the network. So low speed of BGP can be a big problem. In the case where a topology change event such as a link or node going down occurs, the IGP flooding mechanism allows the topology information to be propagated to the TE controller much faster than as would be accomplished using BGP-LS. This is because BGP-LS has to wait for the local IGP on the routers in the network to update the TED before the BGP-LS signals this change event to its peers.

A. Reducing the latency

Our approach to solve problem focuses on adjusting certain timers of protocols involved in minimizing the time needed to establish dynamic optimal tunnels. In the network, OSPF is used as an IGP protocol, MPLS, RSVP-TE, BGP-LS and PCEP are also established. So, we will continue to work on improving the configuration settings associated with these protocols. Network topology consists of nodes R1, R2, R3 and R4 and links L1, L2, L3, L4 and L5 with certain costs C1, C2, C3, C4 and C5. R4 is configured as Route Reflector, and is connected to the Ubuntu virtual machine on which OpenDayLight - ODL [21] [22] [23] [24] is installed. OSPF costs are equal on all links. As a router ID, a loopback device is used (1.1.1.1, 2.2.2.2, 3.3.3.3 and 4.4.4.4 for R1, R2, R3 and R4 respectively). BGP-LS [25] is also built on the devices so that the full mash topology is obtained through the establishment of a BGP session of each device with Route Reflector - RR that makes BGP peering with each device and controller. Also, MPLS and RSVP-TE are configured on the devices. Two tunnels between R1 and R2 - T1 and T2 are manually made. Devices R1, R2, R3 and R4 are configured as PCC [26][27] with peer IP address of controller for PCE, while ODL is configured as a statefull active PCE [28].

In table 1 are shown all default timer values. In order to reduce the time of complete reconvergence, we reduced certain timers and monitored CPU values on devices. In the OSPF part, we reduced Hello and Dead timers 10 times and we did not notice any significant oscillations in CPU values on the device. After that, we set PCEP timers on minimum values, and then reduced BGP timers. After changing BGP timers CPU value increased, but it has not reached dangerous values.

TABLE 1 DEFAULT TIMER VALUES FOR OSPF, BGP AND PCEP PROTOCOLS

OSPF	
Hello	10 seconds
Dead	40 seconds
BGP	
Keep alive	60 seconds
Hold-down	180 seconds
Scan time	60 seconds
bgp update-delay	120 seconds
bgp nexthop trigger delay	5 seconds
PCEP	
Keep alive	30 seconds
Dead	120 seconds

TABLE 2 REDUCED TIMER VALUES FOR OSPF, BGP AND PCEP PROTOCOLS

OSPF	
Hello	1 second
Dead	4 sekunde
BGP	
Keep alive	30 seconds
Hold-down	90 seconds
Scan time	10 seconds
bgp update-delay	60 seconds
bgp nexthop trigger delay	1 second
PCEP	
Keep alive	1 second
Dead	4 seconds

V. CONCLUSION

This paper presents the IP/MPLS network connected to the OpenDayLight controller. BGP-LS / PCEP are used as the southbound protocols. The BGP-LS protocol provides Traffic Engineering database - TED necessary information on links such as costs, bandwidth, TE metrics, etc. On the Ubuntu virtual machine, the Opendaylight controller is configured as a PCE element, other devices in the network are configured as PCC clients. After change in the network occurs, BGP-LS has to wait for the OSPF on the routers to update the TED before the BGP-LS signals this change event. In the OSPF, BGP and PCEP protocol configuration, there are certain timers that can be reduced in order to reduce the overall reconversion time. In the OSPF section, we reduced hello and dead timers. Devices, instead of default 10 seconds, every second check whether all of their neighbors are in function. In case of a failure, the device will wait 4 seconds instead of the default 40 seconds to declare the neighbor down. After changing this value, the CPU value briefly increased but soon returned to normal. The timer values for the PCEP were equaled with the timer value in the OSPF and set to the minimum possible values. We also reduced all timer values in the BGP section as shown in Table 2. After reduction, the CPU value increased, but it did not reach dangerous levels for the device. By reducing these timers, the total reconversion time has been reduced. Devices are sooner aware of changes in the network, faster provide TED with information and less time is needed to take the necessary actions. With this timer reduction CPU values on all devices do not exceed 25%.

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Implementation of NETCONF Protocol

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Abstract - The first version of SNMP (Simple Network Management Protocol) was created in 1988 by IETF (Internet Engineering Task Force) as a standard for network management. However, SNMPv1 (and its newer versions 2, 2c and 3) since its beginning has been used mainly only for the network monitoring and very rarely for the configuration of network devices (routers and switches) with its SET commands. Since the beginning of computer networking, the configuration of network devices (routers and switches) has been usually performed by using the vendors' operating systems and their non-standard user CLI (Command Line Interface). This has proven to be a very complex and ineffective solution, especially with fast development and more complexity in the computer networking area. To solve these issues, IETF standard organization created in 2006 the NETCONF protocol in order to define the standard solution for command-oriented CLI user interface for the configuration of network devices of different vendors. Today, more than ten years after the creation of the NETCONF standard there is the question about the actual acceptance of NETCONF protocol in current networks and about the actual maturity of NETCONF standard. The scope of this paper is to compare three ways of configuring the network devices: non standard CLI, standards SNMP and NETCONF.

I. INTRODUCTION

Computing and computer networks have been developing very fast, and this development is extremely dynamic, interesting and often with unexpected results.

In spite of all the tremendous advances in computing and computer networks, the networking management environment has changed very little and has remained almost the same as fifty years ago, i.e. in the 1970s and 1980s. Thus, even today for the configuration of network devices (routers and switches) the most frequently used is CLI (Command Line Interface) – a user interface which is very similar to DOS and UNIX interface.

The network devices are delivered to the users with the default configuration, which is usually empty, and therefore every device has to be adapted to the network requirements.

The modification of the network device configuration can be done in different ways. The devices can be configured by means of [1]:

- local connection via management interface (for instance connecting to CON or AUX interfaces to Cisco router) by using Command Line Interface (CLI),
- remote connection via TCP/IP protocols, usually by means of Telnet/SSH and SNMP protocols. Every network device has to have a configured IP address, in order to enable access from a remote location.

The traditional way of managing and configuring network devices is by using Command Line Interface (CLI) method with SSH protocol and Simple Network Management Protocol (SNMP). CLI has proven to be a very complex and ineffective solution, especially with fast development and more complexity in the computer networking area. To solve these issues, IETF standard organization created in 2006 the NETCONF protocol.

II. LEGACY METHODS

A. CLI Method

Administering of network devices is performed by means of operating systems of vendors (e.g. Cisco IOS, Juniper JUNOS, Extreme EXOS and others), that are mutually different, but all of them use textual interfaces (CLI – Command Line Interface).

```
Router_1#show running-config
Building configuration...

Current configuration : 460 bytes
!
version 12.4
no service timestamps log datetime msec
no service timestamps debug datetime msec
no service password-encryption
!
hostname Router_1
!
!
interface FastEthernet0/0
 ip address 10.1.1.1 255.255.255.0
 duplex auto
 speed auto
!
interface FastEthernet0/1
 no ip address
 duplex auto
 speed auto
 shutdown
!
interface Vlan1
 no ip address
 shutdown
!
ip classless
```

Figure 1. Cisco IOS CLI

```
user@host> show configuration

## Last commit: 2006-10-31 14:13:00 PST by user1
system {
    host-name exhost;
    domain-name ex1.net;
    backup-router 198.51.100.254;
   time-zone America/Los_Angeles;
    default-address-selection;
    name-server {
```

Figure 2. Juniper JUNOS CLI

Command-line interface (CLI) was created to make it easy for human operators and administrators to interact with networking devices. It is similar to the character-based command-line interfaces used with computer operating systems such as UNIX and DOS.

CLI commands are organized in a hierarchical manner (Figure 3) [2]. Commands that perform a similar function are grouped under the same level and the same name. This hierarchy can be several levels deep. This structure is one of the aspects that make CLI so easy to use for humans. Also, there is no fixed set of CLI commands, so it is always possible for a new feature to introduce its own new command and parameters.

Every network device has to have a configured IP address, in order to enable access from a remote location. Therefore, it is usually necessary to first assign an IP configuration by means of a local access using a console, and then the network device can be accessed also via an appropriate protocol as selected from TCP/IP group of protocols from remote locations.

Protocols Telnet and SSH are used to configure the device using CLI (Command Line Interface) user interface, whereas SNMP protocol is used for GUI (Graphical User Interface).

Telnet and the today more often used safe version SSH are mostly used by network administrators for the access and execution of configuration tasks and diagnostics over remote network devices (e.g. switches, routers).

1) TELNET/SSH Protocol

Telnet is a client/server protocol of the application layer of TCP/IP group of protocols that enables accessing terminal on a remote computer system. Telnet has been

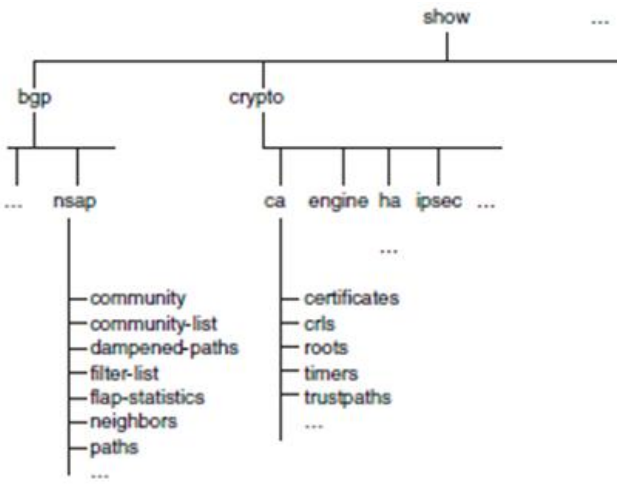

Figure 3. CLI *show* Command Hierarchy [2]

defined in RFC 854 [3].

Telnet was developed in 1969 and it is one of the oldest protocols and services of TCP/IP group of protocols on the application layer. At that time the users accessed from their terminal (which was also called "dummy terminal" and had neither an operating memory, nor a hard disc, nor CPU) the directly connected mainframe by using textual interface. At that time the Graphical User Interface (GUI) had not been used yet, and the access used the textual interface (CLI – Command Line Interface) [1].

After the computer networks were established, there was need to access remote central computers in the same way as by means of directly connected terminals. The purpose of the telnet protocol is to enable such access. Today telnet is usually used to enable the user of one device to establish a session to use CLI interface on another device.

Telnet is a client/server application which allows emulated access of CLI terminals to remote devices on the computer network. Instead of connecting the device physically directly to the server, telnet software is used to create the Virtual Terminal (VT) that features the same possibilities as a directly connected terminal which accesses the server by means of CLI interface.

Telnet is both the name of the protocol which is used and the software application as a service.

Secure Shell (SSH) protocol is a protocol that provides the same possibilities as telnet, but in a much safer way. SSH has an implemented safer authentication and encryption of data during transmission. It is therefore recommended to use SSH instead of telnet application and protocol whenever possible [1].

B. SNMP Protocol

Simple Network Management Protocol (SNMP) is a protocol for managing network devices. SNMP enabled managing devices (getting configuration, configuring …) of network devices from remote computers.

In applying SNMP protocol one or several NMS computers perform monitoring and management of network devices. The controlled devices (i.e. routers, switches, firewalls) that are managed by means of SNMP protocol contain a software process (SNMP agent) which is performed continuously. The agent collects and stores the information from the local computer system and

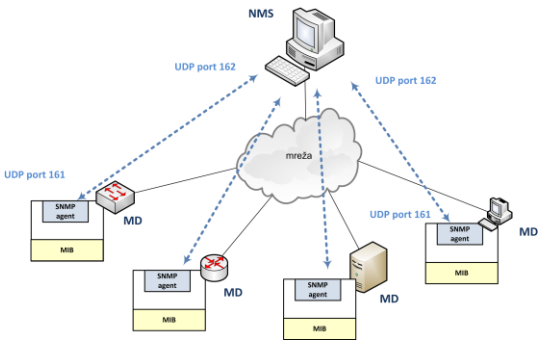

Figure 4. SNMP architecture [4]

provides NMS (Network Management Station) with their accessibility. NMS uses the commands *read and write* to obtain and change information on the SNMP agent. These commands use UDP port 161. SNMP agents present data as variables on the controlled device. The variables are organized into a hierarchy (data tree), and the hierarchy of data and the data description itself are called MIB (Management Information Base). MIB uses notation defined in ASN.1. Some devices can be configured to send messages (*trap*) toward NMS in case of the failure of an interface or another pre-defined case. These messages are sent toward NMS as SNMP *trap* that uses UDP port 162.

The SNMP protocol versions are the following [1]:

• SNMPv1 (SNMP version 1) is the first implementation of SNMP protocol and it was developed in 1988.

• SNMPv2 and the simpler version SNMPv2c have improved the performances of SNMPv1.

• SNMPv3: from the start the security was the biggest weakness of SNMP protocol, so that SNMPv3 essentially improved the security, as well as the possibility of remote configuration. SNMPv3 also changed significantly the terminology and the concept of SNMP protocol.

In 2004 IETF proclaimed SNMPv3 (defined in RFC 3411–RFC 3418) as standard, and versions 1 and 2 were proclaimed outdated [3]. Because of compatibility with the already installed and older devices, today, in everyday application SNMP implementations support several SNMP protocol versions: usually SNMPv1, SNMPv2c and SNMPv3 [1].

C. NETCONF Protocol

Since it was developed by IETF organization in mid 1980s, SNMP has proven to be a very widespread and popular protocol of network management.

However, it has been proven in practice that SNMP protocol mainly fails to be used for the configuration of network devices (although it was initially developed for that purpose, using SNMP command *set*), but rather it is used to control the networks (network monitoring) using commands *trap* and *get.*

In June 2002 Internet Architecture Board and the most important members of IETF community for networking control held a meeting with the network operators. The results of the meeting have been documented in RFC 3535. It showed that the network operators were using CLI user interfaces of network equipment manufacturers for the configuration of devices, i.e. console operating method and telnet/SSH protocols. The advantage of such operating method is that it is text-oriented, unlike BER (Basic Encoding Rules), i.e. ASN.1 coded method of SNMP protocol.

Requirements marked in RFC 3535 are the following [5]:

- Ease of use is a key requirement for any network management technology from the operators' point of view.
- It is necessary to make a clear distinction between configuration data, data that describe operational state and statistics.
- It is required to be able to fetch separately configuration data, operational state data, and statistics from devices, and to be able to compare these between devices.
- It is necessary to enable the operators to concentrate on the configuration of the network as a whole rather than of individual devices.
- Support for configuration transactions across a number of devices would significantly simplify the network configuration management.
- Given configuration A and configuration B, it should be possible to generate the operations necessary to get from A to B with minimal state changes and effects on the network and systems. It is important to minimize the impact caused by configuration changes.
- A mechanism to dump and restore configurations is a primitive operation needed by operators. The standards for pulling and pushing configurations from/to devices are desirable.
- It must be easy to do consistency checks of configurations over time and between the ends of a link in order to determine the changes between two configurations and whether those configurations are consistent.
- Network wide configurations are typically stored in the central master databases and transformed into formats that can be pushed to devices, either by generating sequences of CLI commands or complete configuration files that are pushed to devices. There is no common database schema for network configuration, although the models used by various operators are probably very similar. It is desirable to extract, document, and standardize the common parts of these network wide configuration database schemas.
- It is highly desirable that text processing tools such as diff, and version management tools such as RCS or CVS, can be used to process configurations, which implies that devices should not arbitrarily reorder data such as access control lists.
- The granularity of access control needed on management interfaces needs to match operational needs. Typical requirements are a role-based access control model and the principle of least privilege, where a user can be given only the minimum access necessary to perform a required task.
- It must be possible to do consistency checks of access control lists across devices.

- It is important to distinguish between the distribution of configurations and the activation of a certain configuration. Devices should be able to hold multiple configurations.
- SNMP access control is data-oriented, while CLI access control is usually command (task) - oriented. Depending on the management function, sometimes data-oriented or task-oriented access control makes more sense. As such, it is a requirement to support both data-oriented and task-oriented access control.

Based on the meeting of these requirements the first version of NETCONF protocol was developed, defined in RFC 4741 published in December 2006. NETCONF protocol was then improved in June 2011 in RFC 6241 [3] [6].

D. NETCONF Protocol Characteristics

NETCONF provides the mechanism of installation, manipulation, and deletion of network devices configuration.

The operations of NETCONF protocol have been realized by means of a simple layer of Remote procedure call (RPC) [6].

RPC is an Inter-process Communication (IPC) which allows the computer program to perform a subprogram or a procedure on another address space (usually on another computer connected by means of a computer network) without the programmer explicitly having programmed the communication details between the computers. In other words, the programmer writes the same programming code regardless of whether the subprogram is being executed locally or on a remote location. RPC is initiated by the client who sends a message request towards a remote server to execute a certain procedure with the sent parameters. While the server is executing its task, the client is blocked and waits for the response (except if the client sends an asynchronous request, such as e.g. XHTTP call). After the server responds to the client with the results, the client continues to execute the application. There are different variations of the RPC protocol in use, which are mutually incompatible.

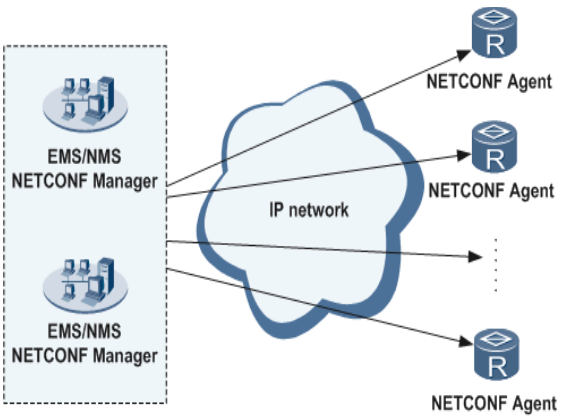

Figure 5. NETCONFl [7]

NETCONF uses RPC mechanism to enable communication between the client and the server. The client can be a script or an application which is usually part of the networking application, and the server is usually a network device [6].

NETCONF session is a logic connection between the network administrator (or the application for network configuration) and the network device. The network device has to support the establishment of at least one session, although there has to be a possibility of establishing several sessions simultaneously [6]

NETCONF protocol uses XML (Extensible Markup Language) for the coding of configuration data and protocol messages. The protocol messages are exchanged by means of secure transport protocol [6].

E. NETCONF Protocol Layers

NETCONF protocol can be divided into four layers [6]:

- secure transport layer,
- messages layer,
- operations layer, and
- content layer.

Secure transport layer provides secure and reliable transmission of messages between the client and the server. Secure transport layer allows communication between the client and server. NETCONF can use any transport protocol that satisfies the basic conditions of secure transmission: authentication, data integrity, confidentiality and replay safety. Obligatory implementation of secure transmission is "NETCONF over SSH" (RFC 6242).

Messages layer describes the coding mechanism of remote procedure call (RPC) and notification.

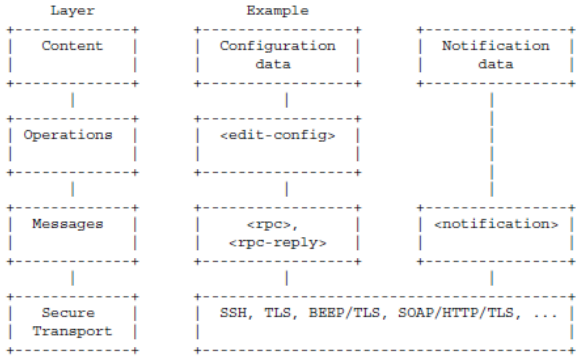

Figure 6. Layers of NETCONF protocol [6]

TABLE I. NETCONF OPERATIONS [6]

Operation	*Description*
<get>	Retrieve running configuration and device state information
<get-config>	Retrieve all or part of a specified configuration datastore
<edit-config>	Edit a configuration datastore by creating, deleting, merging or replacing content
<copy-config>	Copy an entire configuration datastore to another configuration datastore
<delete-config>	Delete a configuration datastore
<lock>	Lock an entire configuration datastore of a device
<unlock>	Release a configuration datastore lock previously obtained with the <lock> operation
<close-session>	Request graceful termination of a NETCONF session
<kill-session>	Force the termination of a NETCONF session

Messages layer allows simple and independent (of transport layer) mechanism of coding RPC messages and notifications. RFC 6241 defines RPC messages, whereas RFC 5717 defines notifications [3].

The basic NETCONF messages are the following [6]:

- RPC requirement (<rpc> message),
- RPC response (<rpc-reply> message),
- notification (<notification> message).

Operations layer defines a group of basic operations of the protocol that allow retrieval and editing of configuration data.

Table 1 presents the basic operations of NETCONF protocol.

Basic NETCONF functionalities can be expanded by defining additional possibilities (NETCONF capabilities) while establishing the session between the client and the server.

The possibilities of subscription and receipt of asynchronous notifications of events by the network device are defined in RFC 5277 whereas the possibility of partial locking of operating configuration is defined in RFC 5717 [3].

The possibility of controlling NETCONF protocol is published in RFC 6022, which explains the model for

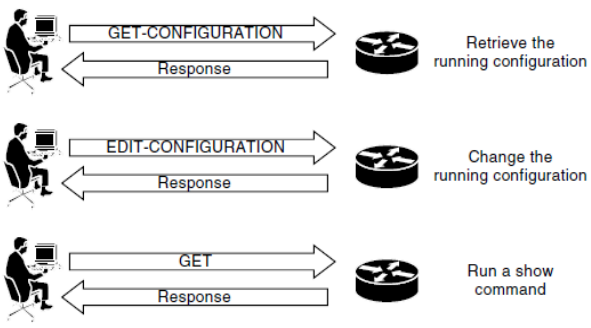

Figure 7. Example of implementation of NETCONF protocol [8]

datastore, session, locking and statistics which allows control of NETCONF servers.

Content layer consists of configuration data and notification data.

NETCONF protocol does not deal with the contents layer in its RFC documents, but rather a separated protocol has been made, titled YANG. NETMOD task group of IETF organization has determined the modelling language for the definition of the semantics of operation data, configuration data, notification and operations and has called it YANG. YANG is defined in RFC 6020, and RFC 6021 presents the types of data [3].

YANG protocol has been developed by NETMOD task group of IETF organization and published in RFC 6020 in October 2010 [3].

YANG is a language used to model the NETCONF protocol data. YANG defines the hierarchy of data that are used by NETCONF operations, including configuration, state data, RPC calls and notifications. YANG provides a full description of data that are exchanged between the client and the server [6].

YANG is a modular language which shows the structure of data in XML tree format. YANG as a language for data modelling has some in advance built-in and certain data types [9].

YANG models the hierarchical organization of data in the form of a tree, in which every node has its name and a value, or group of child nodes. YANG enables a clear and short description of every node, as well as interaction between the nodes.

III. IMPLEMENTATION OF NETCONF PROTOCOL

In this chapter the three methods of network device configuration have been compared: non-standard CLI access, SNMP standard and NETCONF standard. After that the current condition of NETCONF protocol implementation by the vendor and user are considered, as well as further research that should be made.

A. Comparison of Configuration Access

Table II presents the comparison of protocols for the configuration of network devices.

SNMP is not **human readable** and this is the basic reason why it has been rarely used for device configuration since its development. Command Line Interface (CLI) has been invented in order to facilitate to human operators and administrators, an interaction with the network equipment. CLI reminds of command interface based on characters which are used on the UNIX operating systems (Figures 1 and 2).

Many books on data networking contain sections that tell you how an administrator can configure a desired feature of the network device in practice. They provide sets of associated CLI commands that could be entered into the device through a device console. The shown sets of CLI commands are an excellent way to explain the operability and functionality of different features. This is one of the most important reasons why CLI access has been so widely accepted from the start.

TABLE II. METHODS OF COMPARISON

Feature	***CLI***	***SNMP***	***NETCONF***
Human readable	Yes	**No**	Yes
Standard	**No**	Yes (IETF)	Yes (IETF)
Data Models	Proprietary	Defined in MIBs	YANG Core Models
Data Modeling Language	Proprietary	SMI	YANG
Encoding	Proprietary	BER	XML
Resources	Proprietary	OIDs	Paths
Remote access	Yes (Telnet/SSH)	Yes	Yes (SSH)
Transport Stack	TCP	UDP	TCP
Secure protocol	Yes	Not/(v1, 2 and 2c) Yes (v3) but not strong security	Yes
Programmability	**No** (Only scripts could be used)	Yes	Yes
Distinguish configurational and operational data.	No	No	**Yes**
Get collection of status fields	Yes (with scripts)	Yes	Yes
Set collection of configuration fields	Yes (with scripts)	Yes	Yes
Transactions across multiple network elements	No	No	**Yes**
Send event notification	Yes (by using Syslog protocol)	Yes	Yes (but must be connected)
Backup and restore configuration	No	No	**Yes**
Test configuration before final commit	No	No	**Yes**

CLI access of configuration has not been defined by a **standard** and this has great disadvantages in application.

Network administrators usually have to manage a network with many different kinds of devices that can vary in terms of the following:

- Device types (routers, switches, firewalls, gateways, ...)
- Size and capacity of the device (different number of ports, switching and routing capacity. ...)
- Vendor - different vendors for different device types in the network (one approach is to have primary (90%) and secondary vendor (10%) for the same device type in the network), and
- Operating system version - even devices of the same vendor and model can differ in terms of the operating system version and patch level they are running.

If each agent requires a set of different interoperability rules, the manager will be confronted with an exploding number of language variants, different flavors of management functions, and alternative representations of management information.

There is no single, standardized CLI. Instead, there are different flavors, which generally differ between vendors and even different operating systems of the same vendor (for example Cisco has IOS, IOS XR, NX OS).

Figure 1 shows Cisco IOS command *show running-config*, whereas Figure 2 shows Juniper JUNOS command *show configuration.* Both commands have the same goal (show complete configuration on the network device), and as seen in the figures, the commands syntax is different, and the print of command results is also different.

A network administrator can make perfect sense of the information that is presented. However, the use of different delimiters and text that surrounds the values that are being returned make CLI relatively difficult for scripts and applications to use.

Different commands and the syntax of these commands exist in the operating systems of different vendors, but also in different OSs of the same vendor, in software versions for different platforms that use the same OS, and even in different versions of software for the same platform of one vendor.

A list of commands changes constantly in providing new features for the devices, so that it is very strenuous for a network administrator to know all the commands for the network devices, particularly if the network is composed of the devices of different vendors.

The role of standards is to establish common rules that everyone adheres to. For management, standards address all aspects affecting interoperability [2]:

- The rules for managing message exchange, and the way in which management messages encode information;

- A complete and consistent set of basic management functions with well-known meaning, parameters, and function return codes;
- The way in which the entities that are being managed are modeled as management information.

Standard management protocols address the first aspect (standardizing management messages and rules that guide their exchange). They also include a set of base functions, addressing the second aspect.

NETCONF is a standard-based solution for configuration management with all the advantages brought by the standards.

The traditional way of managing network devices is by using Command Line Interfaces (CLIs) for configurational (*configuration* commands) and operational data (*show* commands). With CLI, human intervention is required to understand and interpret their text-based specification. The solution lies in adopting a **programmatic** way of writing configurations to any network device, replacing the process of manual configuration. NETCONF provides the solution of automated and programmable network operations.

Transaction-based configuration across multiple network elements is a very important feature of NETCONF protocol. There are four properties that define a transaction [10]:

- Atomicity: transactions are indivisible, they are either executed or not.
- Consistency: transactions are transferred all at once. Also, there is no internal order of changes inside transaction. Therefore, transaction is a set of changes, not a sequence. In other words, the order matters in the execution, but it is not network administrator's concern in the transactional system.
- Independence: parallel transactions do not interfere with each other.
- Durability: committed data always remain in the system, even in case of fail-over, power failure, system restart and other similar situations.

NETCONF allows a network administrator to send down to one or more network devices a set of configuration changes, or an entirely new configuration, in a simple <edit-config> transaction. When doing so, the network administrator does not need to:

- Figure out in which order to send down the configuration changes. All different sequences are treated equally.
- Recover if the transaction fails. If the transaction was unsuccessful because of inconsistency in the configuration, an out of memory condition or any other reason, none of the transaction content has been activated. Transaction did not roll-back, it was simply never activated. Network-wide transactions are a very important feature because error recovery and sequencing tasks are removed from the list of network administrator concerns.

B. Current Status of NETCONF Protocol as a Standard

ISO model of computer networks managing has been known as acronym FCAPS (fault, configuration, accounting, performance, security). FCAPS is today a component of ITU-T reference model TMN (Telecommunications Management Network). TMN represents a concept of generic model for the management of the service provider's network, but it is also applicable in other business environments.

The objective of FCAPS model is to provide common base of coordinated development of management standards.

FCAPS as a concept, introduces the categorization of management functions [2].

- Fault management;
- Configuration management;
- Accounting management;
- Performance management;
- Security management.

Configuration management serves to configure the network devices, manage the configuration databases and software support.

IETF made in RFC 6632 a classification of network management protocol in FCAPS model as presented in Figure 5, and for the Configuration management it defined SNMP and NETCONF protocols [11].

In this way SNMP and NETCONF have been defined as basic protocols for Configuration management.

Fault Mgmt	Config. Mgmt	Accounting Mgmt	Performance Mgmt	Security Mgmt
SNMP notif. with trap operation (S. 2.1.1)	SNMP config. with set operation (S. 2.1.1)	SNMP monitoring with get operation (S. 2.1.1)	SNMP monitoring with get operation (S. 2.1.1)	
IPFIX (S. 2.3)	CAPWAP (S. 3.7)	IPFIX (S. 2.3)	IPFIX (S. 2.3)	
PSAMP (S. 2.3)	NETCONF (S. 2.4.1)	PSAMP (S. 2.3)	PSAMP (S. 2.3)	
Syslog (S. 2.2)	ANCP (S. 3.8)	RADIUS Accounting (S. 3.5)		RADIUS Authent.& Authoriz. (S. 3.5)
	AUTOCONF (S. 3.1.2)	Diameter Accounting (S. 3.6)		Diameter Authent.& Authoriz. (S. 3.6)
	ACAP (S. 3.9)			
	XCAP (S. 3.10)			
	DHCP (S. 3.1.1)			

Figure 8. Protocols matched to management task [11]

New trends in the development of computer devices and networks (virtualization, centralization, and mobility of the device) are the basis of cloud computing with SDN (Software Defined Networking) architecture for computer networks management. SDN offers programmable access to computer network management and enables more efficient and simpler installation, management and monitoring of the computer networks statuses.

Since the SDN access to network management developed fast and was created from different sources, IETF published RFC 7426 in January 2015 when it performed a review and systematization of the SDN architecture development, and defined the guidelines for future development.

SDN architecture has the need for standard interface for the command configuration of network devices so that RFC 7426 uses two basic protocols for configuration management (Management plane MPSI and SAL) of network devices: command-oriented NETCONF network devices and data-oriented SNMPv3 (Figure 9). For the Control plane CPSI and SAL the Openflow protocol is recommended [12].

In this way both NETCONF and SNMP have been defined as the basic protocols for management in computer networks of the future, as two compatible protocols that supplement each other.

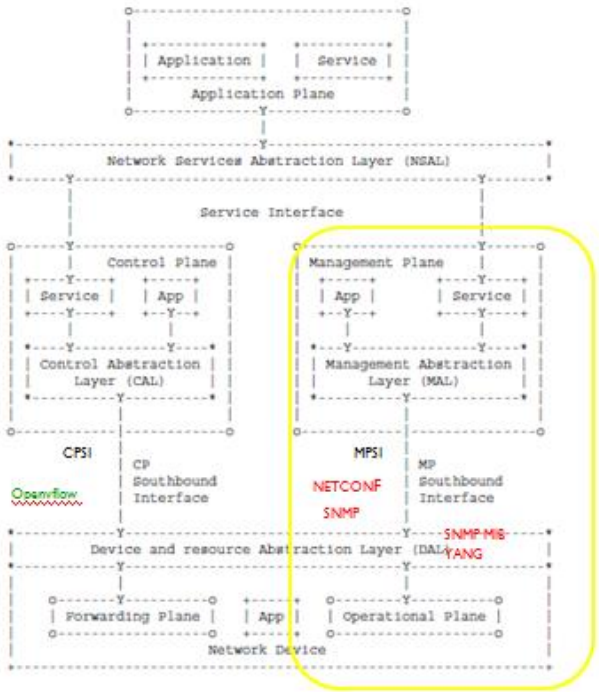

Figure 9. SDN layer architecture [12]

C. *Maturity of NETCONF Standard*

After more than ten years since the emergence of NETCONF standard a question has been asked as to what the real acceptance and application of this standard is in today's networks and what is its maturity.

IETF defines in RFC 6410 the existence of two levels of RFC standard maturity: the "proposed" and the "Internet standard". In order for the standard to pass into the highest level (status "Internet standard") this standard should be widely used in everyday application [14]. The current status of NETCONF standard is "proposed", and SNMPv3 has the "Internet standard" status.

Since the users (administrators, system engineers, network system architects, and others) determine the importance and maturity of an RFC standard by selecting and installing a certain protocol in their networks, the width and application method of NETCONF standard in Croatia should be examined (more than a decade after the first version of the standard was launched, which is a very long period in ICT area).

The more a certain technology has been applied, the higher level of its maturity will be reached. Maturity means the level of the application by the producer, functions that are applied, frequency of software errors (bugs) that occur, interoperability between different products and producers, documentation and education of manufacturers, and other. An extremely important factor whether a certain standard was going to succeed in ICT application and be widely applied in computer systems are the users and their (subjective) acceptance and application of the technology. An increase in the application of a standard results in an increase of its maturity, along with increase of the availability of network devices and the entire network system [14].

TABLE II. NETCONF OPERATIONS

Vendor	***Platform/OS***
Cisco	IOS 12.4(9)T and later IOS XE 2.1 and later
Juniper Networks	JUNOS 7.5 and later
Brocade	NETIRON XMR, CES and CER MLX series VDX (announced, not released)
Huawei	AR3200/2200 Enterprise routers
Ericsson	SEA 20

Examples of NETCONF protocol application by some of the biggest network equipment producers has been presented in Table III.

It should be mentioned (as can be seen in Table II) that the network equipment manufacturers implement NETCONF in certain versions of their operating system, and on certain platforms, so that it cannot be found on all devices for a certain version of OS. Therefore, the real question is how much the NETCONF protocol actually is being implemented (on which devices and on which OS version for each vendor). This list changes constantly but still it does show at a certain moment whether and how much the vendors implement NETCONF protocol on their devices.

D. Further Research

This paper analyses and presents significant advantages of NETCONF protocol in comparison to non-standard CLI access. However, a question is how much NETCONF is actually implemented in current networks.

Therefore, it is necessary to perform a research with the following research issues:

1. What is the implementation of NETCONF standard in practice by vendors?

The following research sub-questions can be considered:

1a. Which major vendor implements and on which network devices is NETCONF standard implemented?

1b. What are the reasons of implementing and not-implementing NETCONF standard on certain types of network devices?

1c. Do the vendors support a greater implementation of NETCONF standard in users and in which way (documentation, education, participating in the development of the standard, etc.)?

1d. In which way to increase the implementation of NETCONF standard by the vendor?

By answering this research question and sub-questions it is determined which of the possible advantages of NETCONF standard are implemented by the network device manufacturers and on which devices.

2. What is the implementation of NETCONF standard in practice by the users in their networks?

The following sub-questions can be considered:

2a. What types of users and on which devices do they use NETCONF standard?

2b. What are the reasons for using (or not using) NETCONF on devices?

2c. What is the level of knowledge of the users about NETCONF standard? Are the users familiar with NETCONF standard advantages in increasing the availability of the network system? Do they recommend possible improvements?

2d. In which way to increase the implementation of NETCONF standard by the users?

By responding to these research questions and sub-questions it is determined whether the users are familiar with the advantages of NETCONF standard and what is their perception of NETCONF standard in everyday implementation.

IV. CONCLUSION

The traditional way of managing network devices is by using two methods: Non-standard Command Line Interface (CLI) for configuration (*configuration* commands) and troubleshooting (*show* and *debug* commands) and Simple Network Management Protocol (SNMP) for monitoring of network and network devices status.

Although CLIs and SNMP are heavily used, they have several restrictions.

SNMP does not distinguish between configurational and operational data and it is not human readable and user friendly for network professionals.

Non-standard CLI methods are proprietary and syntax of commands and their output depend on the vendor IOS. Therefore human intervention is required to understand and interpret their text-based specification, and it is not suitable for automatic and programmatic management required by new SDN networks.

NETCONF is a newer standard for the configuration of network devices that could solve the drawbacks of the non-standard CLI and SNMP configuration methods.

As analysed in this paper, the main advantages and strengths of NETCONF protocol are (Table III):

- NETCONF is human readable and command-oriented;
- NETCONF is a standard-based solution for configuration management;
- NETCONF provides the solution of automated and programmable network operations;
- NETCONF is transaction-based. Therefore, it offers the possibility to send configuration across multiple network elements, to backup and restore configuration (if necessary) and to test configuration before final commit;

Also, NETCONF has been defined by standard body IETF as recommended protocol for current and future network management:

- NETCONF and SNMP have been defined by IETF in RFC 6632 for network management as basic protocols for Configuration management;
- NETCONF and SNMP have been defined by IETF in RFC 7426 as the basic protocols for network management of the future (Software Defined Networks), as two compatible protocols that supplement each other.

Using the NETCONF standard should enable standardized, simpler, programmatic and more efficient configuration of network devices. Besides, transactions achieve greater availability of network devices.

The possibility of implementing NETCONF standard is extremely wide and important for the future development of computer networks.

However, the implementation of NETCONF protocol after ten years since its publication seems to be very rare. Therefore, the authors of this article (and based on its results) are currently working on the following research:

- how much is NETCONF really used by users,
- how implementation of NETCONF can be improved by vendors and users.

This research should provide information about the maturity of NETCONF standard.

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Fault management API for SNMP agents

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***Abstract* - In previous works we have concluded that fault management SNMP integration state of the art is not idyllic from the integrator's point of view. Every umbrella fault management system has to implement number of different SNMP manager modules capable to communicate with different SNMP agents, irrespective of the fact that management information structure is almost the same among those agents (e.g. alarm message always consists of start time, perceived severity, probable cause, additional information, affected network element info and other attributes). In this paper, we are going to present Fault management API (Application Programming Interface) for SNMP agents (FM SNMP API). This C++ API is aimed to be used during SNMP agent software development process. Using this API, software developers will focus on fault management data handling while SNMP support for fault management will be covered by FM SNMP API. That approach should decrease SNMP agent software development time, but also it should simplify SNMP management process and new equipment integration into umbrella fault management systems. This paper is structured as follows: first, API architecture will be described. After that, functions to be used by developers are described briefly. Finally, FM API pilot use case will be presented.**

Keywords - Fault management API, integration, umbrella management system

I. INTRODUCTION

When providing services, telecom operators rely on network infrastructure. Its capacity should be optimized, in order to reduce service provision cost. However, service level must not be degraded. From the customer's point of view there is no network, but service quality only [6].

In order to provide agreed service quality to its customers, "every network operator has some kind of centralized network and/or service operation and maintenance center (official names vary, such as "Operation and Maintenance Center", "Network/Service Operation Center", etc.), tracing current network status and triggering appropriate restoring actions in case of network problems." [8].

Network monitoring is often done using manager-agent concept [1]. In such architecture, manager controls number of managed objects via agent. Agents are located close to the managed objects while managed objects are abstraction of real network resources.

Both, manager and agent, are pieces of software. Manager application serves as an interface between the real world (e.g. network staff) and management information provided by agent. Network management applications typically include graphical user interface with alerting, reporting and filtration functions. Agent acts as an interface between management system and real telecommunications network [9].

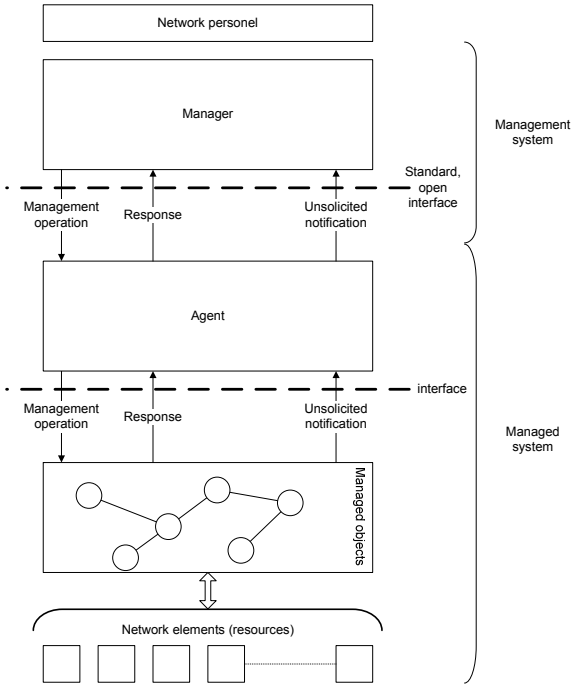

Figure 1. Manager-agent concept [9]

A. Manager-agent communication

In order to exchange network management information, manager and agent must "talk" the same language. They must use the same communication protocol on lower level but also, they must use the same semantic structure of network management information. Hence, it was necessary to develop number of network management protocols, architectures and standards for usage in telecommunications network management domain. In this paper, we will focus on SNMP (Simple Network Management Protocol), which is *de facto* standard in network management domain [2]. Further, we will focus on fault management functional area of network management. Fault management primarily covers the detection, isolation and correction of unusual operational behaviors of telecommunication network and its environment [5]. When a network problem appears, the network generates a large number of unsolicited events and the corresponding data carrying information about the malfunction. Those events, propagated from agent to manager, are called "alarms".

SNMP network management concept is based on manager-agent model. As mentioned above, manager and agent use the same information model of network management information. In SNMP protocol, those model is defined in MIB (Management Information Base) [3], [4].

B. *Previous work*

In our previous work [9], we have concluded that all SNMP agents handle almost the same alarm information content. Further, we have concluded that all network management data analyzed have different structure and format. It means, different SNMP manager application must be developed for every single network element type, although it handles the same alarm data content.

As a solution, we have proposed usage of unique Management Information Base for fault management functional area. ITU-T recommendation X.733 [7] provide the detail for the general parameters of the event reporting service, which is used to report events ("alarms" actually). Hence, it can be used for that purpose. Thinking about efficient software implementation of both SNMP managers and agents, we have proposed API structure that can ensure unique SNMP support as well as management information format in fault management functional area, with minimum SNMP manager's or agent's implementation cost. Proposed API should be used at SNMP agent side, in order to ensure standardized format of network management information. In such case, one SNMP manager would be capable to handle number of SNMP agents, located on different network elements, without need for further development.

II. FAULT MANAGEMENT API IMPLEMENTATION

A. *Basic SNMP agent functionalities in fault management domain*

In fault management domain, SNMP agent must ensure support for SNMP communication as well as alarm handling function. Further, alarm database must be implemented, storing all active and history alarms from network equipment. SNMP agent is located on network element or very close to it.

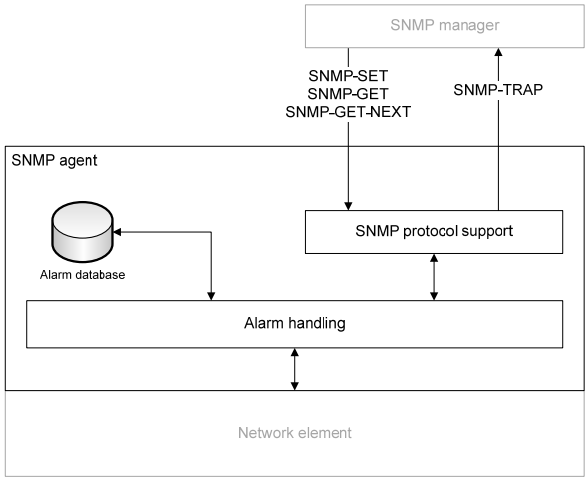

Figure 2. SNMP agent basic architecture

Alarm handling means handling of active alarms from network element, their storage into alarm database as well as support for retrieving alarm database using SNMP protocol primitives (SNMP-GET and SNMP-GETNEXT). Every new alarm must be reported to "subscribed" SNMP manager by sending SNMP trap message (figure 2).

In order to be able to handle network element's alarms SNMP agent must have access to network element data. Data interchange between network element and FM SNMP API is established through shared memory concept. Part of memory is shared with exclusive access between FM SNMP API and network element system software. It can be realized as shared binary file or shared part of the RAM (figure 3).

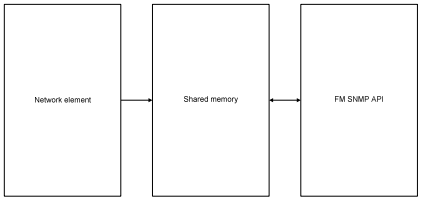

Figure 3. Shared memory concept

Network element writes values of key performance indicators while FM SNMP API read those values. In opposite direction, FM SNMP API is allowed to write into shared memory which *de facto* allows sending commands to network element.

B. *Shared memory concept in FM SNMP API*

Shared memory is memory shared between network element and FM SNMP API. It is determinated by its starting position and size. All values from shared memory are stored into FM SNMP API variables according to the rules written in so-called "Variables table". Variables table is part of FM SNMP API configuration. It consists of number of triples:

- Variable position
- Variable type
- Variable symbolic name

Variable position is absolute null-indexed position from the shared memory first byte. There are three predefined variable types: BYTE (1 byte long), SHORT (2 bytes long) and LONG (4 bytes long). According to the position given as well as variable type, to every variable symbolic name current value is assigned in periodic intervals (e.g. 1 second).

Symbolic variable names and its values are used for alarm handling. Namely, according to the so-called "Alarm conditions table", for every variable it is allowed to define value range within which alarm condition is fulfilled. Alarm conditions table consist of number of records, each of them containing following attributes:

- Variable symbolic name
- Value range from
- Value rang to
- Alarm managed object class

- Alarm managed object instance
- Alarm probable cause
- Alarm severity
- Alarm additional text

First three attributes serve as logical key – if value assigned to any variable steps into range defined, alarm condition is indicated with alarm attribute values given in Alarm conditions table.

Alarm conditions table is check periodically, after variables table is refreshed.

C. Alarm resynchronization algorithm

FM SNMP API has its own table for alarm storage called "Alarm database". For this purpose, SQLite database is used. SQLite is a C-language library that implements SQL database engine. It is small, fast, self-contained engine with high-availability.

Upon periodical check of current variable values, algorithm is performed in order to resynchronize FM SNMP API Alarm database with current alarm status as defined in Alarm conditions table (Table 1):

TABLE I. ALARM RESYNCHRONIZATION ALGORITHM

```
Input: Variables table, Alarm conditions table, Alarm database
Output: Alarm database
1: Refresh Variables table

//Set all alarm status to „alarm deleted“
2: foreach record in Alarm database do
3:            update record status to „alarm deleted“
4: end foreach

//Check which alarms are new, which are really deleted
3: foreach record in Alarm conditions table do
4:     find variable value in Variables table
5:     if variable value between range from and range to:
6:         //alarm condition recognized
7:         if alarm record already exists in Alarm database:
8:             update record status to „alarm exists“
9:         end if
10:        else
11:            insert alarm record into Alarm database
12:            set record status to „alarm added“
13:        end if
14:    end if
15: end foreach

//Delete from Alarm database all records with status „alarm
//deleted“ and send notification; Also, send notification for just
//added alarms
16: foreach record in Alarm database do
17:    if record status is „alarm deleted“
18:        delete record (move it to alarm history)
19:        send alarm deleted SNMP notification (trap)
20:    endif
21:    else if record status is „alarm added“
22:        send alarm added SNMP notification (trap)
23:    end if
24: end foreach
```

D. FM SNMP API structure

FM SNMP API is structured as follows:

- Initialization functions
- Alarm resynchronization functions
- Alarm table handling functions

Function:

void InitializeFMSNMPAPI (int nTimeoutSeconds);

must be called once at the application startup.

Function will ensure load of configuration (Variables table, Alarm conditions table, list of SNMP managers, database connection string, etc.). If it is necessary, configuration can be re-loaded in runtime by calling function explicitly:

void LoadConfiguration();

Parameter *nTimeoutSeconds* in *InitializeFMSNMPAPI* function defines how often function *void OnIdleProcess()* will be called. That function is typically used for calling periodical alarm resynchronization or variables refreshment:

void ResynchronizeAlarms();

void RefreshVariablesTable();

Alarms in Alarm database are stored in two different ways.

First, alarms are stored in alarm table containing as much records as alarms are currently active. However, in order to respect SNMP philosophy, there is one more table called MIB table. In that table all alarms' attributes are "linked" with specific object identification used in SNMP communication.

SNMP support runs is separated thread, receiving SNMP messages through UDP socket. When SNMP request is received, appropriate function is called:

bool ProcessSNMPGetRequest(std::string sObjectId, std::string &sValue, int &nType);

bool ProcessSNMPGetNextRequest(std::string sObjectId, std::string &sValue, int &nType, std::string &sNextObjectId);

Functions will return true if object with given object identification exists in MIB table, otherwise will return false value. Parameters will be filled and transferred as C-references.

After reception of function result, SNMP response is sent from SNMP support thread.

E. Pilot use-case

In [10] we have described simple environment for cloud-based services for the Internet of things. Part of that environment was DS18B20 temperature sensor connected to Raspberry Pi in lab environment. Temperature sensor values were read by application written in C (further: "sensor app").

We have use it for test pilot for testing FM SNMP API. On the same Raspberry Pi we have installed simple SNMP agent developed by using FM SNMP API. Temperature measured was defined as one variable in *Variable table*, while real-measured values were written into shared memory by sensor app. Further, in Alarm conditions table

temperature conditions under which alarm should arise were defined. As a SNMP managed we have used one open access SNMP trap receiver.

After that, we have changed sensor type. Instead DS18B20 driven by C application, we have used humiture sensor driven by python script.

Final result is that SNMP agent was developed in less than two hours. Implementation was the same for both cases. The only difference was in FM SNMP API configuration – Variable table and Alarm conditions table. However, it must be considered that there was only one variable to define. In real network condition, that number can increase to thousands.

III. CONCLUSION

In this paper we have presented FM SNMP API (fault management SNMP API). Manager-agent architecture was described briefly as well as basic SNMP agent functionalities. After that we have presented way of communication between FM SNMP API and network element which is aimed to be controlled by SNMP agent. Since communication is achieved through shared memory concept, we have described how variables and alarm conditions based on variables' values are processed within our API. As an important feature, we have explain alarm resynchronization algorithm in more detail. Finally, basic API functions are presented as well as pilot-case where two different hardware items are put under control of SNMP agent developed by FM SNMP API.

Further work should be concentrated on performance management functional area. Also, real proof of concept should be realized in more complex environment.

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Enhancing REST HTTP with Random Linear Network Coding in Dynamic Edge Computing Environments

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***Abstract*—The rising number of IoT devices is accelerating the research on new solutions that will be able to efficiently deal with unreliable connectivity in highly dynamic computing applications. To improve the overall performance in IoT applications, there are multiple communication solutions available, either proprietary or open source, all of which satisfy different communication requirements. Most commonly, for this kind of communication, developers choose REST HTTP protocol as a result of its ease of use and compatibility with the existing computing infrastructure. In applications where mobility and unreliable connectivity play a significant role, ensuring a reliable exchange of data with the stateless REST HTTP protocol completely depends on the developer itself. This often means resending multiple request messages when the connection fails, constantly trying to access the service until the connection reestablishes. In order to alleviate this problem, in this paper, we combine REST HTTP with random linear network coding (RLNC) to reduce the number of additional retransmissions. We show how using RLNC with REST HTTP requests can decrease the reconnection time by reducing the additional packet retransmissions in unreliable highly dynamic scenarios.**

I. Introduction

Machine to machine communication with its ongoing development is considered a key aspect to be studied in the area of the Internet of Things (IoT). IoT scenarios come with a high number of implementation difficulties demanding computation tasks to be performed in different networks and system architectures, all while maintaining high mobility and dynamicity, and dealing with different challenges ranging from resource management, communication and interoperability issues to data processing and analysis. In order to satisfy the requirements of these new scenarios, well known and accepted technologies such as cloud computing, have been merging with novel technologies that are shifting part of the computation closer to the edge devices, known as fog computing. There have been many research efforts and projects dedicated to solving each of the problems found in these scenarios with fog-to-cloud system solutions, many of which are focused on optimizing network infrastructure and connectivity itself. In this paper we will focus on the improvement of the communication aspect of these systems, particularly on the application layer communication in highly dynamic mobile scenarios by combining the REST HTTP protocol with random linear network coding.

The HTTP protocol following the architectural style defined by REST is being widely used as a communication protocol for web services and also for creating REST APIs for distributed system communication. The ease of use and compatibility with the already existing systems made its adoption as a communication protocol faster than with any other protocol, even with the known limitations this protocol has in some scenarios. One of these scenarios is when building RESTful applications with certain reliability requirements in dynamic environments where connectivity is intermittent and unreliable. A common developer practice for dealing with that kind of situations where timeout events occur is to resend request message following certain self made procedure, instead of any standard procedure. Due to the intrinsic nature of REST HTTP as a polling protocol, the so-called unsafe methods can modify resources in the server side even when the acknowledgments fail. This problem makes the client unaware of the modified resources and forces the client to resend repeated requests. In order to avoid duplicated modification of resources, some policies are usually applied on the server side to make the client aware whether the resources were already modified or not.

In this paper we try to address this issue by combining REST HTTP with random linear network coding (RLNC) in order to minimize the amount of extra requests that have to be sent to the server. We propose a solution in form of a library for the developer to use that will automatically perform RLNC over REST HTTP with no extra development effort for the developer. In our coding scheme, instead of sending native messages, we dispatch coded messages, where the main goal is to predict the loss rate and adjust, more accurately, the number of additional messages in order to improve bandwidth utilization. The designed scheme is designed to be applied in dynamic environments, where the communication between client and server is intermittent. Specifically, we study the case where a mobile client, for instance a smart car, wants to update information to different servers located in base stations along a roadway, and because of tunnels the signal is intermittently lost. Our numerical results show how we reduce the number of additional messages necessary for the client to update the data when using network coding in combination with REST HTTP.

II. Related Work

Handling dynamic mobile scenarios has been one of the key issues for many real-time IoT based systems. In [1] authors explain the limitations of cloud computing solutions in handling mobility issues in these kind of systems. As a solution they propuse a framework that combines cloud comuting with computing closer to end devices in a wireless IoT systems. The advantages of the fog computing in different dynamic IoT application scenarios have been also detailed in [2] and [3]. While [2] offers a more general overview of these advantages, [3] focuses on a specific scenario which includes communication between smart vehicles and their fog computing nodes positioned at base stations.

However, even with the improvements gained with fog based system architectures, the issue of intermittent connections in highly dynamic IoT applications and disruptions that come as their consequence has still many open questions. This has led to many different research efforts in improving these solutions. In [4] authors approach the problem by developing a handover mechanism for mobility support in a IoT-fog systems tested in a health monitoring application. The handover procedure has also been optimized for another fog based framework that tackles high dynamic scenario of connected vehicles in [5]. Beside handover optimization, the choice of the application layer protocol has also been a subject of research when tackling consequences of unreliable connections in these kind of solutions. In [3] authors are using a fog based solution and RESTCONF, an HTTP based protocol for smart vehicle related communication and data computations. In [6] authors have presented a disruption-tolerant RESTful support, tested both with HTTP and CoAP. Their main goal was to improve communication in a dynamic scenario where many devices are prone to disconnections while moving. Idea of improving communication with the adaptation of REST can be used, this time by using network coding.

Network coding (NC) can be dated in 2000 [7], a technique which allows network systems to combine several native messages into one coded message in order to expand the maximum bandwidth utilization. In [8] authors use a network coded protocol operating between the network and transport layers in a wireless network. The results have shown that by using RLNC, this protocol was able to recover from packet losses. In order to improve performances of dynamic IoT scenarios the interesting path is the combination of network coding and fog based computing. Possible applications of NC in IoT and fog based systems have been described in [9] with promosing results reported in [10], where authors have used NC to improve efficiency of data communication protocols in fog computing wireless sensor environment. In this paper we will explore combination of NC and REST HTTP protocol in IoT to fog communication scenario, as it is still application layer protocol of choice for developers according to multiple research efforts as the one reported in [11].

III. System design

This section shows our solution on applying network coding operations as an embedded mechanism on top of the HTTP protocol when using it with REST. Before entering into details, we recall one definition and one proposition for the concept of "Seeing a packet" taken from [12]:

Definition 1 (Seeing a packet): A node is said to have seen a packet p_k if it has enough information to compute a linear combination of the form $(p_k + q)$, where $q = \sum_{l>k} \alpha_l p_l$, with $\alpha_l \in F_q$ for all $l > k$. Thus, q is a linear combination involving packets with indices larger than k.

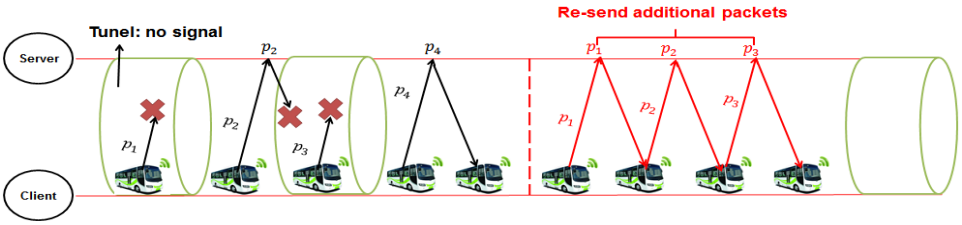
Proposition 1: If a node has seen packet p_k, then it knows exactly one linear combination of the form $p_k + q$ such that q is itself a linear combination involving only unseen packets.

Based on this assumptions, upon receiving a coded packet, instead of waiting to have enough information to decode the desired packets, the server immediately tries to perform Gauss-Jordan elimination (GJE) to find out which packet has been newly seen and responds for that packet using the definition and the proposition above. That means the server side can pretend to have received the packet even if it has not been really decoded yet. For example, let us assume the server knows the two linear combinations $c_1 = p_1 + 2p_2 + 3p_3 + 4p_4 + 5p_5$ and $c_2 = p_1 + p_2 + 7p_3 + 8p_4 + 9p_5$. The server uses GJE to compute $2c_2 - c_1 = p_1 + 11p_3 + 12p_4 + 13p_5$ and $c_1 - c_2 = p_2 - 4p_3 - 4p_4 - 4p_5$. According to definition 1 and proposition 1, the linear combinations of $2c_2 - c_1$ and $c_1 - c_2$ have the form $p_k + q_k$, therefore packets p_1 and p_2 are seen, and packets p_3, p_4 and p_5 are unseen. With a large finite field size, every linear combination coming may cause the next unseen packet to be seen. Then, according to theorem 1 [12], if all of the packets in a file have been seen, they can also be decoded.

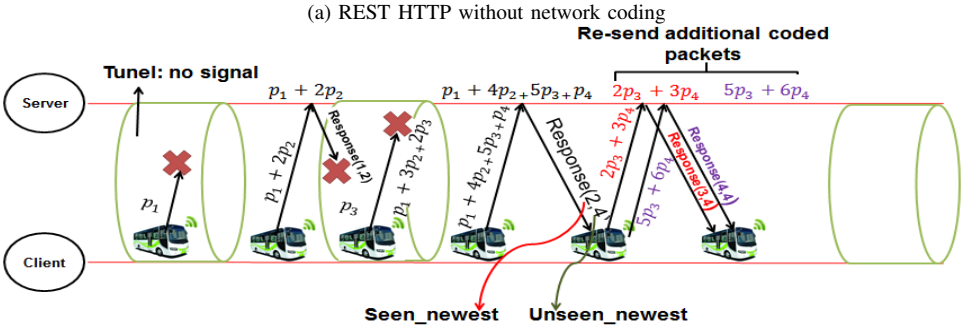
A. Scenario

As mentioned before, our focus will be on the highly dynamic scenarios. These kind of systems are often met with connectivity and bandwidth issues, causing message losses. We assume REST HTTP based communication and observe the behaviour of particular type of requests. We consider the example, shown in Fig.1, which takes place between one mobile client (e.g. smart vehicle) and one static server. The client wants to open four connections in order to send four POST request messages, i.e. $p_1, p_2, p_3, and\ p_4$, to the server.

In Fig.1a we consider request messages related to unsafe methods exchanged between the client and the server. With REST HTTP, these ones can be safely re-sent several times to receive the responses corresponding to those requests back from the server [13]. However, re-sending them many times while we are not sure what is occurring in unreliable connections, i.e. whether the timeout happened during sending the request to the server or the response to the client, can cause a bandwidth waste in term of the traffic sent. For example, in the scenario of Fig.1a, re-sending message p_2 is not necessary because it was already



(a) REST HTTP without network coding



(b) REST HTTP with network coding

Figure 1: Case study of REST HTTP communication with and without network coding

updated at the server side. In order to solve this problem, we propose a RLNC, as shown in Fig.1b. Before analyzing our scenario, we need to know the two notations: *seen_newest* and *unseen_newest* contained in response messages from the server module are IDs of the newest seen and unseen message after GJE. Refering to the example of definition 1 and proposition 1, after GJE at the server side, we can find out *seen_newest* has $ID = 2$ which identifies message p_2 and *unseen_newest* has $ID = 5$ belonging message p_5.

In Fig.1b we observe that each REST HTTP message is updated at a different time, stored in the NC layer and only removed from the coding buffer when its response is gone back from the server. Request message p_1 is lost, therefore at the time of arriving request message p_2, a random linear combination of messages p_1 and p_2 is dispatched to the server, where the coefficients are randomly chosen for the whole message, not each symbol, but its response is lost. Similarly, at the time of arriving p_3 and p_4, the server has the random linear combinations $p_1 + 3p_2 + 2p_3$ and $p_1 + 4p_2 + 5p_3 + p_4$, respectively, but only the latter is successful on both the client and the server side. At the time of receiving the linear combination $p_1 + 4p_2 + 5p_3 + p_4$, the server performs GJE on the linear combinations that exist on the server side, and then has the coefficient matrix, as shown in Fig.2a. With that information in Fig.2a, the server can respond the response message Response(2,4) containing $seen_newest = 2$ (ID of request message p_2) and $unseen_newest = 4$ (ID of request message p_4). Note that this response can be sent even when the original request messages have not yet been decoded. Based on Response(2,4), the client can compute by performing $unseen_newest$ - $seen_newest$ = $4 - 2 = 2$ (2 means the server lacks the two coded messages), and then re-send the

$$\begin{array}{cccc} p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & -5 & -1 \\ 0 & 1 & 5/2 & 1/2 \end{array}$$

(a)

$$\begin{array}{cccc} p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & 0 & 13/2 \\ 0 & 1 & 0 & -13/4 \\ 0 & 0 & 1 & 3/2 \end{array}$$

(b)

$$\begin{array}{cccc} p_1 & p_2 & p_3 & p_4 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{array}$$

(c)

Figure 2: Matrices after performing Gauss-Jordan elimination at the server side

two additional random linear combinations (i.e. $2p_3 + 3p_4$ and $5p_3 + 6p_4$) to compensate losses. The two additional linear combinations do not include request messages p_1 and p_2 because they have already been removed from the coding buffer after the client received the Response(2,4) (the reason is explained in the part of buffer management at the client side). Fig.2b shows the coefficient matrix after performing GJE at the time of receiving the additional linear combination $2p_3 + 3p_4$, where response message Response(3,4) contains $seen_newest = 3$ and $unseen_newest = 4$. Fig.2c shows the coefficient matrix after performing GJE at the time of receiving the additional linear combination $5p_3 + 6p_4$, where response message Response(4,4) contains $seen_newest = unseen_newest = 4$, meaning all original request messages have been decoded. With respect to the message gain, using network coding, we can shorten one resource update cycle compared to the traditional REST HTTP.

However, the problem is still that the current REST HTTP protocol does not allow response to a request message before it has been decoded. Therefore, a modification of REST HTTP is required to respond to every coded request message received by using definition 1 and proposition 1 in the paper [12]. In addition, we use the progressive non-generation-based coding implementation as done for TCP/NC [12] and dynamic coding

[14]. On the other hand, as mentioned in our scenario, each request message is updated at a different time, so the newest arrived request is presented by only one linear combination at a time. As a result, to anticipate the number of losses and reasonably adjust the number of additional request messages, we modify the dynamic coding algorithm [14] for REST HTTP with network coding.

B. Client NC layer

1) Coding header: The coding header, shown in Fig. 3, includes ID list, length of messages list and coding coefficient list involved in the linear combination.



Figure 3: Network coding header.

A coded message is generated by forming a linear combination of the messages in the coding buffer, where the coding coefficients are randomly selected for the whole each message, not every symbol. In our implementation data coding is operated over a finite field $\mathbb{F}_{2^8}$. Each message has a specific identifier (ID) assigned in order. The header of a coded message will contain information that the server NC layer can use to perform the decoding process and manage its buffer. The meaning of various fields is described as follows.

- "$ID\ list$" shows a numbered list of message identifiers involved in a linear combination. "ID_{oldest}" and "ID_{newest}" are the indexes of the oldest and the newest message, buffered into the current coding buffer at the client NC layer. "ID_{oldest}" and "ID_{newest}" are enough in order for the server to know all of the messages in that linear combination. For instance, the client has the linear combination with "ID_{oldest}" $= 4$ and "ID_{newest}" $= 7$, which means that the linear combination contains 4 messages p_4, p_5, p_6 and p_7, where p_k has the number $ID = k$.
- "$Length\ list$" shows the size list of messages and $length_i$ represents the length for the ith message contained in the linear combination. This information is crucial because when implementing the coding process, a problem raises that messages contained in the linear combination have different sizes. In order to address this problem, we may sufficiently append many dummy zero symbols to the shorter messages until all of the messages have the same length. Upon decoding the message at the server NC layer, the dummy zero symbols are pruned using the "$Length\ list$" header field in the coding header.
- "$Coding\ coefficient\ list$" shows the list of coding coefficients and α_i denotes the coefficient used for the ith message involved in the linear combination. Note that these ones are randomly chosen for the whole message.

2) Coding algorithm: This subsection describes the whole coding algorithm on the server NC layer, as shown in Fig.4. $reduntdant_val$ is the value denoted for the number of additional messages needed to compensate losses. r_ID represents the highest ID number of message involved in the additional linear combination. For instance, assume if we re-send the additional linear combination of 3 messages p_1, p_2, p_3, then r_ID will be 3. The operations are detailed as follows.

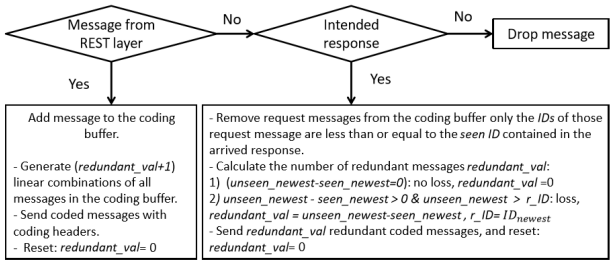


Figure 4: Coding algorithm at the client NC layer.

- Calculation method for re-sending additional coded messages: The client NC layer accepts messages from the REST layer and stores them into the coding buffer. Then, the client NC layer generates random linear combinations in the coding buffer, some of them including $redudant_val$ additional linear combinations, where the coding coefficients are randomly chosen for the whole message, and also conveyed in the coding header. Based on $seen_newest$ and $unseen_newest$ contained in the response message from the server side, the number of additional coded messages $redundant_val$ is calculated. If $unseen_newest - seen_newest = 0$, no loss occurs. Else if $unseen_newest - seen_newest > 0$ and $unseen_newest > r_ID$, then losses occur on the way to the server, therefore we set $redundant_val = unseen_newest - seen_newest$ and $r_ID = ID_{newest}$. We reset $redundant_val = 0$ after re-sending the additional messages.
- Buffer management method: The request messages will be removed from the coding buffer only if the IDs of those request messages are less than or equal to the newest seen ID ($seen_newest$) contained in the arrived response. If a new request message from the REST layer comes when the buffer is not totally empty, then that one must be dropped and it will be retransmitted later by the REST layer.
- Subset coding buffer: In case a very small time interval is selected to update information to the server, probably, the client buffers a large number of messages in the buffer. As a result, combining all messages in the coding buffer will make the coding header too large, increasing in that way the coding/decoding complexity. In order to address this problem, we define subset coding buffer that has a fixed size, in order to limit the number of messages in the coding buffer to participate in random linear combinations.

C. Server NC layer

This subsection describes the whole decoding algorithm on the server NC layer, as shown in Fig.5. The operations are detailed as follows.

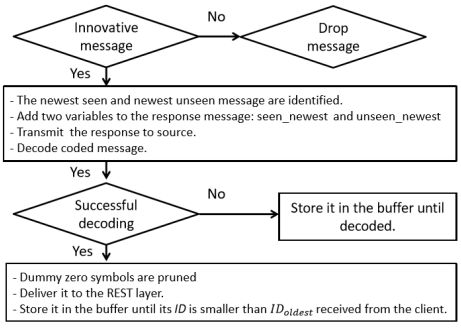


Figure 5: Decoding algorithm at the server NC layer.

- Response method: The server NC layer stores a newly arrived coded message in the decoding buffer, and then reads the coding header and correctly appends the coefficient vector to the decoding matrix. In order to know whether that message is linearly independent, GJE only needs to be performed on the decoding matrix. If the message is not linearly independent, it is deleted. Otherwise, the row transformation operations of GJE on that coded message are also performed. The server NC layer will send a response including the newest seen ID ($seen_newest$) and newest unseen ID ($unseen_newest$) identified after GJE, and this job can be performed before the message is decoded and delivered to the REST layer. The seen and unseen ID values are very important for the client NC layer because it uses them to predict and reasonably resend the number of additional messages.
- Decoding and delivery method: When a new message is decoded, the dummy zero symbols are pruned using the coding header. After that, that decoded message is delivered to the REST layer.
- Buffer management method: The arrived coded messages that have not been yet decoded need to be stored in the decoding buffer. The arrived messages without coding or the messages that have been already decoded and delivered are still stored in the buffer until the server NC layer makes sure that they have already been dropped by the client NC layer, then it removes them. This is because they may still be involved in the next linear combinations if their responses are lost on the way to the client side. Using ID_{oldest} belonging to the "$ID\ list$" header field in the coding header, the server NC layer can remove a decoded message if its ID is smaller than ID_{oldest}.

D. Analysis

We now analyse the impact of REST HTTP with network coding (NC_REST) on reducing the number of additional messages compared to traditional REST HTTP (REST). Let p be the loss probability including both the loss due to sending request message to the server, and sending response message to the client. N denotes the total number of request messages sent. For REST, re-sending is performed when both lost requests and responses occur, therefore p and N, on average, are only fraction $N \cdot (1-p)$ of them successfully negotiated. As a result, to be able to compensate losses for sending N request messages, REST needs to transfer at least $\frac{N}{(1-p)}$ request messages and the number of additional request messages of REST A_{WoNC}, which is calculated by:

$$A_{WoNC} = \frac{N}{1-p} - N \tag{1}$$

where $p < 1$. For NC_REST, re-sending is only considered for lost requests. Let α be the loss rate when sending response message to the client. Hence, to successfully transfer N requests, the number of additional request messages of NC_REST A_{WNC} is given by:

$$A_{WNC} = \frac{N}{1-(\alpha \cdot p)} - N \tag{2}$$

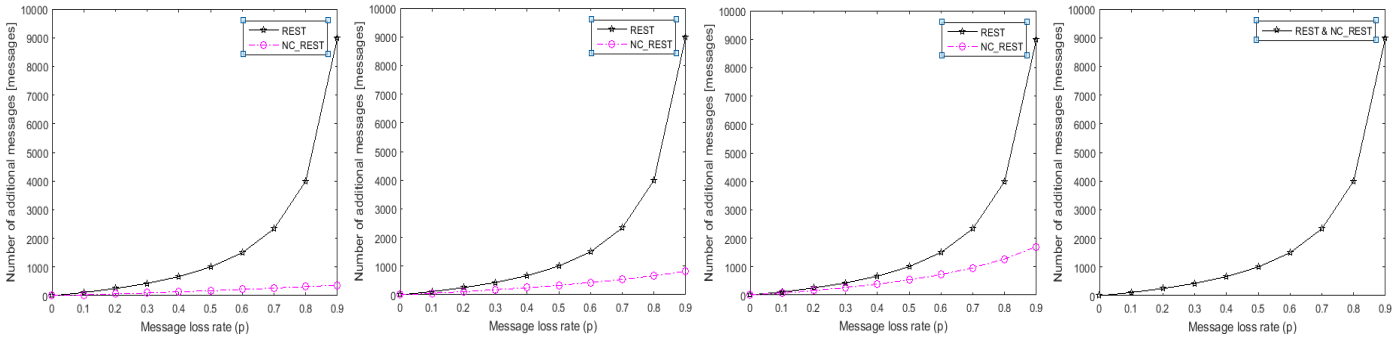
where $\alpha \cdot p < 1$. From Eq.1 and Eq.2, we see that $A_{WNC} \leqslant A_{WoNC}$. We observe that $A_{WNC} = A_{WoNC}$ only when $\alpha = 1$, and this is the case where we do not have any benefit from network coding, causing even worse results because it adds additional bytes of overhead for the network coding header in addition to the REST message.

IV. Numerical results

This section shows numerical results to see the impact of NC_REST on reducing the number of additional messages and its comparison with REST. For our example, we choose a case with $N = 1000$ sent request messages. The message loss probability p including both the request message loss and the response message loss is considered in $[0; 0.9]$. Four examples of the request message loss rate α are selected: $\alpha = 0.3$, $\alpha = 0.5$, $\alpha = 0.7$ and $\alpha = 1$.

Fig.6 shows examples of NC_REST and REST in term of the number of additional messages. The scenarios include different values of α shown in Fig.6a ($\alpha = 0.3$), Fig.6b ($\alpha = 0.5$), Fig.6c ($\alpha = 0.7$) and Fig.6d ($\alpha = 1$). The x-axis and y-axis represent the message loss probability p and the number of additional messages, respectively. The number of additional request messages is calculated by using Eq.(1) for REST and Eq.(2) for NC_REST. Observing Fig.6, the number of additional messages increases when loss probability p increases for both REST and NC_REST, since the higher loss probability p the more re-sendings occur.

First of all, we consider an example with a small loss rate of $p = 0.1$. Compared with NC_REST, REST increases 259.260%, 111.110% and 47.620% for the example shown in Fig.6a, Fig.6b and Fig.6c, respectively. With $p = 0.5$, REST needs to re-dispatch 1000 request messages for all of



(a) $\alpha = 0.3$ (b) $\alpha = 0.5$ (c) $\alpha = 0.7$ (d) $\alpha = 1$

Figure 6: Number of additional messages with network coding NC_REST and without REST

request message loss rate values α, but NC_REST only re-sends 176.470 request messages for $\alpha = 0.3$; 333.333 request messages for $\alpha = 0.5$ and 538.461 request messages for $\alpha = 0.7$. In case of a high loss rate of $p = 0.9$, REST re-sends 9000 request messages for all the cases, while NC_REST only re-sends 369.863, 818.181 and 1702.700 request messages shown in Fig.6a, Fig.6b and Fig.6c, respectively. With those results, NC_REST always outperforms REST in term of the number of additional messages. Besides that, we see that the lower the loss probability of sending request message to the server α is, the better the benefit of NC_REST is. The reason for those is because NC_REST only re-sends for the lost request messages. Therefore, compared to request message loss rate with $\alpha = 0.5$, $\alpha = 0.7$ and $\alpha = 1$, a request message loss rate of $\alpha = 0.3$ has the best benefit from network coding. For the case of $\alpha = 1$ in Fig.6d, there are no advantages in using NC_REST, and the number of additional messages for REST and NC_REST is the same for all loss probability values p. Moreover, if we take network coding header into account, NC_REST will consume an amount of traffic for this, therefore decreasing bandwidth utilization. With the analysed numerical results, we can conclude that NC_REST outperforms REST in all of cases, except when the request message loss rate is $\alpha = 1$.

V. Conclusion

The network coding method has been used for improving efficiency and bandwidth utilization, as well as the novel paradigm of fog computing. In this paper, taking into consideration highly dynamic scenarios that include the communication between a mobile client and fog processing nodes, where connection is often unreliable, we combine REST HTTP protocol with random linear network coding. We show how our solution can decrease the reconnection time by reducing the additional packet retransmissions. In future works, we will do practical implementation for our algorithm to better understand the impact of network coding on the performance of REST HTTP.

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CYBERSECURITY CHALLENGES

Analysis of Cybersecurity Threats in Cloud Applications Using Deep Learning Techniques

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***Abstract* – In this paper we present techniques based on machine learning techniques on monitoring data for analysis of cybersecurity threats in cloud environments that incorporate enterprise applications from the fields of telecommunications and IoT. Cybersecurity is a term describing techniques for protecting computers, telecommunications equipment, applications, environments and data. In modern networks enormous volume of generated traffic can be observed. We propose several techniques such as Support Vector Machines, Neural networks and Deep Neural Networks in combination for analysis of monitoring data. An approach for combining classifier results based on performance weights is proposed. The proposed approach delivers promising results comparable to existing algorithms and is suitable for enterprise grade security applications.**

***Keywords* – cybersecurity, ids, deep learning**

I. INTRODUCTION

Research in the field of Cybersecurity has been ongoing for decades. With the continual increase of data volumes protecting computer and telecommunication systems has become primary concern. There are several approaches which are currently in use: traffic analysis, content analysis, application and user behavior analysis.

As provided on Fig.1 below there exist a number of layers with common groups of threats, existing protection capabilities and ICT resources that are under constant attack nowadays.

The most popular applications based on traffic analysis [1] can be grouped into the fields of network intrusion detection, botnet detection and malware detection. In recent years there are approaches based on machine learning algorithms for each of these fields. Some of the intrusion detection and protection techniques (IDPS) are trained to recognize abnormalities in traffic, e.g. in peer-to-peer applications. There are IDS for protecting against distributed denial-of-service (DDoS) attacks. There are e-mail protection services detect harmful applications that steal information: especially widespread are mobile malware applications [2]. Malware application behaviours is analyzed and detectors are trained to classify an application or part of it as harmful [2]. Another threat type of threat are botnets: many compromised devices or hosts, infected with malware and connected to the Internet that are controlled and manipulated by botmasters [3]. Botnets are mainly used for sending spam emails, DDoS attacks, identity thefts or just making use of the victim's computational resources for purposes of e.g. tunnelling, proxying or even cryptocurrency mining.

Over the recent years, several proposals have appeared on the usage of advanced techniques for intrusion detection [4]. The authors propose cybersecurity framework based on two-stage Markov model for early prediction of malicious edge devices as well as legitimate edge devices in fog computing.

In [5] recent focus has been given on the rise of security incidents affecting critical infrastructure such as power grids and water suppliers, the German BSI cybersecurity agency reported that not all of the incidents were due to hacking. Another [6] recent publication shows flaws and vulnerabilities in an entire European country. The author shows how vulnerability scanning can be organized by a single person and justifies the importance of cybersecurity threat detection software.



Figure 1. Classification of existing cybersecurity threats, protection services and resources

II. THREAT DETECTION TECHNIQUES BASED ON NETWORK TRAFFIC ANALYSIS

A. *Intrusion Detection (IDS) and Intrusion Prevention (IPS) Systems*

Both IDS and IPS systems are entitled to try and recognize malicious traffic from normal traffic. There are Host-Based (HIDS) and Network Intrusion Detection systems (NIDS) [7]. To achieve this goal, both IDS and IPS rely on network traffic analysis. Most of the existing systems rely on rule-based classification to detect the nature of the attacks: the malicious traffic is often concealed within botnet, DDoS attack traffic or spam traffic. It can be expected that the accuracy of such systems is relatively low [8], due to the limits of their operation modes: signature based and anomaly-based [7]. Signature based threat detection uses a set of pre-determined rules that are available from the community of manufacturer with rules containing signature patterns threats similar to antivirus software. The anomaly based detection function is to detect abnormalities in the current network traffic or states of services in logs.

The big manufacturers of network equipment offer bundles of IDS/IPS systems which claim high accuracy and machine learning capabilities. It is worth exploring some of the open source available systems.

- OSSEC [9] stands for Open Source Security. It is open source host intrusion detection system owned by Trend Micro, one of the leading names in IT security. The software, on Unix-based OS has capabilities of analyzing log and configuration files.On Windows OS, OSSEC can detect registry modifications. OSSEC, as a typical host intrusion detection system (HIDS) is installed on each protected computer. It consolidates information from each protected node in a single management console. The central software only runs on Unix-Like systems; an agent is available for Windows nodes. Console-based and email-based notifications are available.

- SNORT [10] is an open source intrusion prevention system capable of real-time traffic analysis and packet logging. It uses a rule base similar to a firewall and responds to many types of events such as stealth port scans, buffer overflow attacks, CGI attacks, SMB probes, and OS fingerprinting. Some of the basic rules offered are signature-based while others are anomaly-based.

- Suricata [11] is a free and open source, mature, fast and robust network threat detection engine. The Suricata engine is capable of real time intrusion detection (IDS), inline intrusion prevention (IPS), network security monitoring (NSM) and offline pcap processing. Suricata inspects the network traffic using a powerful and extensive rules and signature language, and has powerful Lua scripting support for detection of complex threats. With standard input and output formats like YAML and JSON integrations with tools like existing SIEMs, Splunk, Logstash/Elasticsearch, Kibana, and other database become effortless. Suricata's fast paced community driven development focuses on security, usability and efficiency.

- Zeek [12] (ex. Bro) is a powerful network analysis framework that consists of event engine and policy scripts. Correspondingly it detects events in the logs and uses the scripts for analysis of the detected events. Among its capabilities are capturing HTTP, DNS, and FTP activity as well as monitoring SNMP traffic.

- The Samhain [13] host-based intrusion detection system (HIDS) provides file integrity checking and log file monitoring/analysis, as well as rootkit detection, port monitoring, detection of rogue SUID executables, and hidden processes. Samhain been designed to monitor multiple hosts with potentially different operating systems, providing centralized logging and maintenance, although it can also be used as standalone application on a single host. Samhain is an open-source multiplatform application for POSIX systems (Unix, Linux, Cygwin/Windows).

- Fail2ban [14] scans log files (e.g. /var/log/apache/error_log) and bans IPs that show the malicious signs - too many password failures, seeking for exploits, etc. Generally Fail2Ban is then used to update firewall rules to reject the IP addresses for a specified amount of time, although any arbitrary other action (e.g. sending an email) could also be configured. Out of the box Fail2Ban comes with filters for various services (apache, courier, ssh, etc). Fail2Ban is able to reduce the rate of incorrect authentications attempts however it cannot eliminate the risk that weak authentication presents. Configure services to use only two factor or public/private authentication mechanisms if you really want to protect services.

- Security Onion [15] is a free and open source Linux distribution for intrusion detection, enterprise security monitoring, and log management. It includes Elasticsearch, Logstash, Kibana, Snort, Suricata, Bro, Wazuh, Sguil, Squert, CyberChef, NetworkMiner, and many other security tools. The easy-to-use Setup wizard allows you to build an army of distributed sensors for your enterprise in minutes!

B. *Malware analysis*

Malware detection has been a field of interest for computer virologists for a long time. In order to address the automated classification of malware based on behavioral analysis, the researchers usually need a virtual machine where they can start and analyze the malware behaviour in all of it aspects like function calls [2].

According to the authors [8], there is a growing number of malware threats worldwide and also the level of technological sophistication of malicious software is increasing mainly due to the popularity of smartphones. This is what makes malware analysis an important task in cyber security. Malware detection systems which detect malicious traffic are usually able to classify threads in the following categories: unclassified (0-day), misc-attack, Trojan-activity, not-suspicious, and misc-activity.

Among the most wide-spread malwares on the Internet as of November 2018 according to [16], there are:

- *Coinhive* – Cryptominer designed to perform online mining of Monero cryptocurrency when a user visits a web page without the user's knowledge or approval, and without sharing the profits with the user.

The implanted JavaScript uses great computational resources of the end users to mine coins and might crash the system.

- *Cryptoloot* – Cryptominer, using the victim's CPU or GPU power and existing resources for cryptomining – adding transactions to the blockchain and releasing new currency. It is a competitor to Coinhive, trying to pull the rug under it by asking a smaller percentage of revenue from websites.

- *Andromeda* – Modular bot used mainly as a backdoor to deliver additional malware on infected hosts, but can be modified to create different types of botnets.

- *Roughted* – Large scale Malvertising used to deliver various malicious websites and payloads such as scams, adware, exploit kits and ransomware. It can be used to attack any type of platform and operating system, and utilizes ad-blocker bypassing and fingerprinting in order to make sure it delivers the most relevant attack.

- *Dorkbot*- IRC-based Worm designed to allow remote code execution by its operator, as well as the download of additional malware to the infected system.

- *Jsecoin* – JavaScript miner that can be embedded in websites. With JSEcoin, you can run the miner directly in your browser in exchange for an ad-free experience, in-game currency and other incentives.

- *Emotet* – Advanced, self-propagate and modular Trojan. Emotet once used to employ as a banking Trojan, and recently is used as a distributor to other malware or malicious campaigns. It uses multiple methods for maintaining persistence and evasion techniques to avoid detection. In addition, it can be spread through phishing spam emails containing malicious attachments or links.

- *Conficker*- Worm that allows remote operations and malware download. The infected machine is controlled by a botnet, which contacts its Command & Control server to receive instructions.

- *XMRig*– XMRig is an open-source CPU mining software used for the mining process of the Monero cryptocurrency, and first seen in-the-wild on May 2017.

- *Nivdort* – Multipurpose bot, also known as Bayrob, that is used to collect passwords, modify system settings and download additional malware. It is usually spread via spam emails with the recipient address encoded in the binary, thus making each file unique.

Among the mobile devices, the authors [16] report the following threats:

- *Triada* – Modular Backdoor for Android which grants super user privileges to downloaded malware, as helps it to get embedded into system processes. Triada has also been seen spoofing URLs loaded in the browser.

- *Hiddad* – Android malware which repackages legitimate apps and then released them to a third-party store. Its main function is displaying ads, however it is also able to gain access to key security details built into the OS, allowing an attacker to obtain sensitive user data.

- *Lokibot* – Android banking Trojan and info-stealer, which can also turn into a ransomware that locks the phone in case its admin privileges are removed.

The three most exploited Common Vulnerability Exposures (CVE) are:

- *Microsoft IIS WebDAV ScStoragePathFromUrl Buffer Overflow* (*CVE-2017-7269*) – By sending a crafted request over a network to Microsoft Windows Server 2003 R2 through Microsoft Internet Information Services 6.0, a remote attacker could execute arbitrary code or cause a denial of service conditions on the target server. That is mainly due to a buffer overflow vulnerability resulted by improper validation of a long header in HTTP request.48% of organizations have dealt with this threat;

- *OpenSSL TLS DTLS Heartbeat Information Disclosure* (*CVE-2014-0160; CVE-2014-0346*) – An information disclosure vulnerability exists in OpenSSL due to an error when handling TLS/DTLS heartbeat packets. An attacker can leverage this vulnerability to disclose memory contents of a connected client or serve that had global impact of 44%.

- *OpenSSL tls_get_message_body Function init_msg Structure Use After Free* (*CVE-2016-6309*) – A use-after-free vulnerability has been reported in the tls_get_message_body function of OpenSSL. A remote, unauthenticated attacker could exploit this vulnerability by sending a crafted message to the vulnerable server. Successful exploitation allows the attacker to execute arbitrary code on the system impacting 42% of organizations

C. *Botnet detection*

Compromised devices in botnets provide attackers with means to send spams, launch distributed denial-of-service (DDoS), run brute-force password cracking, steal private information, and hide the origin of cyber attacks [3], [17]. Malware network traffic can spread rapidly through various platforms and this is what makes botnet detection an important part in cyber security. According to the structure of botnets, two categories exist: P2P and centralized botnet [8]. The P2P botnet, the botmaster can control each bot with distributed commands sent from peers; whereas in a centralized botnet, the centralized Command & Control (C&C) architecture is formed with protocols like relay-chat (IRC) and HTTP.

Network traffic analysis serves for detection of the botnets: the typical approach to detect compromised hosts on the network and filter botnet traffic is to maintain a blacklist of openly available C&C domains. The efficiency is poor because the blacklist has to be updated manually. There are botmasters who often use unchanged P2P-based C&C structures with pseudo random domain generation algorithms to evade the detection by blacklisting and to increase the reliability of the botnet. That is, the bots search for working C&C servers by periodically generating a set of pseudo-random domain names and resolving the generated domain names to IP addresses through DNS queries [18]. Therefore, these botnets can still survive even after some C&C servers are detected and blocked.

Machine learning techniques are vital for the statistical based traffic classification [19]. The traffic can be processed by supervised learning, also known as classification, or by unsupervised learning, also known as clustering [20], [21]. The disadvantage of the Machine Learning approaches for network traffic analysis comes mainly from the lack of online (or as some authors refer to it: real-time) detection capabilities [22]. There are many prerequisites for the successful application of supervised learning [23] with – the most important of which is the annotation of the dataset. This is what makes the unsupervised clustering ML techniques, rule-based and anomaly-based approaches preferable in these scenario.

III. CYBERSECURITY THREAT DETECTION BASED ON DEEP LEARNING TECHNIQUES

The main idea of our current work is to present a linear system for pre-processing of incoming traffic and contents towards cloud applications which serve multimedia (Fig 2). The incoming traffic is analyzed in an IDS and threats are blocked based on rules, anomaly detection and correlation analysis.

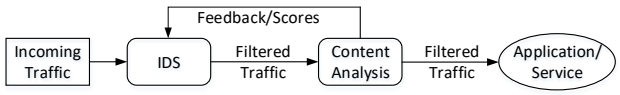

Figure 2. Workflow of the proposed protection cybersecurity protection system for cloud applications

In our experiments we used Suricata and module based on the Google TensorFlow framework for Deep Learning [24]. The IDS filtered traffic is then subjected to content analysis where the traffic is decoded in a proxy server and the incoming text, video and images are analyzed with deep neural network classifiers [25, 26] (Fig.3).

The appearance of large quantities of unstructured (or partially structured data) – the so called Big Data and the improvement of computing power, deep learning has become extremely popular both for research and commercial purposes. Machine learning algorithms are highly dependent on the choice of features. There are described cases with Bayesian classifiers where feature selection can greatly improve classification accuracy [25]. Deep learning techniques solve some of these challenges by automatically combining low-order features of the input, transforming and arranging them in order to calculate high-order features.

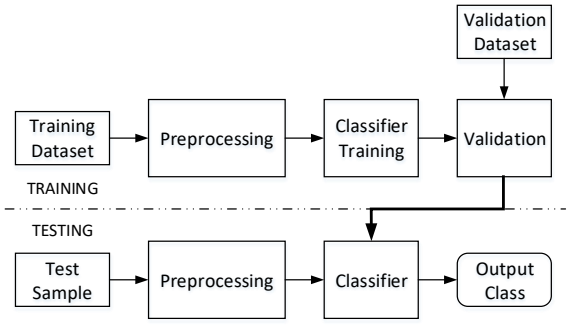

Figure 3. Classifier for network traffic analysis

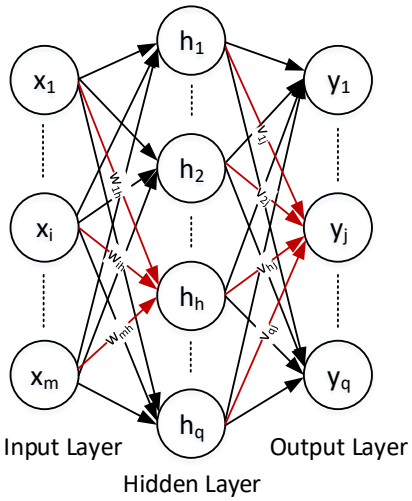

Figure 4. Multi-layer neural network general structure

In such scenario it is not needed to add a manual step to eliminate for calculation of higher-order features of the training set. To an extent, the deep neural network structure is similar to the multi-layer neural network which would include input layer, hidden layer and output layer.

The network parameters are initialized with random values, and the neuron weights are updated using the Back Propagation (BP) algorithm. In the standard neural network schema (Fig. 4), the input for the j-th neuron from the output layer is calculated as follows:

$$o_j = \sum_{h=1}^{q} w_{hj} b_h \,, \tag{1}$$

For the input of the h-th hidden neuron, the following is calculated:

$$\sigma_h = \sum_{i=1}^{m} w_{ih} x_i \,, \tag{2}$$

For the k-th training sample (x_k, y_k), the output of the neural network is $\hat{y}_k = \left(\hat{y}_1^k, \hat{y}_2^k, \hat{y}_q^k\right)$. With another representation known as offset term ε_j, it is given as $\hat{y}_q^k = f\left(o_j - \varepsilon_j\right)$. The aim of the back-propagation training algorithm is aimed to minimize the mean square error of the network on the k-th training sample. It is used for automatic update of the weights of the neural network. The traditional multi-layer neural network increases carries the pitfalls of the disappearing gradient and with the increase in the number of layers, the number of weight parameters is correspondingly increased, leading to a more complex model, and thus to overfit. Deep learning introduced the new activation function ReLU, new weight initialization method, the new loss function, new anti-fitting method (Dropout, regularization, etc.) to solve the traditional multi-layer perceptron disadvantages in the network structure and training.

IV. COMBINING CLASSIFIER RESULTS

The classifier combination in our approach depends on the modality of the cyberthreat in each classifier. The final score is given through:

$$C_{out} = \arg\max(C_i), \quad (3)$$

where C_{out} is the final class label and C_i is the output from the i-th classifier. The final score represents the most certain classifier [27] out of several classificators which use different modalities and learning algorithms.

V. EXPERIMENTAL RESULTS

We have used the Pytbull framework [28] to test the rules in Suricata. The accuracy of the detection with the most current rulesets was about 85%. The test setup included 4 virtual machines in private cloud at the University of Telecommunications and post.

We created a neural classifier using datasets obtained from [29], [30] and modeled a neural network in the Weka [31] tool. The model delivered the highest accuracy of about 83% with 115 inputs and four hidden neuron layers and 11 output neurons. The used dataset was derived from [23] containing 10 types of data with 249 attributes. Some of the classes contain fewer training samples and we have observed other researches who have excluded it from their training set.

Content analysis in terms of Spam detection was realized with a CNN trained in the Weka tool. The model was tested on the dataset [32] and the achieved accuracy in two classes was about 70%. Image classification was based on our previous work [27] on human emotion analysis and is intended to be used on image data uploaded to a transparent proxy on the system. The achieved classification accuracy in 5 classes in about 73%.

VI. CONCLUSIONS

In this paper an approach based on Deep Neural networks for analysis of Cybersecurity threats in cloud applications. The proposed system uses 4 neural classifiers for network traffic, spam comments, spam email and images. The achieved results are comparable with contemporary approaches. The achieved accuracy for the individual components is comparable to contemporary works. In the future we will aim our work at building a comprehensive framework for cybersecurity threat detection in the cloud.

ACKNOWLEDGMENT

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Phishing in Depth – Modern Methods of Detection and Risk Mitigation

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***Abstract* – Nowadays, everyone is living in a digital world with various of virtual experiences and realities, but all of them may eventually cause real threats in our real world. Some of these threats have been born together with the first electronic mail service. Some of them might be considered as really basic and simple, compared to others that were developed and advanced in time to adapt themselves for the security defense mechanisms of the modern digital world. On a daily basis, more than 238.4 billion emails are sent worldwide, which makes more than 2.7 million emails per second, and these statistics are only from the publicly visible networks. Having that information and considering around 60% and above of all emails as threatening or not legitimate, is more than concerning. Unfortunately, even the modern security measures and systems are not capable to identify and prevent all the fraudulent content that is created and distributed every day. In this paper we will cover the most common attack vectors, involving the already mass email infrastructures, the required contra measures to minimize the impact over the corporate environments and what else should be developed to mitigate the modern sophisticated email attacks.**

Keywords - phishing; machine learning; threat;

I. INTRODUCTION

Nowadays, many individuals and small businesses believe that because of their size, hackers aren't interested in them, preferring instead to target bigger companies, with lots of customer and sensitive information. In the not-too-distant past this might have been true, but hacking methods today are quite different [1]. A year from now, at least 43 percent of the cyber-attacks against businesses were targeted at small companies, and today that number is 58 percent and keep increasing. Automated attacks can scour the Internet for unsecured computers with minimal effort on the behalf of the cybercriminals behind the attacks [2]. Once compromised, a computer can be mined for its sensitive information, infected with malicious code that will spread, and even be put into service as part of a botnet – a remotely-controlled network of computers used to infect other machines for greater efficiency.

Most businesses recognize that they need to do something to protect themselves and the sensitive information they hold and process. Traditionally, this has taken the form of erecting defense mechanisms designed to keep the malicious actors out. Firewalls, Endpoint Antivirus software and most commonly Spam filters are the first choice of building layered protection against various types of intrusion. Unfortunately, once an attacker finds their way in, through those defenses, these systems are mostly not capable to do much to protect the corporate data. Regardless the applied standard security measures and the size of the company, the volume and variety of the threats are constantly growing, leading to the conclusion that the risk of being hacked is now changed from "if" to "when."

The phishing attacks are associated with usage of deceiving methods to convince the users to provide their confidential information by masking the email body content, pretending to be a legitimate advertisement, or spoofing an entire Internet web page [3]. Using an email masked as a legitimate message, cybercriminals trick the recipient to open either an infected attachment or hyperlink that takes them to a compromised or intentionally forged malicious website. The goal is to lure individuals to provide their sensitive, personal information, bank accounts, credit card numbers, passwords and not only, and to use them further to get more valuable information [4], as shown below on Fig. 1.

As nowadays, the phishing attacks are becoming more sophisticated and targeted, it is common that even security-savvy people to find themselves eventually a victim.



Figure 1. Phishing email

The more links in the email body, the more likely is the message to be fraudulent, so there are a couple of ways for the users to be certain, that they will not get easily tricked by phishing emails. The first and most important thing for the users is not to open hyperlinks, unless they are sure that email itself is legitimate and it originates from trusted source, which could be identified by following the above-mentioned points. Those users that are more tech-savvy, could check all the hyperlinks contained within the suspicious emails, without opening the links, by utilizing some online platforms that provide real-time link scanning and result from most of the available antivirus solution providers and more robust security analysis, checking the signatures and comparing them against various threat databases, which is tough task to be performed by hand for the small businesses or the regular individuals. Some of these platforms are Virustotal, Metadefender, Hybrid-Analysis, and not only.

If we have to recap, there are solid markers that are able to protect the users of being tricked and to save their personal, corporate or financial information, and still, according to Intel, 97% of people around the world are unable to identify a sophisticated phishing email. This is one of the reasons an automated spam filters are being implemented more and more in the modern corporate world, however they are not 100% effective against the inventive hackers. [5]

II. PHISHING DETECTION METHODS

Despite the technological peaks nowadays, the detection methods for phishing emails are still quite the same, as five or ten years ago.

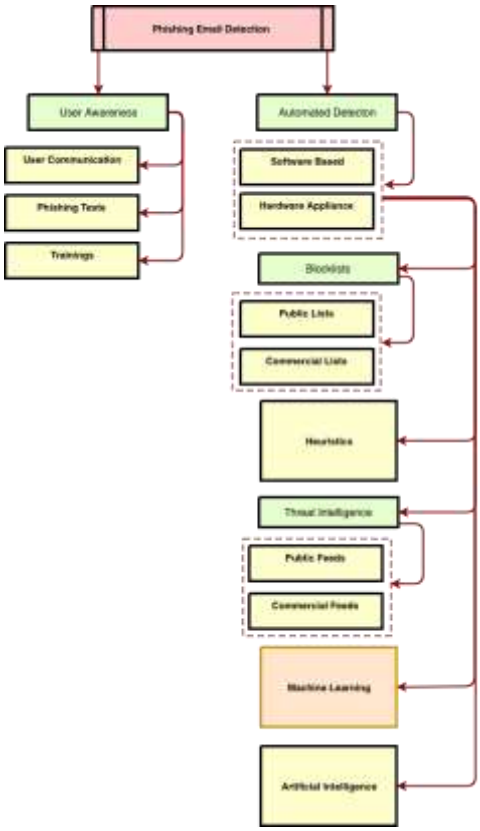

Figure 2. Phishing Detection Approaches

Based on our experience with the used in that area techniques and technologies, the methods are still not changed or replaced, they are just a bit more adjusted to become compliant with the new demands of the modern threats.

If we have to classify the approaches used to detect phishing emails, they could be as per the depicted in Fig. 2. The main two approaches are still User-dependent and Automated, respectively with their subsidiary subdivisions. [6]

A. *User-dependent approach:*

- User Communication is expressed in regular communication related to the potential phishing threats and their most important symptoms and methods to be identified;
- Trainings are required as they would provide the users with practical experience;
- Phishing Tests are mandatory to assess the users' current awareness;

Combined, all of the above three are really crucial for each organization, as if they are being properly planned and executed on a regular basis, this would decrease the potential risk of infection for the organization and will increase the users' awareness for phishing emails [7].

B. *Automated approach:*

- The software-based distributions and hardware appliances are basically performing identical actions, despite the fact that most of the software-based distributions could be used without the need of payed support or license subscriptions and respectively their detection rates are significantly lower;
- Blocklists are widely used by a lot of the security vendors, as a reference and also to offload their processing devices;
- Heuristics analysis are no longer feature of the high-end antivirus solutions, they are now used also to perform analysis over multiple criteria and evaluate potential phishing data;
- Threat Intelligence is also one of the powerful solutions of the modern Anti-Spam systems, however such feeds are still mostly used to be ingested into a Security Incident and Event Management (SIEM) systems;
- Machine Learning (ML) as well as the Artificial Intelligence (AI) technologies are the some of the cutting-edge technologies of our times, having endless applicability. Detecting phishing emails, links are only few of ML and AI application.

All of these mechanisms, regardless if they are implemented as a single solutions or as a single, complex one, are assuring better security and respectively decreasing the risk of financial or other losses for every organization that is about to implement them as a phishing, malware, spam or other detection mechanism.

III. EXPERIMENTAL DATA

Unfortunately, none of the yet available antivirus products could assure 100% or even close rate of detection and prevention, so it might be a good idea to complement their preventive functionalities with some near to real-time retrospective ones. This approach is slightly different, as the logical actions and calculations should be performed post factum. It is known that some of the more sophisticated and targeted phishing attacks could be targeting a few individuals (up to 5 or 10) and this method will probably be slightly ineffective. However, in the wild, majority of the successful campaigns are targeting more individuals, as the chances of someone to be tricked are getting bigger with the increased number of targeted employees. One of the attacker's most preferred ways of distributing phishing emails (which are not been yet detected in the wild) to significant amount of users, through defense systems is by sending the emails on a small portions in time. Using this method allows them a couple of things:

First, to avoid any potential bulk email detection threshold. This mechanism is known as rate control, or the number of connections made to the given Spam Filter in a certain period of time.

Second, to identify if the Spam Filter is detecting their emails as malicious, so they could modify the parameters of the given message, before they schedule massive distribution.

Having that information into account, we may assume that a well-planned attack could take up to two business days in the following scenario. **Company-X** is targeted by a hacking group and precise phishing campaign for 120 employees of the company is planned and forged especially them. In order to deliver the emails, the hackers are sending a couple of the malicious emails and they noticed that the emails are passing through the Spam Filters without being detected, so they proceed scheduling the distribution to the targeted 120 employees. As Company-X is well known service provider, the hackers are scheduling the emails to be sent up to 10 in an hour and only during the company's business hours (ideally from 09:00 to 17:00), in order not to buzz the defense systems. Considering the scenario above, the Spam Filtering will pass the emails to be delivered to the targeted users and no blocking actions will be taken.

To confirm and observe that scenario with real-life data, information for three consecutive months was collected from Spam Firewall, configured to recognize and filter the following categories: certain spam; probable spam; dangerous attachments; phishing; virus and uncategorized.

As the classification algorithms are detecting the most obvious and certain email samples, the more targeted and especially forged ones will not be classified. Due to that reason all email under category Unclassified will subject of our experiment. Three major scenarios were selected and executed in order to achieve three different viewpoints and select the most optimal solution of filtering and displaying appropriate recommendations. Total of 26 625 entries of inbound Uncategorized traffic, with the following parameters was analyzed:

- Timestamp;
- Source IP;
- Recipient;
- Header From;
- Envelope From;
- Subject;
- Size;
- Message ID.

For the purpose of the test, and to simplify the resultant data, only Source IP, Subject and Header From and Recipient fields were used. In the first scenario, all the historical data was sorted by Subjects per Source IP. As a result, the noisiest Source IP Addresses was identified. Having that information on-the-go, it was easy to identify and crosscheck the information with some of the most famous and widely adopted and industry approved online security tools like virustotal, mxtoolbox and not only.

Starting to explore the different Source IP Addresses, quickly showed us that the majority of the detected emails recognized as phishing, were part of phishing test campaigns, internally organized by the given company, but not categorized correctly, which performed a lot of noise in the Spam Filter.

The rest of the noisiest addresses were identified as Marketing and News related emails, which are also really noisy and could cover some malicious emails, trying to mask their selves as such, so if we have to recap, the effectiveness of that test will help to retrospectively identify all noisy sources, and based on really simple checks (which could be automated), recommendations could be issued on a regular basis, so the legitimate traffic will be filtered and handled properly.

In the second scenario, all the historical data was sorted by Subjects per sender name (Header From). That approach helped us to recognize and identify the noisiest senders, according to the Spam Filtering's data:

Having that information, provided us with the flexibility to identify the most suspicious senders, based on the count of messages that are received from these particular senders. Unfortunately, it wasn't as easy as with the IP addresses go gather and analyze the information, however we were able to crosscheck the information that we had with some of the widely adopted and industry approved online security tools like virustotal, mxtoolbox. As a result, the following categories could be furtherly used to train the Spam Filtering device and reduce the noise with approximately 50%.

During the process of recognition and categorization of the senders, a few of them were identified as Suspicious, which means they were previously detected and added to a well-known Spam Blocklists – approx. 5% of the top 10 discovered senders.

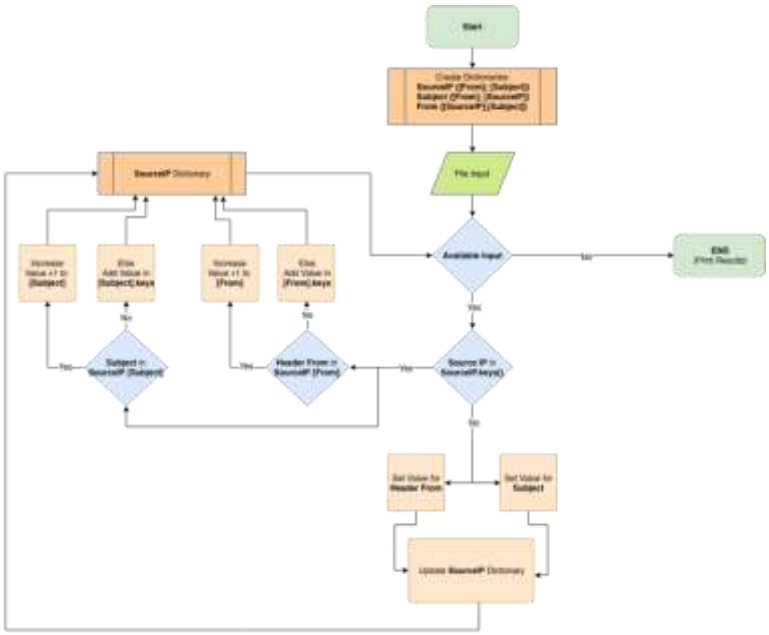

Figure 3. Logical flow diagram of Python script logic for Phishing retrospective detection and post optimization

In the last scenario, all the historical data was sorted by Recipient per received emails (Subject). That approach helped us to mark the recipients that are most likely at risk, concluded based on the amount of emails that they have received during the monitored period. It is considered that they might be at risk, as the amount of emails is assumed to be increased based on the potential user data leakage, individual targeted attack or previous user exploitation. Top probable users at risk, based on Messages Count med to be less effective and efficient than the previous two, as that approach required each of the email's entries of the top 10 users to be individually investigated. Even if the required time is spent for proper investigation or automation of that process, the potential value of that would be probably less than 1%.

Due to that, more efficient approach could be utilized. If the first two scenarios are executed for at least once, the amount of email noise will be significantly reduced. Then, the data could be sorted by Recipient and the result will be definitely more reliable and valuable.

IV. IMPROVEMENT POINTS

Instead of doing all these sophisticated actions by hand, these processes could be performed by script, or even could be built into the modern protection solutions as part of their reporting or detection and response modules. A simple Python script with the following logic (depicted in Fig. 3) has been developed, providing a tuple of the top source addresses and the number of the emails send by them.

V. CONCLUSIONS

If we have to sum up, none of the existing Anti-Spam Filtering solutions invented so far are able to ensure 100% effectiveness against Spam, Phishing or other malicious emails. Considering this, additional measures are mandatory. Based on the performed analysis described above, collecting historical email data, sorting it by the Subject property of that date and analyzing it would drastically increase the effectiveness of the given Anti-Spam system and will decrease the risk of malicious infection or organizational losses, especially if that analyzes are performed on automated and regular schedule. However, for better effectiveness, efficiency and resource optimization, the automated execution of such measures is significantly preferred.

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Sklopovska i programska provjera primitivnosti binarnih polinoma

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***Sažetak* - U ovome radu opisujem *metodu* određivanja *m*-nizova posmičnim registrom s povratnim vezama za registre do 31 stanja, paralelno koristeći Galois načelo, C^{++} programe i simulacijski alat Logisim 2.7.1. Tablično prikazani rezultati istraživanja, upućuju na mogućnost smanjenja vremena obrade i programske pristupe računanju primitivnih polinoma. Za navedene obrade, napravio sam programe primjenjujući *permutacije* odnosno *varijacije* s ponavljanjem od 2 elementa pripadnoga razreda. Grafičkim programskim alatom, potvrdio sam programski ostvarene rezultate (brojevni razredi do 31 bita). Zbog povećanja brzine obrade *m*-nizova, primijenio sam C^{++} programske strukture na razini bitova. Na istim sustavnim načelima mogu se obrađivati polinomi s više od 31 stanja koristeći duže vrste podataka. Zbog bolje razumljivosti, predlažem nove načine označavanja binarnih polinoma i algoritme obrade podataka posmičnim registrom (Galois/Fibonacci). U obradu podataka, osim obrade *m*-nizova, uključio sam množenje i diobu binarnih polinoma te izračun FCS na prije naznačenim programskim i sklopovskim (simulacijskim) načelima. Za tu namjenu, simulacijski alat Logisim nadopunio sam novim vrstama pod-sklopova. Preinačio sam i automatizirao LFSR sklopove za istovremen rad multiplikacijskoga i adicijskoga sklopa LFSR što dodatno potvrđuje točnost dobivenih rezultata. Posmični registar temelj je svih modernih (tele) komunikacijskih mreža i uređaja te sastavni dio kodera i dekodera za sve FEC kodove (blok, konvolucijski i turbo). Ciklički kodovi su podskup navedenih skupina i ovdje nisu predmet mojih istraživanja.**

Ključne riječi - nizovi maksimalne dužine (MLS), posmični registar s povratnim vezama (LFSR), Fibonacci (adicijsko) i Galois (multiplikacijsko) načelo

I UVOD

Sve vrste binarnih kodova za ispravak pogrešaka prema naprijed, FEC (*Forward Error Correction*) koriste posmične registre. U radu se ne opisuje niti jedna podvrsta kodova (npr. ciklički kodovi). Klasičan način uporabe binarnih polinoma iz tabličnih podataka, ima nekoliko nedostataka. U znanstvenoj i stručnoj literaturi, primitivni (nedjeljivi) binarni polinomi prepisuju se desetljećima. Ne postoji jednostavan i sustavan programski alat provjere nedjeljivosti (*primitive*) binarnih polinoma. Veliki brojevi i njihove duge vremenske obrade obeshrabruju istraživače. Središte takvih istraživanja su nizovi maksimalne duljine (*m*-nizovi). Vrijeme provjere, generira li cjelobrojna potencija *n* konačno polje $GF(2^n)$, usporava se linearno porastom potencije *n* do reda veličine 200, a zatim je taj porast eksponencijski [10]. Berlekamp-Massey algoritmom [3] određuje se linearna složenost konačnoga binarnog niza. Dobar pseudo-algoritam za klasičan postupak određivanje nedjeljivih binarnih polinoma opisao je Abhijit Mitra u [2]. Nekoliko algoritama za provjeru primitivnosti može se pronaći u [7]. Pseudo algoritmi provjere nedjeljivosti binarnih polinoma opisuju se u [1] i [9]. Literatura u ovome području brojna je i iscrpna, ali bez konkretnih programskih rješenja.

Za generiranje *m*-nizova, odgovarajuće programske alate izradio je Sean Erik O'Connor [6], ali uz složene postupke rukovanja njima. Dva programska alata napravili su A. Asimi i A. Lbekkouri [1] ali im rezultati nisu cjeloviti. Iz teorije brojeva poznate su metode određivanja primitivnih binarnih polinoma: Eulerova Ψ funkcija, Fermatov *Little Theorem*, Rabin-Millerova metoda te metoda određivanja primitivnosti polinoma ispitivanjem pripadnih *m*-nizova [2]. Posljednju metodu koristio sam u ovome radu s ciljem brze provjere nedjeljivosti bilo kojega binarnog polinoma. Postigao sam dvostruko manji računalni gubitak $O(2^n)$ u usporedbi s gubitkom $O(2^{2 \cdot n})$ standardnih postupaka algoritma predloženoga u [3]. Primjenu podataka na razini bitova i različite brzine rada C^{++} programa, analizirali su Pieterse, Watson i Cleophas u [10].

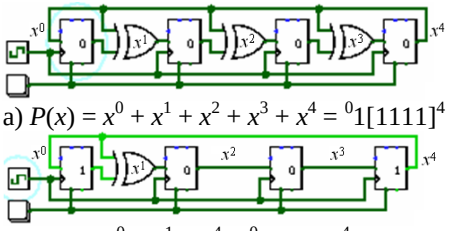
Struktura rada je sljedeća. Odjeljak II opisuje značaj primitivnih polinoma za oblikovanje LFSR (*Linear Feedback Shift Register*) strukture. Odjeljak III opisuje matematičku metodologiju glavne teorije. Sklopovske rezultate opisuje odjeljak IV. U odjeljku V opisujem i programska rješenja i postignute numeričke rezultate. Odjeljak VI opisuje ujednačenje sklopovske i programske primjene. Zaključke sadrži odjeljak VII.

II ODREĐIVANJE PRIMITIVNIH BINARNIH POLINOMA ZA STRUKTURE LFSR

Osnovni problem obrade podataka posmičnim registrom s povratnim vezama LFSR za *m*-nizove MLS (*Maximal Length Sequence*), jest priskrba opisa njegove strukture binarnim polinomom. Za obradu *m*-nizova koriste se primitivni binarni polinomi. To su nedjeljivi polinomi čiji članovi uz nultu i maksimalnu potenciju imaju koeficijente 1. Ako se polinom prikazuje kao redni vektor, ti jedinični članovi polinoma smješteni su na njegovoj lijevoj i na desnoj strani, a omeđuju ga potencije označene x^0 i x^{max}. Potencija x^{max} definira broj stanja, a potencija x^0 predstavlja povratnu vezu s izlaza na ulaz LFSR. Detalji primjene jednoga od 2 osnovna načela (*adicijsko* i/ili *multiplikacijsko* načelo), opisao sam (projekt LFSR) u tridesetak objavljenih i javno dostupnih radova [13].

Matematički način označavanja binarnih polinoma općenito se opisuje kao $P(x) = x^0 + x^1 + x^2 + \ldots + x^{n-1} + x^n$. Ispred varijable *x* pretpostavlja se koeficijent 1 i ne piše ga se. Ako je neki koeficijent 0 onda se ne prikazuje ni sam član polinoma, jer je umnoškom jednak 0. U vektorskome prikazu binarnoga polinoma pišu se svi koeficijenti (0 ili 1) uz članove pa se dobije binaran broj. Obzirom da ovi polinomi predstavljaju strukture

posmičnoga registra, koeficijenti prvoga i zadnjega člana su jedinice. Opis strukture sadrži prikaz povratnih veza s izlaza prema ulazima u jedinične registre LFSR uz priključke EXOR (*EXclusive OR*) vrata. Slika 1 prikazuje takav, cjelovito ožičen registar.



a) $P(x) = x^0 + x^1 + x^2 + x^3 + x^4 = {}^0 1[1111]^4$

b) $P(x) = x^0 + x^1 + x^4 = {}^0 1[1001]^4$

Slika 1. Posmični registar s povratnim vezama

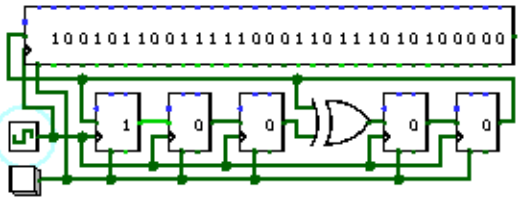
Posmični registar s potpunim skupom povratnih veza na slici 1a, spojen je u načinu rada *množenja* binarnih polinoma. Da bi ostvario bilo kakvu suvislu funkciju, kao što su stvaranje *PN*[1] niza, *m*-niza, množenje i dijeljenje binarnih polinoma, kodiranje i dekodiranje, FCS[2], itd.…, ovu shemu treba preurediti prema strogo zadanim matematičkim pravilima. To znači da se moraju preurediti i broj i položaji EXOR vrata odnosno povratne veze. Za primjer *m*-nizova[3] s 4 stanja, u razredu postoje dvije različite (simetrične) strukture [10011] i [11001]. Ako se najniža i najviša potencija ni ne označe, zbog same simetričnosti vektora u ovome primjeru ne može se napraviti pogreška. Za sve veličine LFSR (broj stanja), svaki polinom koji generira *m*-niz ima svoj obrnuti (*reverse*) polinom.

Izraz $x^n = 2^4 = 16$ ujedno je i formula za izračun broja varijacija s ponavljanjem od 2 elementa (x) 4. (n) razreda (uključuje stanje sve "0"). Stanje registra sve "0" za LFSR je posebno, jer se iz njega ne može izaći niti se u njega može ući. LFSR ima svojstvo da se nakon izmjene svih različitih stanja, vraća u početno stanje. Treba naglasiti još jednu značajku - vrijednost *m*-niza ne ovisi o početnome stanju LFSR. Izlaz iz 4. jediničnog registra nema EXOR vrata ali "1" simbolički predstavlja povratnu vezu s izlaza na ulaz i u vektoru je naznačuje "1" sasvim desno (izvan zagrade). Binarni brojevi u pravokutnim zagradama predstavljaju stanja unutarnjih registara LFSR. Ovakvo označavanje nužno je zbog matematičkoga opisa rada LFSR C^{++} jezikom na razini bitova (u nastavku rada). Unutarnja stanja prikazanoga LFSR prikazuje tablica I.

TABLICA I. VARIJACIJE S PONAVLJANJEM OD 2 ELEMENTA 4. RAZREDA

~~0000~~	~~0001~~	~~0010~~	~~0011~~	~~0100~~	~~0101~~	~~0110~~	~~0111~~
~~1000~~	1001	~~1010~~	1011	~~1100~~	1101	~~1110~~	1111

Da bi se dobile sve (moguće) strukture LFSR s 4 stanja iz prethodnoga primjera, potrebno je analizirati strukturu LFSR od 5 stanja (ili općenito za 1 stanje više). Slika 2 prikazuje takav LFSR koji generira *m*-niz od 31 stanja (2^5–1, bez stanja sve "0") uz sva ostala moguća stanja. Dakle za primjer LFSR na slici 1, varijacije s ponavljanjem od 2 elementa 5. razreda sadrže sve *strukture* posmičnoga registra, a korisne su samo one koje u binarnome prikazu započinju i završavaju brojem "1". Generira ih LFSR na slici 2.



$P(x) = x^0 + x^3 + x^5 = {}^0 1[00101]^5$

Slika 2. LFSR s 5 stanja za generiranje *m*-niza od 36 bitova

Slika 2 prikazuje LFSR koji vektorom ${}^0[10010]1^4$ generira *m*-niz (ili pseudo slučajan šum) od 36 bitova [100101100111110001101110101000000], što jamči da je polinom primitivan. Struktura ovoga LFSR nalazi se u sljedećem skupu stanja od 6 binarnih znamenaka odnosno u rasponu brojeva od 0x41 do 0x7F i podliježu istim zakonitostima kao i prethodne skupine (0x5-0x7, 0x9-0xF, 0x11-0x1F, 0x21-0x3F). U svakoj brojčanoj skupini, LFSR ima jednak broj memorija, a svaka sljedeća skupina veća je od prethodne skupine za 1 memorijsko mjesto. Rezultat rada LFSR na slici 2 je generiranje *m*-niza, a sva njegova unutarnja stanja (ukupno 2^5) prikazuje tablica II.

TABLICA II. SVIH 32 STANJA POSMIČNOGA REGISTRA NA SLICI 1B

~~00000~~	~~00001~~	~~00010~~	~~00011~~	~~00100~~	~~00101~~	~~00110~~	~~00111~~
~~10000~~	~~10001~~	~~10010~~	10011	~~10100~~	10101	~~10110~~	~~10111~~
~~01000~~	~~01001~~	~~01010~~	01011	~~01100~~	01101	~~01110~~	~~01111~~
~~11000~~	~~11001~~	~~11010~~	11011	~~11100~~	11101	~~11110~~	~~11111~~

U skupu dobivenih stanja, nalaze se (barem) dvije strukture (paran broj) za LFSR od 4 stanja odnosno nedjeljivi binarni polinomi (*primitive*). To je nužan[4] uvjet stvaranja *m*-niza. Pripadni *m*-niz (za LFSR od 4 stanja) je 0000111101011001000 i sadrži sva stanja ako se pojedinačno promatra prozorom širine 4 bita, a prozor se pomiče svaki put u desno za 1 korak. Polinomi koji se dobiju kao stanja LFSR višega stupnja, predstavljaju *strukture* LFSR nižega stupnja.

Niti jedan od vektora u prvome retku tablice nije kandidat za strukturu LFSR, jer svaki započinje "0" pa su svi elementi retka precrtani. Za opis strukture LFSR od 4 stanja (slika 1) raspoloživo je 8 vektora (polinoma) u drugome retku. Pri tome vektori mogu imati 3, 4 ili 5 spojeva (priključnih točaka). Samo vektori s neparnim brojem spojeva (sve "1" u vektoru) jesu strukture za moguće generiranje *m*-nizova, a njih ima 4. Od ta 4 vektora, vektori ${}^4[0101]1^0$ i ${}^4[1111]1^0$ nisu primitivni polinomi tj. generiraju periodičke nizove kraće od *m*-niza. Vektori (primitivni polinomi) [10011] i [11001] su jedina 2 polinoma za strukture LFSR od 4 stanja što generiraju *m*-nizove i oni su osno simetrični (*reverse*).

Od 8 brojeva u donjemu retku tablice II, 3 broja završavaju "0" pa ni oni ne mogu biti kandidati za strukture LFSR. U tablici I u binarnome broju ima samo 4

[1] PN … *Pseudo Noise* (*pseudo-slučajan*) šum

[2] FCS … *Frame Check Sequences* niz za provjeru okvira

[3] *m*-nizovi su primitivni binarni nizovi točno određene dužine, čije se binarne cjeline ponavljaju nakon što LFSR izmijeni sva različita stanja u svojim jediničnim registrima (bez stanja "sve 0") te se nakon toga vrati u svoje početno stanje.

[4] Nužan uvjet da bi binaran polinom $P(x)$ bio primitivan (*irreducible*) nad $GF(2)$ jest $x^{2^m} = x \bmod p(x)$.

binarne znamenke. Dakle, skup stanja koja generira LFSR s 4 registra može opisati strukture LFSR od 3 stanja. Analogno, strukture LFSR s 4 stanja mogu opisati stanja koja generira LFSR od 5 stanja (2^5). Ovo je osnovna ideja primjene *varijacija s ponavljanjem* za generiranje svih struktura LFSR računalom (od 2 do 31 stanja i iznad toga). Za rubna stanja od 31 bita, 32. rubni bit ("1") koristi se za opis povratne veze.

U ovome radu, istraživanja i njihovi rezultati usmjereni su metodi generiranja strukture LFSR što je novina u odnosu na sve dosadašnje opisane metode u obilnoj i bogatoj literaturi posljednjih 70-tak godina npr. [3]. Jedinstvenost pristupa je u činjenici da se razlikuju opis strukture LFSR i broj njegovih stanja, jer se struktura opisuje polinomom koji ima broj članova za 1 veći od broja stanja. Upravo ovo temelj je novoga pristupa u stvaranju strukture LFSR i njegove uporabe za stvaranje *m*-nizova (brzo programsko *nalaženje primitivnoga polinoma* odgovarajućih svojstava), *dijeljenje* ili *množenje* binarnih polinoma, stvaranje binarnoga niza za *provjeru podatkovnoga okvira pri prijenosu podataka* FCS (*Frame Check Sequence*), kružnu provjeru zalihosti CRC (*Cyclic Redundancy Check*) ili uporabu u sustavima *pristupa kanalu* CDMA-ca (*Code-division multiple access - Collision Avoiding*). Posmični registar LFSR koristi se u kriptografiji ali to za sada nije predmet mojih istraživanja.

Izvornost ovakvoga pristupa podupire korištenje C^{++} jezika u stvaranju potrebne programske podrške. Pri tomu, težište je na korištenju razreda <**vector**> i <**bitset**> te logičkih operatora na razini bitova ("**&**", "|", "^", "~", "<<" i ">>").[8] Ovime se postupak obrade maksimalno ubrzava. Također, primijenio sam matematičke zakonitosti o kompleksijama: permutacije (*permutation*), kombinacije (*combination*) i varijacije (*power set*) u kreiranju potrebnih skupina nizova. Iz dobivenih rezultata [13] vidi se da u ukupnome skupu binarnih polinoma, ima značajno manje (za red veličine) primitivnih polinoma u odnosu na ne-primitivne (djeljive) polinome.

III KOMPLEKSIJE (KOMBINATORIKA)

"Kompleksije" su zajednički naziv za sustavno i organizirano baratanje nizovima (binarnih) podataka. U obradi strukture LFSR u radu [4, 325049518][5], opisujem primjenu *varijacija*, *kombinacija* i *permutacija* s ponavljanjem.

A. Kombinacije

Kombinacije bez ponavljanja od *n*-elemenata ($n = 5$) *r*-toga stupnja ($r = 3$) (skupine od *r*-članova). Elementi: *a*, *b*, *c*, *d*, *e* tvore sljedeće kombinacije, a njihov broj određuje jednadžba (1), a u ovome primjeru ima ih 10:

abc, *abd*, *abe*, *acd*, *ace*,
ade, *bcd*, *bce*, *bde*, *cde*.

$$K_n^r = \binom{n}{r} = \frac{n!}{r!(n-r)!} = \binom{n}{n-r} \qquad (1)$$

Kombinacije s ponavljanjem su kombinacije u kojima se pojedini elementi ponavljaju. Ako su elementi: 1, 2, 3, 4, onda se kombinacije trećega razreda ($r = 3$) od 4 elementa ($n = 4$) dobiju jednadžbom (2) i ima ih 20.

$$K_n'^r = \binom{n+r-1}{r} = K_{n+r-1}^r = \frac{(n+r-1)!}{r!(n-1)!} = \frac{\prod_{k=n}^{n+r-1} k}{r!} \qquad (2)$$

Na primjer, niz $^{max}[101101001]^0 = 101101001_2$ predstavlja binaran vektor, a "1" naznačuje navedena mjesta spojeva EXOR vrata s dva ulaza. Na jedan ulaz spaja se povratna veza, a na drugi spaja se izlaz iz unutarnjega stanja LFSR. Izlaz iz EXOR vrata spaja se na ulaz sljedećega unutarnjeg registra LFSR. Članovi polinoma s koeficijentima "0" predstavljaju težinska mjesta u vektoru, ali nisu spojeni na EXOR vrata. U ovome primjeru jednoznačno se opisuje brojanje u vektoru (polinomu) s desna u lijevo $^{max}[\ldots]^0$. Vektor ima 9 binarnih znamenaka i predstavlja binaran broj. On se također ravnopravno može prikazati heksadekadski 0x169 (ili 169_{16}), dekadski 361_{10} ili oktalno 551_8 (ili 0551). U ovih 9 binarnih znamenaka, prva znamenka desno "1" ima težinu x^0. Prva znamenka lijevo "1", (u ovome primjeru) ima težinu x^8. Za dobiti sve vektore navedenih svojstava i određenoga razreda, koristim varijacije.

B. Varijacije

Varijacije su kombinacije bez ponavljanja čiji se elementi međusobno permutiraju. Varijacije od 2 elemenata *r*-toga razreda, znači na sve moguće načine svrstati ta 2 elementa u skupine od po *r*-članova time da skupine sadrže i jednake članove. Kao matematički alat, one su veoma prikladne za opis strukture LFSR. Njihovo svojstvo je da "1" prikazuju mjesta priključaka vrata izričito "ILI" (EXOR) odnosno mjesta priključaka povratnih veza posmičnoga registra. Takav opis vektora započinje i završava brojem "1" (binarna mjesta u vektoru sasvim lijevo i sasvim desno). Ovako organizirane skupove "0" i "1" matematički opisuju varijacije s ponavljanjem od 2 elementa zadanoga razreda. Dakle od ukupnoga broja raspoloživih varijacija, koristi se samo 50% varijacija (one koje započinju brojem "1"). Odmah se može zaključiti da opis strukture LFSR tvore samo neparni brojevi što za 50% preostalih varijacija dodatno smanjuje broj raspoloživih varijacija za opis strukture, a to znači samo 25% od ukupnoga broja varijacija.

Dodatno ograničenje je paran broj "1" u binarnome vektoru, a povezano je kraćenjem polinoma. Dakle od ukupnoga broja od 16 varijacija, samo njih 1/4 (=4) zadovoljavaju uvjete za tvorbu strukture LFSR. Ali, nisu sve 4 varijacije prikladne za tvorbu strukture LFSR za generiranje *m*-nizova. Nužan uvjet je da vektorski prikazani polinomi moraju biti *primitivni* (nedjeljivi). Međutim, primitivnost i nedjeljivost su 2 uvjeta (nužan i dovoljan) za dobivanje *m*-nizova.

Upravo, istraživanje primitivnosti raspoloživih prikladnih polinoma za sve varijacije od 2 elementa do 31. razreda (kao obrazac) problem je čije se moguće rješenje opisuje u ostatku ovoga rada. Napominjem da se 32. bit ovih polinoma koristi za oznaku povratne veze LFSR i ne može se koristiti kao 32. stanje LFSR. Potpuno jednaka načela vrijede za ostale skupine polinoma (64. bit, 128 Za primjer vektora 101101001_2, samo 8 znamenaka predstavljaju 8 stanja LFSR, a sve "1" osim 1. jedinice sasvim lijevo, mjesta su spojeva EXOR vrata u povratnim vezama. Jedinica ("1") sasvim lijevo također se ubraja u

[5] Oznaka [4,123456789] … [redni broj literature, poveznica na web stranicu Researchgate].

povratnu vezu ali ona simbolički, samo je fizički spoj izlaza natrag prema ulazu pri primjeni *multiplikacijskoga* načela. Osim ovoga načela postoji i *adicijsko* načelo spajanja LFSR (tzv. Fibonacci) što u priskrbi rezultata nadopunjuje Galois načelo. Razlika između njih je u smjeru nizanja prikupljenih podataka i u sklopovskoj prikladnosti spajanja određenoga sklopa (vanjske povratne veze) [4, 325046149], jer su u binarnoj matematici *zbrajanje* i *množenje* iste operacije.

Za ovaj primjer vektora od 9 bitova, stanja simboliziraju prvih 8 znamenaka brojeći ih s desna u lijevo. Uvodim sljedeći opis strukture LFSR $^{max}1[\ldots1]^{0}$. Uočite prvu "1" sasvim lijevo koja je izdvojena (izvan pravokutne zagrade), jer ne predstavlja stanje LFSR nego samo njegovu povratnu vezu. Ovakvo označavanje trebalo mi je za izgradnju algoritama na razini bitova. Također upozoravam čitatelja da se zabunom često miješa prikaz stanja LFSR s prikazom njegove strukture. Detalji se mogu pronaći u radovima koje sam publicirao na WEB stranicama *Researchgate* [12] i *Academia.edu*.

Ukupan broj varijacija s ponavljanjem od 2 elementa (0 i 1) 8. razreda (skupine od 8 članova-binarnih znamenaka), računa se formulom (3).

$$V_n^{'r} = n^r \tag{3}$$

Ukupna količina varijacija jednaka je 1/4 mogućih varijacija. Unutar toga skupa kriju se djeljivi i nedjeljivi polinomi koje treba razlučiti. Programsku obradu varijacija C^{++} jezikom ostvaruje nekoliko jednostavnih funkcija. Te funkcije su:

(a) provjera, analizira li se *m*-niz:

```
while(r!=1){n++;r<<=1;if(r&t)r^=torp;}
```

(b) programska petlja koja ispituje polinome unutar istoga broja registara LFSR: uzima gornju granicu raspona brojeva u heksadekadskome obliku 1, 3, 7, F, 1F, 3F, 7F, FF, 1FF, 3FF, 7FF, FFF, 1FFF, …. Donje granice su: 1, 2, 4, 8, 11, 21, 41, 81, 101, 201, 401, 801, … (sve do vektora dužine 32 bita, odnosno vrste podataka od barem 4 Byte).

(c) određivanje obrnutih (reverse) polinoma:

```
for(j=1;j<reg;j++)if(p&((u
int)1<<j))i|=(t>>j);i=i|t;
```

(d) pretvorbe brojeva među osnovnim brojevnim sustavima: [4, 330853869]

```
if(hd=='h')stringstream stream;cin>>hex>>piq;

if(hd=='d')cin>>dec>>piq;

if(hd=='b')if(p_bin.size()<=32){piq=bitset<32>
(p_bin).to_ulong();}

if(hd=='o')stringstream stream;

cin>>p_oct;istringstream(p_oct)>>oct>>piq;
```

Programski detalji i sami programi obrade primitivnih polinoma, slobodno, javno i legalno dostupni su na mojoj stranici [13]. Osim skupina brojeva, program može pojedinačno ispitivati polinome. Rezultati se ispisuju na predočniku i u log datoteku. Ako se umjesto čitavoga binarnoga polinom-vektora ispituje sam "unutarnji" dio bez rubnih "1", onda je prikladan alat ispitivanja - *permutacije*.

C. *Permutacije*

Analize struktura polinoma mogu se ubrzati za 4 i više puta ako se primijene permutacija s ponavljanjem od 2 elementa (0, 1) time da se svaki element ponavlja zadani broj puta. Za vrstu podataka od 4 Byte, ukupan broj elemenata je 30, ne računajući rubne jedinice. Minimalno se može analizirati jedna "1" između dviju krajnjih, koja se permutira maksimalno 30 puta (30, 1). Ostale parove permutacija prikazuje tablica u [4, 330854319]. Korištenjem ove metodologije ispitivanja primitivnih polinoma, dodatno smanjuje broj analiziranih binarnih vektora za 2 reda veličine (odnosno četverostruko) tj. vrijeme obrade je proporcionalno $O(2^{n-2})$. Permutacije su posebno zanimljive s matematičkoga motrišta. Naime, broj permutacija računa se prema jednadžbi (4).

$$P_n^{'\alpha} = \frac{n!}{\alpha!} = \frac{7!}{3!\cdot 4!} = \frac{1\cdot 2\cdot 3\cdot 4\cdot 5\cdot 6\cdot 7}{1\cdot 2\cdot 3\cdot 1\cdot 2\cdot 3\cdot 4} = \frac{5040}{6\cdot 24} = \frac{5040}{144} = 35 \tag{4}$$

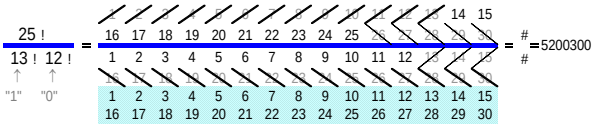
Korištenjem faktorijela u izračunu i za potrebe određivanja primitivnih polinoma, ovakvo računanje *brojnika*, *nazivnika* i *kvocijenta* za velike brojeve, ubrzo postaje nemoguće. Potreban je algoritam koji racionalizira takav izračun, a opisao sam ga u brojnim programskim rješenjima [4, 330854215].

D. *Faktorijel*

Iz toga razloga u pripadnome C^{++} programu 4330854319 primijenio sam algoritam za faktorizaciju *brojnika* i *nazivnika* prema jednadžbi (4).

```
for(unsigned i=0,j=0;i<V.size();)for(unsigned
n=0;n<N.size();i++,j=0){//nazivnik
if(V.at(i)==0)j=1;for(unsigned
k=0;k<V.at(i)+j;k++,n++){N.at(n)=k+1;}}
```

Nakon toga, primijenio sam algoritam za skraćenje broja množitelja u brojniku i u nazivniku, što množitelje u nazivniku svodi na umnoške samih jedinica. Ono što preostane u brojniku jeste *količnik* i taj broj predstavlja broj permutacija. Za ad hoc potrebe dovoljan je i "priručni" Excel kalkulator, a prikazuje ga slika 3.



Slika 3. Excel kalkulator za računanje broja permutacija binarnih polinoma

Kalkulator sam napravio kao vizualan alat prema istim, prije navedenim načelima. Broj permutacija dobiva se upisom odnosa između brojeva "1" i "0" u polinomu, a onda kraćenjem jednakih pribrojnika i u brojniku i u nazivniku. Kalkulator zadovoljava sve permutacije s ponavljanjem do 32 bita u polinomu.

IV OBRADA VELIKOGA BROJA M-NIZOVA PERMUTACIJAMA

A. *"Klasične" metode određivanja primitivnih binarnih polinoma programskim jezikom*

Klasičnu programsku obradu primitivnih polinoma uz smanjenje složenosti vremena obrade, opisao je Abhijit Mitra u [2]. Predložio je dvije jednostavnije programske metode ali na razini obrade polinoma. Programski podržane obrade opisao je i O'Connor u [6] također polazeći od polinoma. U ovome radu predlažem primjenu

metode *m*-nizova za određivanje primitivnosti (nedjeljivosti) binarnih polinoma prikazavši ih kao vektore. Jedinice ("1") u vektorskome prikazu polinoma predstavljaju priključne točke LFSR pa je stoga, važno poznavati smjer porasta potencija varijable.

B. *Prijedlog nove metode određivanja primitivnih binarnih polinoma*

Na temelju prethodnih opisa i ostvarenih rezultata predlažem: *a*) pojedinačno ispitivanje primitivnosti binarnih polinoma; *b*) traženje skupa primitivnih binarnih polinoma; i *c*) popis djeljivih binarnih polinoma, korištenjem varijacija s ponavljanjem od 2 elementa određenoga razreda. Također, predlažem korištenje permutacija s ponavljanjem s ciljem smanjenja vremena pretrage i analize takvih polinoma za 2 reda veličine. Prijedlozi su materijalizirani u programima i opisani u radovima s DOI brojem, koje sam objavio u [4, 325479080, 325479004].

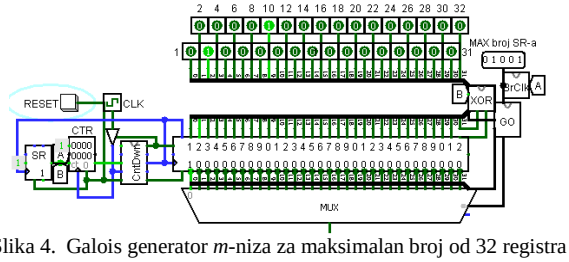
V SKLOPOVI ZA ISPITIVANJE M-NIZOVA

Programski alat Logisim 2.7.1. veoma je prikladan alat (Java) za osnovne simulacijske potrebe. Omogućio mi je tvorbu vlastitih razvojnih sklopova za (međusobnu) provjeru dobivenih rezultata (programski ↔ sklopovski). Rezultati se odnose na matematičke operacije *dijeljenja* dvaju binarnih polinoma, *množenja* dvaju binarnih polinoma i računanje FCS niza. Naročito su značajni osmišljeni sklopovi zbog brzoga preoblikovanja potrebnih sklopova. Također sam riješio osnovni problem multiplikacijskoga načina spajanja jediničnih sklopova posmičnoga registra, ako se EXOR vrata serijski spajaju između unutarnjih registara (Galois) odnosno paralelno na njihove izlaze (Fibonacci).

1) *Sklop za generiranje m-nizova* Ako se često i brzo mora promijeniti oblik probnoga sklopa, baratanje komponentama simulacijskoga alata Logisim 2.7.1. nije prikladno. Za te namjene izgradio sam automatizirane sklopove u istome (Logisim) okruženju. Osnovne sklopove primjene, prikazuju, slika 4 (Galois) [4, 324994792] i slika 5 (Fibonacci) [4, 324922928] načelo.

A. *Stvaranje m-nizova primjenom Galois načela*

Galois sklop je posmični registra s *unutarnjom* povratnom vezom LFSR. Njegovo osnovno svojstvo (i problem) je potreba brzoga oblikovanja i preoblikovanja sheme posmičnoga registra združenoga s izričito ILI (*Exclusive OR*) vratima u povratnoj vezi, postavljenih između memorijskih stanja. Problem je naročito izražen pri stvaranju simulacijskih krugova različitih maksimalnih potencija polinoma (različitoga broja stanja LFSR). Za različite primitivne polinome trebaju se simulirati *m*-nizovi (nizovi maksimalne duljine). Rad ovoga sklopa (slika 4) detaljno sam opisao u [4, 325474261].

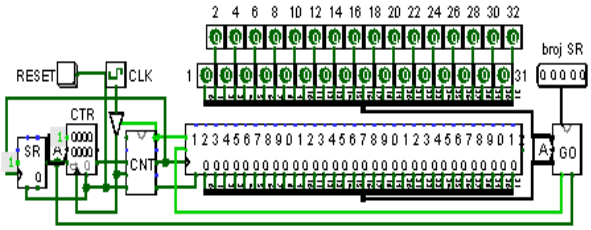


Slika 4. Galois generator *m*-niza za maksimalan broj od 32 registra

Treba samo odabrati željeni broj stanja LFSR združenih s EXOR vratima te tako opisati primitivan polinom. Na temelju rednoga broja maksimalno odabranoga stupnja polinoma, automatski se određuje potreban broj taktova. Registar iz početnoga stanja "100…0", prolazi kroz sva različita stanja i ponovno se vrati i zaustavi u isto početno stanje. To je *nužna* potvrda ispravnoga prolaska kroz sva različita stanja. Broj takvih varijacija računa se prema izrazu (3). Za *dovoljnu* potvrdu ispravnoga rada, sklop automatski određuje i postavlja odgovarajući brojač. Ukupna dužina takvoga niza računa se prema izrazu: $2^n+(n-1)$, a obuhvaća i stanje "sve 0". Ukupna dužina takvoga niza računa se prema izrazu: $2^n+(n-1)$, a obuhvaća i stanje "sve 0".

B. *Sklop za stvaranje m-nizova primjenom Fibonacci načela*

Na sličan način kao i sklop koji koristi Galois načelo, napravio sam sklop za primjenu Fibonacci načela, a njegov rad opisao sam u [4, 324994792], a prikazuje ga slika 5.

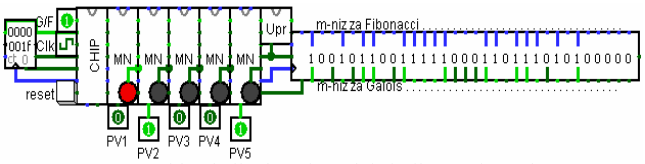


Slika 5. Stvaranje *m*-niza od 2 do 32 stanja prema Fibonacci načelu

Izborom strukture posmičnoga registra, broj taktova automatski se računa i postavlja u brojaču. Rad kruga pokrene se prečacem Ctrl+K uz automatski postavljeno početno stanje LFSR jednako 1000…0. Nakon odbrojenoga *m*-niza, krug se zaustavi u početnome stanju što je vidljiva potvrda ispravnosti rada. Detaljan opis strukture i rada obaju krugova je u [4, 324994792]. Unutarnji rad obaju opisanih sklopova odvija se na isti način.

C. *Integracija sklopova, koji rade prema dvama načelima, u jedan fizički sklop*

S ciljem navedene integracije, osmislio sam dodatan sklop i nazvao ga MN-bistabil. On objedinjuje primjenu oba načela (G/F) u jednome sklopu na slici 6.



Slika 6. Sklop koji združuje Galois i Fibonacci načela

Broj stanja LFSR proširuje se dodavanjem osnovnoga MN-bistabila, već postavljenim i priljubljenim MN-bistabilima, a konfiguraciju strukture LFSR ostvaruju prekidači PVx. Sklop sam detaljno opisao u dokumentu [4, 325479253].

VI PROGRAMSKA RJEŠENJA ZA LFSR JEZIKOM C^{++}

A. *Galois načelo za LFSR jezikom C^{++}*

Slika 7 prikazuje način tvorbe programskoga algoritma analize rada LFSR na razini bitova [4, 325479253].

			⇒⇒⇒		
stanje			00000001		0x001
maska			10111001		0x171
(izlaz%2) izlaz			11111111	&	0x1FF
presjek=maska&izlaz			10111001		0x171
stanje			00000001	^	0x001
novo			10111000		0x170
(sljedeće) stanje = novo>>1			01011100		0x0B8

Slika 7. Grafički prikaz algoritma LFSR prema Galois načelu

Pretvoreno u kôdne crte C++ programskoga alata, prethodno definiran algoritam izgleda ovako:

```
unsigned long izlaz=0x0;
if(stanje%2==1)izlaz=0x1fffffff;
presjek=maska&izlaz;//trenutno stanje LFSR
stanje=(presjek^stanje)>>1;//novo stanje LFSR
```

Detaljan opis izvornoga koda i algoritma nalazi se u [4, 325479253].

B. *Fibonacci načelo za LFSR jezikom C++*

Slično kao sintezu algoritma za rad LFSR u analizi *m*-nizova, napravio sam slično i za programsku primjenu Fibonacci načela.

			⇐⇐⇐		
stanje			000001		0x3E
maska			100101		0x29
(izlaz%2) izlaz			111111	&	0x3F
presjek=maska&izlaz			101001		0x29
stanje			111110	^	0x37
novo			010111		0x17
(sljedeće) stanje = novo>>1			101110		0x2C

Slika 8. Grafički prikaz algoritma LFSR prema Fibonacci načelu

Pretvoreno u kôdne crte C++ programskoga alata, prethodno definiran algoritam izgleda ovako:

```
presjek=maska&izlaz;//trenutno stanje LFSR
stanje=(presjek^stanje)>>1;//novo stanje LFSR
```

Algoritmi obaju načela združeni su u jedinstven program, a programske crte detaljno sam opisao u [4, 325479253] te ih ugradio u zajednički program.

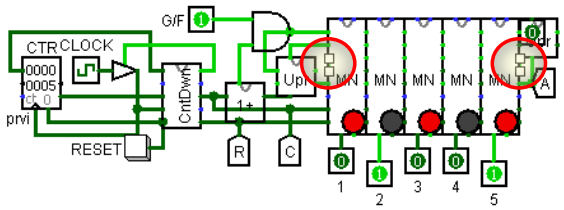
C. *Sinteza programskih i sklopovskih algoritama obrade m-nizova*

Napravio sam programsku i sklopovsku sintezu dvaju prethodnih sklopova, a prikazuju ih sljedeće crte i slika 9.

```
//Galois LFSR
  if(g=='g'){if(stanje%2==1)UlazIzlaz=0x1fffffff;
  presjek=maska&UlazIzlaz;stanje=(presjek^stanje
  )>>1;}

//Fibonacci LFSR
  else{UlazIzlaz=stanje&maska;ima=jedinice(UlazI
  zlaz);

  if((ima%2)!=0x0){UlazIzlaz=pow((double)2,a);}
  stanje=(UlazIzlaz|stanje)>>1;}
```



Slika 9. Modularna primjena Galois i Fibonacci načela u istome sklopu za *m*-nizove

Detaljan opis rada sklopa na slici 9, kao i svi moji dosadašnji opisi, također se nalazi u [4, 325479253].

VII PRIMJENE LFSR U KOMUNIKACIJAMA

A. *Smetnje komunikacijskoga kanala (šum)*

Signali su materijalni nositelji informacije u najširemu smislu i mogu poprimiti razne oblike. Najčešći materijalni nositelji informacija u komunikacijama su naponi, struje, svjetlo ili općenito, elektromagnetski valovi. Reverzibilan postupak, pretvorba je informacije iz jednoga oblika u drugi te ponovna pretvorba u izvoran oblik. Primjer ireverzibilnoga postupka, prijevod je iz jednoga prirodnoga jezika u drugi. Kodiranje je postupak kojime se ostvaruje maksimalna reverzibilnost. Utjecaj smetnji nikada se ne može potpuno ukloniti pa ni uvođenjem kodova s otkrivanjem i ispravkom pogrešaka.

B. *Kodiranje kanala - ARQ i FEC metode*

Upravljanje pogreškama kodiranjem (također se naziva i kodiranje kanala), koristi se za otkrivanje i ispravak informacija koje se prime kao pogrešne. Otkrivanje pogrešaka može se koristiti kao početni korak u tehnici ispravke pogrešaka, npr. uputiti prijemnik da zahtijeva automatski ponavljanje već prenijetoga signala (informacije). Rezultat uspješnoga ponovljenog slanja oštećenih podataka jest ispravan prijem informacije. Ovo pripada ARQ (*Automatic Repeat Request*) tehnikama.

Postupak kodiranja generira uzorak podataka. Kodiranje informacije, prikaz je skupa informacija pomoću niza simbola druge abecede. To je dio mehanizma kojime se omogućuje prijenos podataka velikim brzinama kroz kanale sa šumom. Zaštitno kodiranje, metoda je zaštite od smetnji zbog prolaza informacije kroz kanal sa smetnjama.

Ako su ARQ tehnike nezgodne, što je slučaj velikoga propagacijskoga kašnjenje signala, onda je prikladnije primijeniti *kodiranje prema naprijed s ispravkom pogrešaka* FECC (*forward error correction coding*). Prijenos podataka koji koristi FECC metode, sadrži zalihosne informacije, što se može iskoristiti ne samo za *otkrivanje* pogrešaka, već i njihov *ispravak*, bez potrebe ponovljenoga slanja. [4, 311666773]

C. *Viša razina zaštite informacija*

U višu razinu zaštite informacija od zloupotrebe spadaju: tajnopis (*cryptography*), DES (*data encryption standard*), algoritam vjerodostojnosti (*authentication*) potpisa i zaštita od prijevara. Iako je prethodno opisana tematika usko povezana temom moga rada, njome se trenutno ne bavim osim njezinim temeljima, a to je široka primjena LFSR za mnogobrojne druge namjene.

Linijsko kodiranje dio je zaštitnoga kodiranja koje koristi modulacijske postupke digitalnih modulacijskih metoda. Njihovi ciljevi su: prijenos podataka od izvora do odredišta preko pojedinoga komunikacijskoga kanala te združivanje više kanala u jedan kanal s ciljem smanjenja pogrešaka i učinkovitijim korištenjem pojasne širine (*bandwidth*) kanala.

D. *Značaj ovoga rada za primjene u komunikacijama*

U ovome radu na jednostavan i jeftin način, simulira analiza prijenosa podataka komunikacijskim kanalom sa šumom. Prijenosu podataka koji su kodirani različitim vrstama kodova (Hammingov, Golayev, Reed-Solomon), BCH, itd.[4, 311666773, Tablica 0.2: *Pregledna tablica*

kodova za upravljanje pogreškama], zajedničko je korištenje LFSR i on je u središte svih analiza.

Na prvome sloju OSI modela simulacijski alat Logisim, omogućuje analize utjecaja šuma na prijenos kodiranih podataka do razine bita. Rezultat je zoran prikaz primljenih oštećenih podataka te njihovo dekodiranje i ispravak. Zbog zastoja u razvoju ovoga alata, potrudio sam se unaprijediti i poboljšati rad simulacijskoga alata u primjeni logičkoga sklopa "posmični registar" - SR (*Shift Register*).

Konstruirao sam integrirane simulacijske sklopove prema Galois odnosno Fibonacci načelima što omogućuje brze analize kodiranja i dekodiranja. [4, 325474261, 324994792]. Kratki opisi u prethodnome dijelu, prikazuju cjelovite analize rada LFSR i ostvarene rezultate: Primjena *adicijskoga* odnosno *multiplikacijskog* načela za rad LFSR pri kodiranju i dekodiranju; PN generator za *m*-nizove (odvojena odnosno integrirana primjena obaju načela); Simulacijski sklop za brzu provjeru ispravnosti prijenosa dugih nizova podataka "šumovitim" kanalima (FCS). Sve navedeno napravio sam i programski (C^{++}).

Pri tome sam uočio nedosljednosti označavanja pratećih binarnih polinoma te sam predložio unaprjeđenja. Najvažniji postupak je brzo odrediti *nedjeljivost* (primitivnost) polinoma (*irreducibility*).

E. Algoritmi, pseudo-algoritmi i programiranje

Na matematičkoj razini (linearna algebra) stalno se proučavaju nedjeljivi polinomi bez simulacijskoga prikaza (razina sklopa ili programska razina). Postoji nekoliko pseudo-algoritama još od 60-tih godina prošloga stoljeća (Berlekamp, Golomb) ili novijih [12], ali njihovom pretvorbom u C^{++} program, ustanovio sam da nisu dosljedno opisani (previše ili nedovoljno pseudo-koda). Što je najzanimljivije, teško je (i skoro nemoguće) pronaći upotrebljiv kod napisan C^{++} jezikom. Pseudo algoritmima najviše se opisuju unaprijeđene inačice postojećih algoritama ali opet s matematičkoga motrišta. Preostalo mi je napisati svoje upotrebljive programe [13].

F. Buduća istraživanja

Najviše vremena treba posvetiti programskome određivanja velikih nedjeljivih primitivnih polinoma s minimalnim brojem od barem 3 priključka. To zahtjeva unapređenje postojećih i osmišljavanje novih algoritama. Postojeće algoritme obrade velikih *m*-nizova (reda veličine $>2^{1000}$, treba dodatno unaprijediti, što će se odraziti na generatore PN nizova u povećanju njihove pouzdanosti. Za njihovu potvrdu (vjerodostojnost), simulacijski alat Logisim je za sada najprikladniji, ali nije dovoljno brz. Zbog toga očekujem nastavak njegovoga razvoja kojeg su K. Burch i zainteresirani pridruženi istraživači naprasno prekinuli, prethodno ga dovevši do visoke razine upotrebljivosti. Zbog toga su strukture (polinomi) binarne linearne algebre i dalje u žarištu istraživanja.

Simulacijski alat Logisim prikladan je za provjeru rada budućih novo-napravljenih složenih sklopova (prijedlozi moja rješenja) koji će racionalizirati prijenos podataka u svim komunikacijskim mrežama i uređajima. Istu budućnost očekujem za algoritme koje sam osmislio ili unaprijedio.

VIII ZAKLJUČAK

Rad opisuje posmični registar s povratnim vezama (paralelno: matematički, funkcijski, programski i sklopovski), naglašavajući nedostatke pri njegovu korištenju te nudeći moguća rješenja uočenih nedostataka. Sustavan opis strukture LFSR u svakome razredu, podudaran je onome dijelu brojeva u binarnome prikazu permutacija, koje počinju i završavaju "1". Ovo je osnovna ideja ostvarenih programskih rješenja, a njih prate sukladna sklopovska rješenja simulacijskim alatom Logisim. Šteta što se prestao razvijati. Osnovne binarne matematičke operacije (zbrajanje, oduzimanje, množenje, dijeljenje, potenciranje, korjenovanje, PN-nizovi, CRC, FCS, …) obradio sam paralelno, i programski (C^{++}) i sklopovski (Logisim), a dobiveni numerički rezultati potvrdili su ispravnost pristupa. Nakon sustavne obrade svih podataka, uslijedit će prepoznavanje novih zakonitosti. Ovime naslućujem nedovoljno istraženo područje sinteze programskih rezultata, sklopovskih rezultata i teorijskih temelja.

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NEW ICT INFRASTRUCTURE

Critical infrastructure solutions for upcoming developments in telecom and data industries

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***Abstract* – Upcoming changes in data industry as well as telecommunications, with focus on edge computing and 5G, put new requirements on critical infrastructure. Higher density in ensuring more space for servers or 5G equipment, longer autonomy due to larger number of remote sites, small footprint as result of site planning and state permits, energy saving due to expansion of load would be the main points to be addressed during critical infrastructure design and planning. Key factors to fulfil and satisfy main requirements are critical infrastructure solutions designed to meet high performances, meaning high efficiency, modularity and scalability. Biggest volumes are to be expected in combinations of nodes in telecom and edge computing (edge) as well as in adaptations of 2G, 3G, 4G to 5G. In terms of critical infrastructure, this means a smart combination of AC power and thermal management units for edge computing (servers) should be combined with DC power and thermal management for upgrades to 5G. Article provides short summary of most expected combinations of critical infrastructure solutions, covering power management and thermal management, to achieve best performance in upcoming data and telco innovations.**

Keywords – Infrastructure, 5G, edge computing, data centers, RAN, modular design

I. INTRODUCTION

Looking from perspective of telecommunication and data industries, most talked about trends are the upcoming 5G and edge computing (edge) data centers. Both trends have an impact from almost all known industries, heavy industry like oil and gas digitalization, smart grids, up to smart cities and drones, as enhancement of everyday lifestyle with usage of technologies. High performance requirement is expected to be achieved in data access with 5G and edge, high speed and low latency as main drivers, [4]. But, although there are many white papers related to defining most promising used cases, both for 5G and edge, probably the main goal nowadays is to address the upcoming trends as soon as possible.

The total demand for data is now in exponential growth. The 5G in radio access network (RAN or Access) extends beyond previous generations of mobile communication. With 5G being the end user or data collection point, on network edge, enabling more data to be received or collected, the topology of infrastructure supporting this enlarged amount of data will need to adapt. As it is presented in Fig 1., in the current layout of telecommunication network, the layer which should support large amount of data transfer is missing.

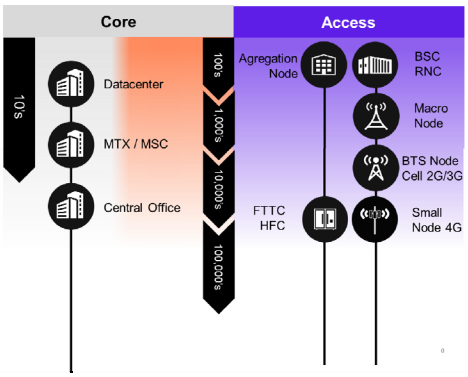

Figure 1 "AS – IS" network topology

The 5G network has evolved far beyond the traditional mobile broadband of networks past. Due to requirements to increase bandwidth and decrease latency, some network functions are being migrated to end user, [4]. Due to this, core site will consolidate and densify. Migrated functions should be moved to new sites or reutilization of existing sites should be performed. This will form the basis of edge sites in terms of network functionality, as it is shown in Fig 2. These sites will be supporting additional hardware to host application services (edge computing) or direct peering.

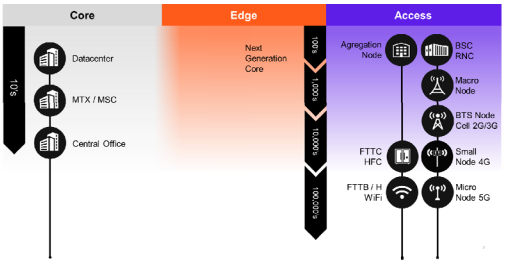

Figure 2 Evolved network topology

Edge sites will support enhancement of speed but also reduce physical distance between the service and end user.

All above mentioned changes in topology drive changes and adaptations on critical infrastructure supporting operation and efficient performance of

telecommunication equipment and servers for efficient deployment of 5G.

II. CRITICAL INFRASTRUCTURE

Active changes in telecommunication equipment due to topology changes also address infrastructure supporting their operation. It is crucial that this operation is continuous and there is no tolerance on outages. This is why supporting infrastructure is usually called critical infrastructure.

Critical infrastructure covers two main categories - power and thermal management. Power management as power supply, covers, depending on used technologies, AC (Alternating Current) and/or DC (Direct Current) supply together with, also depending on technology and site specification, battery back – up. Thermal management covers equipment heat dissipation management as well as, depending on specific site configuration, management of temperature and humidity conditions for equipment best performance. Different technologies used, depending on site configuration, can be addressed with site specific critical infrastructure solutions. Technology mixing requires many types of solutions that define critical infrastructure but all address 3 key factors:

- Efficiency
- Modularity
- Scalability

A. Access and support of 5G infrastructure

Although trends over the last years in radio access networks have put some doubts on future of DC power supply, the upcoming 5G infrastructure on access locations and trough entire network show that DC will remain in operation for many years to come, with technology principal shown in Fig. 3.

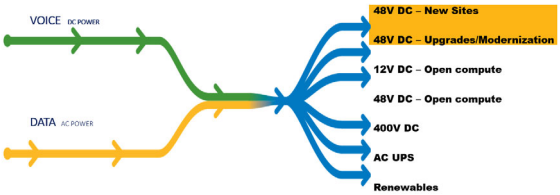

Figure 3 Equipment supply voltages

Access sites tendency in terms of power is to have capacity up to 10kW with battery back – up, depending of network coverage, to up to 2h. This infrastructure is usually accommodated in OSP (Outdoor enclosure).

The start of 5G puts big requirements on network upgrades. Additional equipment, or change and modification, drive additional requirements in power. Among network operators where the number of access locations exceeds 10000, points such as energy costs and grid limitations are high drivers for one of the mentioned key factors in paragraph *II*, efficiency. Rectifiers, as main components of DC power supply, play a key role in calculation of capital expenses (CAPEX) and operational costs (OPEX). Efficiency, as per definition, is the factor providing information about performance of equipment to transfer AC to DC power conversion, with minimum losses. In rectifiers used so far (not mentioning legacy) for telecommunication equipment, efficiency figures are ranged from "old" 90% up to 95%. "New" high efficiency rectifiers, most commonly offered and deployed nowadays, present figures from 96% to even 98%.

As example, network operator has 1000 sites which have rectifiers with efficiency of 92% and is willing to investigate site improvement in terms of efficiency. The tendency in RAN (radio access networks) in terms of power are expected to be around 10kW. Figure which represents why high efficiency is worth the focus is energy savings. By calculating annual power consumption and depending on countries price of electrical energy in EUR/kWh, the values are specified in Table 1.

Table 1 Upgrading with efficient rectifiers, [5]

EXISTING RECTIFIER EFFICIENCY VS. 98% 3500W EFFICIENT RECTIFIER		
	POWER (kWh)	COST (EUR)
Current	57 130 435	11 426 087
After Upgrade	53 632 653	10 726 531
Difference	**3 497 782**	**699 556**

Putting focus on high efficiency results in:

- cost saving
- reduction of cooling units for excessive heat (smaller cooling units). This has an impact on both CAPEX and OPEX calculation.

What can be important in power infrastructure for RAN equipment, is reduction of used space. This is defined by power density of the rectifier module itself which, in comparison to previous years, is 2 times larger. The technology used in production of rectifiers is allowing that foot print of DC power supply is in constant reduction, to leave space for RAN equipment.

Roll out planning and existing site upgrades drive challenges also in power optimization and rationing for current and future power usage. This is addressed with modularity and scalability. Planners do not wish to invest in something now if not necessary and want to have possibility of rational expansion of power. This is the reason why rectifier capacity used in RAN sites are defined from 1kW to max 3,5kW, depending on usage.

B. EDGE

With 5G topology network is changing with bigger requirements on hardware supported on edge computing.

This means that 5G is becoming a major demand driver for distributed locations that will support partially DC supplied but also AC supplied loads. These are different from large centralized data centers that support the centralization of computing (like Hyperscale) or also core telecommunication sites.

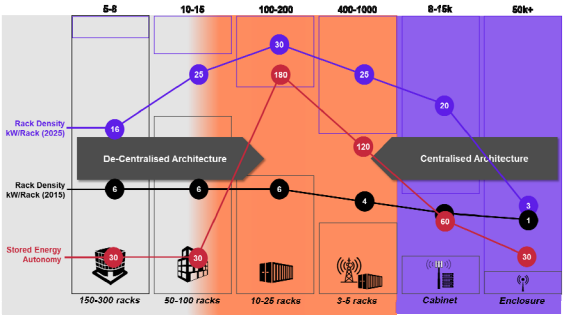

Figure 4 Distinguishing access, EDGE and core boarder

Edge data will range from small clusters of "Edge Cloud" resources located on a street light, to a few racks located in a shelter at the base of a cell tower, inside buildings or a self-contained ready-to-drop and plug-in container, [1]. Locations of traditional core sites are selected in large part based on geographical considerations, including power availability and cost, customer demand, real-estate price, and physical and security risk factors. However, for the edge site, location will also be dictated by the latency requirements of the service it supports and access to network resources, [4].

Edge Data Center location examples include:

- A cabinet located on a street corner or near other utility equipment
- Reutilization of existing macro cell site shelters
- Placement of new shelters / cabinets at macro-cell sites
- Co-location within Central Offices
- In buildings / Smart Buildings
- In factories to support Industrial IoT
- Behind or co-located with gas stations, drugstores and other businesses
- Integrated with community/neighborhood mailbox

All the above-mentioned act like small, named edge data center.

From aspects of telecommunication network upgrades to support 5G, edge sites will be separated into two types:

- Reutilization of existing macro cell site shelters
- Placement of new shelters / cabinets at macro-cell sites

Following chapters present critical infrastructure with their main requirements in these two types.

C. *Critical Infrastructure in edge data center*

The major components that make up an edge data center are as follows:

- Cabinet system
- Power supply and distribution system
- Cooling system
- Fire extinguishing system
- DCIM

1) *Cabinet system*

Hardware is typically mounted into racks to maximize the use of space in the facility. Racks may stretch towards the ceiling leaving just enough room for overhead cable systems, cooling and airflow. Edge data centers expect to range from 3 to 12 racks, [1]. The most commonly used racks, for servers and IT equipment, are 24U or 47U height, 1100 mm or 1200 mm depth and 600 mm or 800mm width. Usually the racks are placed in hot/cold containment.

Hot/cold containment is a layout design for server racks and other computing equipment in a data center. The goal of a hot/cold aisle containment is to conserve energy and lower cooling costs by managing air flow.

A containment system can be used to isolate hot aisles and cold aisles from each other and prevent hot and cold air from mixing. Containment systems started out as physical barriers that simply separated the hot and cold aisles with vinyl plastic sheeting or plexiglas covers. Today, plenums and other commercial options are supported that combine containment with variable fan drives (VFDs), temperature and flow sensors to achieve maximal efficiency and shown in Fig. 5, [6].

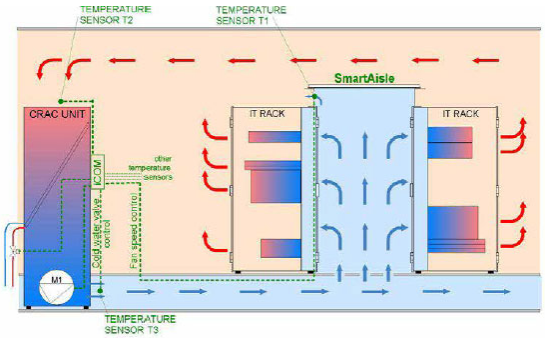

Figure 5 Hot/Cold containment topology

2) *Power supply and distribution*

The purpose of the electrical infrastructure is to take power from the utility grid and deliver it to the equipment without interruption. If the equipment loses power, it will shut down, which is not tolerable. Therefore, the design and operation of the electrical infrastructure is based on redundancy. The electrical distribution is designed and built so that if one system fails or a power connection is lost, there is another energy source to keep the power flowing and the equipment up and running. The typical power of the edge data center is between 10-90 kW.

Figure 6 provides general line diagram of the electrical infrastructure showing how power gets from the utility grid to the IT equipment.

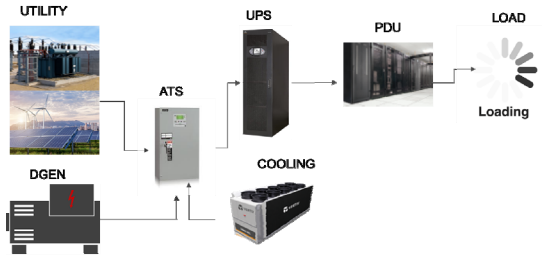

Figure 6 Electrical infrastructure topology

In practice this is more complex and may include further layers of redundancy, but the concept is the same.

The utility grid provides the ultimate source of power for the data center. There can be two connection points to utility grid, depending on site principle and configuration.

Backup generators are diesel powered electrical generators that produce electricity in the event the utility grid goes offline. Generators can provide power for hours or even days until the utility grid can provide power again.

Automatic Transfer Switches (ATS) are able to switch the source of power from the utility grid to the backup generators without interruption.

In the event of a sudden utility outage, Uninterrupted Power Supplies (UPS) provide power to the equipment for the one or two minutes it takes to startup the backup generators. UPS systems typically consist of batteries or flywheels that store enough energy to bridge the power gap. UPS systems cannot provide power to the equipment for a long period of time.

In recent years, and in the edge data centers, the trend has been toward the use of modular UPS with modules of 10 kVA to 50 kVA to make up larger UPS systems. The principle advantages touted for the modular approach are the ability to grow capacity as needed (assuming an initial right-sizing) and reduced maintenance cost. The modules are hot swappable and can be returned to the factory by the user for exchange or repair. Modular systems are also generally designed to accept one more module than is required for their rated capacity, making them inherently "N+1" capable at much lower cost than would be possible with the very large system. The last potential advantage to modular UPS systems is efficiency. A UPS system runs at highest efficiency when it is near its maximum rated capacity. As load level drops, so does efficiency. Modular UPS systems can be configured, and readily re-configured, so they are running close to capacity.

Power Distribution Units (PDU) are the physical „outlets“ that the IT equipment plugs into at the rack level. PDUs are mounted in each rack and contain multiple outlets to be used by the IT equipment.

3) Cooling system

In upcoming trends of edge data centers there will be a lot of initiative in optimization of cooling technologies. With an increasing load of servers in minimized footprint, inevitable laws of thermodynamics will extinguish conventional cooling techniques. Trends are showing changes of heat transfer medium is the natural path of developing cooling technologies in high-density infrastructure.

One of the simplest and effective closed loop designs for thermal solution in edge applications is In-Row unit which cools the hot air from the back of the rack and supplies cold air to the front of the rack. Such a microclimate inside the rack is sustainable and fine-tuned to optimize electricity consumption.

Using the same principle of the closed-loop system it configurations can be done with one rack and one cooling unit or for an even higher capacity, one heavy duty rack and two cooling units. Air-to-server technology can be pushed further and adjustable for extremely high-density loads, but the market is the key player who will aim towards more efficient, cheaper and silent technology.

In edge adaption phase, when technologies from conventional data centers are transferring to edge, the industry has to respond in such a manner. One of the early examples is the hybrid loop system where cooling units will cool servers, but additional equipment needed for functional edge as well. The air flow concept is shown in Fig. 7.

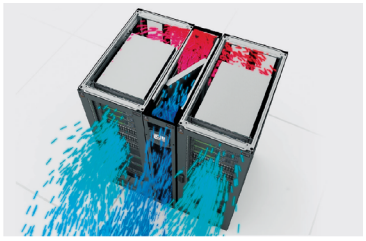

Figure 7 Air distribution, hybrid loop

In direct expansion technology current market standards are providing up to 30kW per one 300mm In-Row cooling unit, while with chilled water technology 300mm In-Row units are able to achieve up to 55kW of capacity, depending on water temperatures.

Modular solutions offer edge data centers according to customer needs, with customizable cooling technologies which will be the backbone of edge development. Standalone edge data centers in developing phase will be slightly stepping back in cooling efficiency, relying mostly on the conventional direct expansion technology. Modular solutions are offering a new approach to edge data centers efficiency through using a different variation of the same cooling technology based on location. Current market standards for complete modular solution are up to 90kW while increasing Power Usage Effectiveness (PUE) of data centers through optimized direct expansion technologies such as pumped

refrigerant technologies, dry coolers, direct free cooling etc.

4) Fire extinguishing system

Fire protection in data centers has evolved significantly in recent years, with new technologies, plus changes to the regulations governing fire protection. Gone are the days of being able to use Halon-based systems. Now, there is a whole new generation of fire protection systems in play.

If the edge data center catches fire, smoke and heat will trigger the smoke and heat detectors, which will send fire alarm signals to the extinguishant control panel. Upon receiving the fire alarm signals, the extinguishant control panel counts down and then opens the electrical actuator on the fire extinguisher so that the fire cylinder discharges extinguishing agent to the protection zone. At the same time, the extinguishant control panel automatically reports alarms. The fire extinguishing system consists of extinguishant control panel, smoke detector, heat detector, fire alarm bell, horn strobe, emergency light, external horn strobe, extinguishant abort button, warning signs, electrical actuator, pneumatic switch, fire nozzle, fire cylinder, Very Early Smoke Detection Apparatus (VESDA), (optional), and exit light.

5) DCIM

Data center infrastructure management (DCIM) is software application used to have visibility on critical infrastructure supporting equipment, as well as equipment distribution in data center. With network expansion it is important to have visibility and control. Software application, DCIM, designed specifically for data center purposes, puts an ease on both current and future planning. Having a software that provides information on complete active equipment assets, understanding where there will be need for expansion and if this expansion is possible, monitor critical infrastructure optimized operation (failures, downtimes, efficiency), are achieved from one place.

D. Prefabricated Modules VS Site Reutilization

Prefabricated Modules address the challenges of deploying datacenters in remote sites, industrial environments, and other locations where a dedicated building or space does not exist.

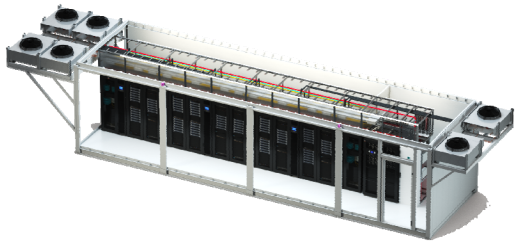

Figure 8 Modular design used for edge

The First generation was in ISO shipping containers, the second generation of modular solutions thought outside the box (literally). These solutions kept the attributes and advantages of being modular but did not conform to just a container. A primary difference between generations was how cooling was supplied. First generation containers were simply a container full of IT and relied on additional infrastructure to operate. Second generation modular container solutions had integrated cooling technology and came as a complete data center solution. Many of these solutions used advanced cooling technology, implementing evaporative cooling and making use of outside air efficiently.

The negative perspective of prefabricated modular approach is additional requirements in permits and civil works. Most of telecom sites that could be used as future edge data centers are sites already in operation, meaning covered from civil and legal perspective.

However, there are more key factors in driving modular approach, as per following:

1) Scalability:

With a repeatable, standardized design, it is easy to match demand and scale infrastructure quickly. The only limitations on scale for a modular solution are the supporting infrastructure at the site and available land. Another characteristic of scalability is the flexibility it grants by having modules that can be easily replaced when obsolete or if updated technology is needed. This means organizations can forecast technological changes very few months in advance. It doesn't have to take years to plan out.

2) Efficiency:

The fact that modules are engineered products means that internal subsystems are tightly integrated which results in efficiency gains in power and cooling in the module. First generation and pure IT modules will most likely not have efficiency gains other than those enjoyed from a similar containment solution inside of a traditional data center.

3) Density and Power Usage Effectiveness (PUE):

Density in a traditional data center is typically 100W per square foot. In a modular solution the space is used very efficiently and features densities as much as 20 kW per cabinet. The PUE can be determined at commissioning and because the module is pre-engineered and standardized the PUE's can be as low as 1.1–1.4. The PUE metric has also become a great gauge of data center green efficiency, [2]

4) Speed of Deployment:

Modular solutions have incredibly quick timeframes from order to deployment. As a standardized solution it is manufactured and able to be ordered, customized and delivered to the data center site in a matter of months (or less). Having a module manufactured also means that the site construction can progress in parallel, instead of a linear, dependent transition.

5) Mobility and Placement:

A modular data center can be delivered wherever it is desired by the end user. A container can claim ultimate mobility, as an ISO approved method for international

transportation. A modular solution is mobile in the sense that it can be transported in pieces and re-assembled quickly on-site. Mobility is an attractive feature for those looking at modular for disaster recovery, as it can be deployed to the recovery site and be up and running quickly. As data center providers look to take on new offerings, they will be tasked with staying as agile as possible. This may very well mean adding additional modular data centers to help support growing capacity needs.

6) Commissioning:

As an engineered, standardized solution, module can be commissioned where it is built and require fewer steps to be performed once placed at the data center site.

7) Standardization:

Seen as a part of the industrialization of data centers the modular solution is a standardized approach to build a data center, much like Henry Ford took towards building cars. Manufactured data center modules are constructed against a set model of components at a different location instead of the data center site. Standardized infrastructure within the modules enable standard operating procedures to be used universally. Since the module is prefabricated, the operational procedures are identical and can be packaged together with the modular solution to provide standardized documentation for subsystems within the module.

8) Total Cost of Ownership:

All the above-mentioned factors reflect on, what is to be most important driving factor for entering any business, that is TCO. It is supported by the following:

- Acquisition: Underutilized infrastructure due to over-building a data center facility is eliminated by efficient use of modules, deployed as needed.
- Installation: Weeks and months instead of more than 12 months.
- Operations: Standardized components to support and modules are engineered for extreme efficiency.
- Maintenance: Standardized components enable universal maintenance programs.

III. CONLUSION

This paper explores why operators need to address critical infrastructure as a strategic pillar of 5G deployment and in which directions to proceed to enable profit from the technology. 5G and edge are driving telecommunication network consumption increase. Decentralization of core sites, bigger requirements on access sites, deployment of new sites serving edge, all need critical infrastructure for operation. All investments in infrastructure together with energy cost, in case not coordinated properly, can drive potential out weight from 5G commercial advantages. Having a complete picture of potential infrastructure solutions means being able to define and meet deployment requirements in terms of location, power and thermal consumption. The market is driving demand on coordination between critical infrastructure and network technology planning in order to meet high performance validated with adequate TCO.

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Accessible Web Prototype Features from Technological Point of View

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***Abstract* – Nowadays, the Internet is widely used among people of all age groups and it has an impact on different aspects of people lives. For all people to be able to access web content, it is necessary to ensure accessibility of the websites. Although many guidelines for ensuring web accessibility can be found, analysis of many websites showed that many accessibility issues are not addressed enough. An accessible website prototype with information about special offers from different telecom operators is developed and described within this paper. Evaluation with web accessibility checking tools and user evaluation were conducted to analyze accessibility and user's satisfaction with the website prototype. Also, some technical instructions for web developers and designers are provided in order to raise awareness about how to develop accessible website using available technology, such as WordPress.**

Keywords – web accessibility; prototype; accessibility options; WordPress; plugin; accessibility evaluation

I. INTRODUCTION

Various initiatives and social movements aimed at ensuring equal opportunities for all people to participate in different aspects of community life are mostly related to the concept of *e-inclusion*. According to [1], *e-inclusion* is defined as 'inclusive Information and Communication Technologies (ICT) and the use of ICT to achieve wider inclusion objectives and policies aiming at both reducing gaps in ICT usage and promoting the use of ICT to overcome exclusion'. The goal of *e-inclusion* is, among others, to involve all people, independently of their ability, age, gender, ethnicity, or economic capacity, in all forms of information society in order to overcome existing barriers to the use of ICT products and services and improve quality of life, employment opportunities, lifelong learning etc.

Nowadays, the Internet has greatly affected the way people look and search for things, learn, share content, shop, communicate, make friends. More than 45% of people in the world use Internet actively via their computers, smartphones, personal digital assistants, digital TVs [2]. Given the aging of the population around the world and the increasing number and longevity of people with disabilities, it is extremely important to take appropriate measures to ensure these groups of people can access different websites and e-services via the Internet. People with disabilities and elderly can benefit from web services in many ways, as described in [3]. In order to fully exploit the potential of websites and web services, it is necessary to make them accessible, i.e. to enable access and use of content on the Web for all users. For example, for people who are blind, software programs that read the content displayed on the computer screen need to be able to interpret websites, for people who have visual impairments, websites need to have options which enable adjustment of font size and color contrast, for people who are deaf or have low hearing, videos with audio content on websites need to be accompanied by subtitles etc.

The importance of web accessibility has been recognized by many countries in the world which have legislated how public web content, such as governmental websites, must be designed in order to be accessible to all people. Examples of government regulations on web accessibility are listed in [4]. The authors in [5] analyzed the accessibility of Italian municipal websites ten years after the enactment of the Sancta Act and the results show that most websites are not accessible despite the existence of the national law related to accessibility. Furthermore, they mention low compliance with regulations on web accessibility in other countries too and highlight the need to document which specific steps the public agencies must take for meeting standard accessibility requirements in public websites.

The research of the accessibility of the most visited web pages within the Croatian catalogue of web pages [1] conducted in 2014 has indicated that the design of the web pages is still not sufficiently accessible and tailored to the needs of specific categories of users. It was then concluded that the greatest responsibility lies in the development of accessible web design or in the development of new services that will be able to interpret the content of individual websites and automatically make adjustments according to the needs of specific categories of users and thus overcome this lack of accessibility design [6]. This research is the result of the cooperation between Croatian Regulatory Authority for Network Industries[2] (HAKOM) and members of the Laboratory for Assistive Technology and Alternative and Augmentative Communication[3] (ICT-AAC Lab) in the area of accessibility of services based on ICT, which was continued later through various research and project activities.

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[2] HAKOM, https://www.hakom.hr/

[3] ICT-AAC Lab (University of Zagreb Faculty of Electrical Engineering and Computing), http://lab.ict-aac.hr/

In order to educate and raise awareness of the barriers that people with disabilities encounter while using the Internet and how to overcome these barriers with proper design, a web application named Quiz[4] has been developed during 2016 as one of the cooperation results. While solving a quiz about user rights in the electronic services market, a user can run different simulations of difficulties that users with specific visual impairments, motor impairments and reading difficulties have. The application also includes description of difficulties and WCAG accessibility guidelines.

The research conducted in 2017 by HAKOM and ICT-AAC Lab has shown that for some people with disabilities modern technology and the Internet are the only way they can connect with the world and be included in different aspects of the community. Therefore, ICT products and services must be available and accessible to them in every sense. Another finding from the research is that people with disabilities have difficulty finding information of interest on the websites of telecom operators and it was concluded that it would be useful to gather information about offers and services from different telecom operators for people with disabilities in one place. That is why it is decided to develop a prototype of an accessible website as a place that will contain information about special offers from telecom operators for people with disabilities. This prototype is developed within the project of cooperation between HAKOM and ICT-AAC Lab named *Accessible website for people with disabilities* [7]. The accessible website prototype is available here: http://usluge.ict-aac.hr/pristupacni-web-2/.

Although there are many recommendations and guidelines for ensuring accessibility of websites, it seems that not many has been done to address all accessibility issues. Insufficient clarity of technical application of these guidelines or lack of awareness for some developers are just some of the possible causes for that [8]. Therefore, we have been motivated to propose technical instructions for developers and designers based on the development of the abovementioned accessible website prototype. In addition, to analyze the compatibility of the prototype with the accessibility guidelines, an evaluation with web accessibility checking tools and a survey was conducted and documented within this paper.

The rest of the paper is organized as follows: Section II describes developed prototype of the accessible website, Section III gives a description of the technical characteristics as well as the challenges we encountered during development, Section IV describes the process and the results of the accessibility evaluation and, finally, Section V concludes the paper.

II. ACCESSIBLE WEBSITE PROTOTYPE

The initial phase of the accessible website prototype development included specification of users' requirements. Users with disabilities are a very heterogeneous group of people whose needs and preferences very much differ. It is inevitably to involve target user groups at this stage in order to develop highly usable and accessible website for them. The users' requirements were collected by interviewing focus groups according to a questionnaire prepared beforehand. Focus groups consisted of persons with different disabilities (or their representatives), such as visual, hearing or motor disabilities, so it was to be expected that their preferences for some functionalities and user interface elements as well as graphical design will be in conflict. Despite that, all the requirements were considered and analyzed, and it was decided to implement requirements that suit most users. The appearance of the website prototype and the accessibility options implemented are described in more details below.

Given the responses of respondents related to design of the website, it was concluded that the end users, above all, prefer an accessible design, but also want it to have attractive, fashionable and business look. Furthermore, the emphasis was on the ease of use, simplicity and availability of information. The website prototype accessibility features provided by the design are related to the careful selection of colors, fonts, images, way of presenting content (e.g. grouping and highlighting related content) and layout of graphic elements [7]. The homepage of the website (tab "*Početna*", i.e., *Homepage*) is shown in Figure 1. As mentioned before, this website gathers information about special offers and services from different telecom operators. In addition to the offers for people with disabilities (PWD) (tab "*OSI*", i.e., *PWD*), the website also includes offers for the elderly (tab "*Seniori*", i.e., *Seniors*), for young people (tab "*Mladi*", i.e., *Youth*) as well as additional benefits that telecom operators offer (tab "*Dodatno*", i.e., *Other*). Also, contact information for every telecom operator and detailed information about the project are available on the website (tabs "Kontakti", i.e., *Contacts*, and "*O projektu*", i.e., *About project*).

Accessibility options can be accessed through a menu on the right of the website which is opened by default or can be opened by clicking on the button available in the upper right corner of the website. The user can close the menu at any time. According to respondents' responses, following accessibility options were selected and implemented on the website prototype [7]:

- *Increase/Decrease Font Size* – an option with which the user can customize the text font size;
- *Recommended Text Size* – an option that sets the text font size to the recommended size (in this case, 16 px);



Figure 1 Homepage of the website prototype with opened accessibility options on the right

[4] Quiz, http://pristupacnost.hakom.hr/

- *Font* – an option for changing between displaying text with two different fonts (one from *sans* and another from *sans-serif* font family);
- *Color Contrast Selection* – an option that offers four color contrast combinations (background and text colors);
- *Highlight Links* – an option that highlights the website text representing links;
- *Underline Links* – an option that underlines the website text representing links;
- *Gray Tones Images* – an option that displays all images on the website in gray tones;
- *Turn off the Lights* – an option that shades parts of the website not representing the main content;
- *Removing Animations* – an option that removes animations that can be disruptive to some users;
- *Reset Accessibility Options* – an option that returns the default website view/deactivates all activated options.

The user can activate or deactivate a single option by clicking the button representing that option. In addition to abovementioned options, two more features were implemented on the website: *wider scrollbar* and *image magnifier*. Technology used for the development of accessible website prototype will be described in more details in the following section.

III. Development of Accessible Web Prototype

As mentioned before, it is very important to keep in mind principles of accessibility when designing different products (applications, tools) in order to fulfill the goal of having products accessible to diverse range of people regardless of their abilities, language, location, hardware or software they use. It is also important to choose the right technology with which that can be achieved. For the development of an accessible website prototype described in the previous section, WordPress[5] has been chosen as a core technology.

WordPress is an open source, content management system based on PHP and MySQL. It began as a blogging tool and throughout the years has evolved to be the most popular content management system [9]. Around 33% of all websites on the Internet are powered by WordPress and it holds 60% market share for content management systems [10]. Well known for its five-minute installation and easily operated, user-friendly administration interface, WordPress can be easily extended with plugins. It also offers a robust template system as well as number of considerable APIs (Application Programming Interfaces) related to a certain set of functionalities. Anyone with experience with PHP programming language can change the website appearance and even modify WordPress functions. There are many available APIs in Wordpress like Plugin, Widgets, Shortcode, Settings, Options etc.

A WordPress Plugin[6] is a PHP script which can extend the functionality, alter the core functionality or add new features to the website with two different types of hooks: *Actions* and *Filters*. The *Action* hook enables plugin to be triggered at specific point during execution while the *Filter* hook modifies text before adding or after retrieving data from the database [11].

Given the simplicity and rapid development that WordPress provides, it has been chosen as a tool for developing our prototype. As for the plugin, considering requirements specified by end users, the WP Accessibility Helper PRO (WAH PRO) plugin[7] has been used. At the early stage of development, we considered this plugin useful because of the accessibility features it offers and compliance with the requirements. The findings which came about with working with the WAH PRO plugin has shown are that it takes insignificant time and effort to install the plugin. Also, early versions of plugins can be unstable, and it is questionable for how long the plugin maintenance and support will be available. Considering the mentioned facts, *development from scratch* is preferred. The WAH PRO plugin can benefit developers as accessibility improves overall user experience, device compatibility, code efficiency and discoverability via web crawlers and search engines. This paper provides basic instructions how to implement accessibility via plugin in any WordPress site which results in better search rank and extended market reach.

The WAH PRO plugin provides the basic accessibility tools. Most of the features that the plugin includes, such as font resize option, keyboard navigation, changing font family, underline links, contrast settings, greyscale photos option, "lights off" mode, remove animations and reset option, are also specified by the end users of our accessible website prototype as compulsory features of an accessible website. The plugin "remembers" all changes (options selected by the user) by storing them into cookies and PHP session. Cookies are small files which are stored on a user's computer. They are designed to hold a modest amount of data specific to a client and website and can be accessed either by the web server or the client computer. This allows the server to deliver a web page tailored to a user, or the web page itself can contain some script which is aware of the data in the cookie and so is able to carry information from one visit to the website (or related site) to the next [13]. For example, one of the requirements was to allow users to change background and font color of the site. Plugin offers contrast setting option where up to four color contrast combinations can be added. Each combination consists of the background color and the text color. When one combination is chosen, its values are stored in a cookie. Using jQuery, we can access those values and easily change CSS (Cascading Style Sheets) *background-color* and *color*

```
jQuery('body').css({
        'background-color': bg_color,
        'color':text_color
});
```

Figure 2 Changing CSS properties of HTML element body using jQuery

[5] WordPress, https://wordpress.org/

[6] WordPress Plugins, https://codex.wordpress.org/Plugins

[7] WP Accessibility Helper Plugin, https://accessibility-helper.co.il/

properties with .css() method. An example of a jQuery code that changes CSS properties is shown in Figure 2.

When it comes to fonts and readability of the text, the website should have options to change font and font size. Websites with only one or only a few fonts are usually easier to read. Too many fonts can create a confusing visual layout which is bad for all users, especially for those with reading disorders, learning disabilities, or attention deficit disorders [14]. In CSS file, a class consisting of only a font-family property, different from the default one, can be created. If a font specified in HTML body element belongs to serif family of fonts, the user should be available to switch to sans-serif font. When the user selects the option for font change, the name of the CSS class is stored in a cookie. Then it is possible to toggle between those two fonts with jQuery function. An example of a jQuery function that changes font family is shown in Figure 3.

```
if(!jQuery('body').hasClass(sansSerifFont) ){
   jQuery('body').addClass(sansSerifFont);
   Cookies.set( 'font_'+sansSerifFont, 'on',
{ expires: 14 } );
}else{
   jQuery('body').removeClass(sansSerifFont);
   Cookies.remove( font_+ sansSerifFont);
}
```

Figure 3 jQuery function that changes font-family

Default font size of 16 px might be too big for some users while others might find it too small. Therefore, it is important that design of a website can accommodate increased or shrink text sizes without loss of readability or functionality. For a font size, it is best to use relative units such as rem or em rather than absolute units (pixels or points) because it provides more flexibility. Rem stands for "root em" and it is relative to the HTML element (root element). If font size of HTML element is 16 px then 1 rem equals 16 px for all elements. If root element does not explicitly define font size than 1 rem is equal to the default font size provided by the browser. An em is equal to the computed font size for the element to which it is applied. When em unit is declared on a child element which does not have defined font size, it will inherit font size from its parent [14]. For example, WAH PRO plugin provides three options for font resizing, depending on units which were used for font size.

The PHP session creates a temporary directory on the server where variables with related values are registered. This data is available to all web pages on the website during the visit. The session ends when the user closes the browser or after leaving the website. The example of a session usage is the switch positioned in the upper left corner of the header in the website. It switches the background image on the header, writing its value in a session variable. Default value is 0 and it displays the photo of the town during the day. When the switch is checked, its value changes to 1. This value is then stored in a session so the background image switches to the photo of the town during the night. After leaving the website, the session is destroyed and the next time a user visits the website, its value will be initialized to 0.

IV. ACCESSBILITY EVALUATION OF A WEB PROTOTYPE

Web Accessibility Evaluation is an assessment procedure to analyze how well the Web can be used by people with different levels of disabilities [15]. The W3C has published a methodological guide which describes the procedures and the considerations for evaluation of conformance with the WCAG 2.0 directive. This methodology is called Website Accessibility Conformance Evaluation Methodology (WCAG-EM) [16].

In order to test our prototype in conformance with this methodology automated web accessibility evaluation tools were used. Automatic evaluation is performed by software which has easy and intuitive interface making testing accessible to variety of people (not only professionals).

In our case study students enrolled in the first and the second year of graduate study of Business Computing and enrolled in a course related to the accessibility (*Ergonomics of computer equipment*) were asked to participate in testing and grading this website. Students evaluated the website using two automatic software tools and a survey with questions regarding parts of a website and general usability in desktop and mobile versions.

A. Web accessibility evaluation tools and instrument

- A-Checker [17] is an online accessibility checking tool that evaluates HTML content for accessibility problems by entering the location of a web page or by pasting the complete HTML source code from a web page. It produces a report of all accessibility problems and groups them in 3 types: known problems, likely problems and potential problems.
- WAVE [18] is an online free community service launched in 2001 and has been used to evaluate accessibility of millions of websites. It allows users to enter the location of a web page or to use it as an extension for Firefox and Chrome browsers. The output is a comprehensive report explaining errors, alerts, features, structural elements, HTML5 & ARIA and contrast errors.
- Survey which embedded questions about key elements of a web page with focus on accessibility and ease of use. Students were asked to grade if parts of the website meet their expected requirements and if the composition of the website is, in their opinion, appropriate to people with disabilities. Grading was done descriptively and was later converted to numbers using qualitative into quantitative data conversion technique [19]. Points assigned to elements are: 1 point if part of the website fully met their requirements, 0.5 points if their requirements were partially met or if there was a problem with site features, and 0 points if parts of the website completely failed to meet their requirements or were unnecessary.

B. Results

Automatic evaluation tool A-Checker reported an average of 2.41 errors in all parts of the website. Most errors were found in subpages *About project* and *Seniors*

while other pages have similar amount of errors. Distribution of errors is shown in Table 1 and Figure 4.

Table 1 Distribution of errors in the website using A-Checker

Num.of errors	Frequency	Cumulative %
2	37	58,73%
3	26	41,27%
More	0	100,00%

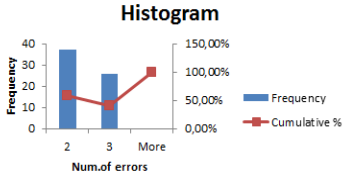

Figure 4 Visual representation of error distribution in the website using A-Checker

A-Checker also reported in average of 192.35 problems concerning the entire website. Most problems were found in subpage *Contacts* here as other pages tend to have similar distribution of problems which is shown in Table 2 and Figure 5.

Table 2 Distribution of problems in the website using A-Checker

Num.of problems	Frequency	Cumulative %
125	8	14,29%
183	9	30,36%
187	7	42,86%
192	8	57,14%
219	8	71,43%
220	8	85,71%
More	0	100,00%

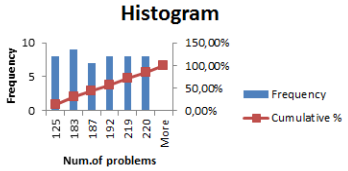

Figure 5 Visual representation of problem distribution in web site using A-Checker

Automatic evaluation tool WAVE reported an average of 9.57 errors in all parts of web site. Most errors were reported in subpage *Youth* whereas other subpages have similar distribution of errors. Concerning the comprehensiveness of this tool we are inclined to show only two components (errors and problems) in order to demonstrate differences in evaluation tools. Distribution of errors in the website is shown in Table 3 and Figure 6.

Table 3 Distribution of errors in the website using WAVE

Num.of errors	Frequency	Cumulative %
8	13	46,43%
9	4	60,71%
11	4	75,00%
12	7	100,00%
More	0	100,00%

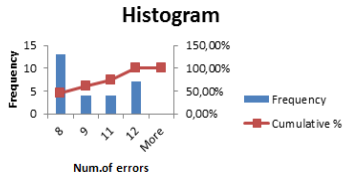

Figure 6 Visual representation of error distribution in the website using WAVE

WAVE reported in average of 19.61 warnings concerning the entire website. Most problems were found in a subpage *PWD* and *Seniors* while other pages tend to have similar distribution of warnings which is shown in Table 4 and Figure 7. Most warnings through site were about missing alternative text or legend, empty button declaration and redundant title text items.

Table 4 Distribution of warnings in the website using WAVE

Num.of warning	Frequency	Cumulative %
15	9	32,14%
16	4	46,43%
18	3	57,14%
22	4	71,43%
24	4	85,71%
28	4	100,00%
More	0	100,00%

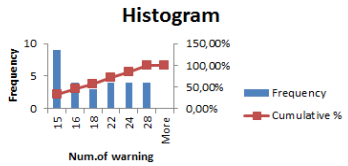

Figure 7 Visual representation of warnings distribution in the website using WAVE

In order to understand differences in numbers shown in tables and graphs, the difference between tools used in testing need to be taken into consideration. WAVE is more comprehensive tool and gives its data in more elaborate way, dividing it into groups which are detail specific whereas A-Checker gives only two types of data (errors and problems). Therefore, we decided to give only two types of data; errors and problems. Other WAVE data is shown in Table 5 below as average values.

Table 5 Remaining averages of data in WAVE

	Average
Features	6
Structural elements	14
HTML5 & ARIA	50,57
Contrast errors	12,57

Students were asked to test the website in mobile and desktop browsers in order to compare accessibility and responsiveness. Results of the survey showed that for more than 166 questions about site asked in survey students were completely or partially satisfied with functionality and accessibility of the website. Browser mostly used for testing was Chrome while mobile platform was Android. In a survey subjects were completely satisfied with *design* and *navigation* through site as well as *load speed* and mobile

Table 6 Distribution of points in website survey

Desktop version					
	Points(grades)	Frequency	Cumulative "less then"	Cumulative "more then"	Cumulative %
	0	29	29	195	14,87%
	0,5	47	76	166	38,97%
	1	119	195	119	46,16%
	More	0	195	0	100,00%

Table 7 Distribution of points in mobile website survey

Mobile version					
	Points(grades)	Frequency	Cumulative "less then"	Cumulative "more then"	Cumulative %
	0	3	3	60	5,00%
	0,5	15	18	57	30,00%
	1	42	60	42	65,00%
	More	0	60	0	100,00%

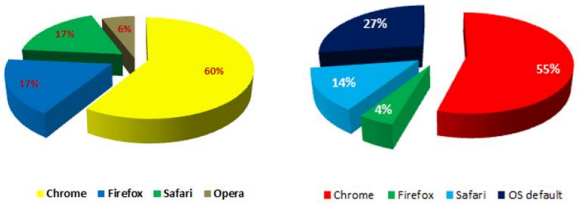

Figure 8 Comparison of desktop browsers (left chart) and mobile browsers (right chart) used in testing

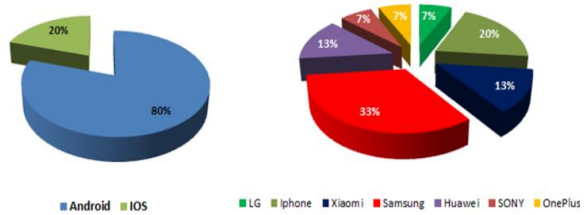

Figure 9 Mobile platforms (left chart) and brands (right chart) used in testing

version. Test subjects reported options like *turn off the lights* and *remove animations* as ambiguous while option to *make all pictures grey* had slight lag in certain browsers. Results of survey are shown in tables and graphs above (Table 6 and 7, Figure 8 and 9).

Points assigned to questions in a survey generally have negative asymmetric distribution meaning that website proved its accessibility and met the requirements. Slight difference is visible in points when comparing mobile and desktop versions leaning towards mobile as more accessible. Results represented in numbers are: α_3 = -0,9811 for desktop and α_3 = -1,4409 for mobile site versions with α_3 as coefficient of asymmetry:

$$\alpha_3 = \frac{n}{(n-1)(n-2)} \times \sum_{i=1}^{n} \left(\frac{x_i - \bar{X}}{\sigma}\right).$$

Visual representation of data through skewness graph leaning to negative points (Figure 10) shows that site accessibility is between 0.5 and 1. Knowing that 0.5 and 1 point where assigned if subject is partially or fully satisfied respectively we can confirm that 80% of subjects report this site is easy to use and accessible to browsers on both desktop and mobile versions.

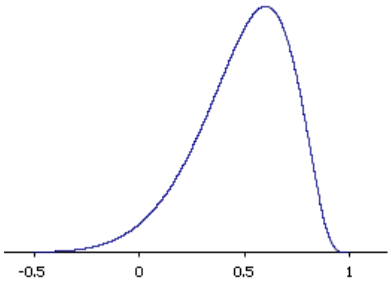

Figure 10 Negative skewness of points in survey

V. CONCLUSION

Most of the basics of accessibility are fairly easy to implement into websites, either by using existing solutions or creating your own. Accessibility optimization overlaps with other good practices such as mobile web design, device independence, usability, design for older users and search engine optimization (SEO). It leads to cleaner interfaces, simpler navigations and other elements that improves overall user experience. As a result, accessible websites have better search rank and extended market reach. Because the WCAG guidelines were followed and user requirements were implemented during the construction of the prototype website, 80% of survey respondents considered it easy to use and accessible on both desktop and mobile platforms.

Accessibility evaluation carried with two online tools and survey results gave this website prototype generally positive feedback. Testing was carried out with desktop and mobile browsers, respondents mostly used Chrome browser and Android platform. Results acquired during testing show that test subjects (students) rated this website as highly accessible and intuitive with good design and responsiveness.

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Databases Performance Evaluation for IoT Systems: the Scrovegni Chapel Use Case

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***Abstract*—Internet of things devices are used to collect data from the physical world, and to present the results in a way well usable to the end user. Therefore, an accurate choice of the most appropriate technology for storing data collected from the network is relevant. In this paper we focus the attention on the selection of the best database management system for cultural heritage applications, in particular referring to the use case of light monitoring at the Scrovegni Chapel (Padua, Italy), to emphasize the Giotto's frescoes. For doing so, SQL and No-SQL solutions are compared, and the obtained results are used to find the best solution for this application. Moreover these results can be used as a practical reference for the more appropriate selection of the right database for real use cases.**

***Index Terms*—Internet of Things, Wireless Sensor Network, Database, SQL, NoSQL.**

I. Introduction

Nowadays, Internet of Things (IoT) applications are widely used for monitoring and control a variety of scenarios, such as: smart museum [1], physical data gathering from harsh environments [2], collecting data of industrial activities [3], Ambient Assisted Living (AAL) applications [4], patient's health care [5], [6], smart cities [7], etc. An IoT system is composed of several sensors, that are small devices with limited computational power and storage capability, used to convert physical measures into electric signals and then transmitted to the sink node through radio interfaces. The sensing data are typically stored into a remote database or also locally (into a database embedded into the sink node, see Fig. 1) and made available to the users via a web or a mobile dedicated application. Fig.1 depicts a typical network architecture of such solution.

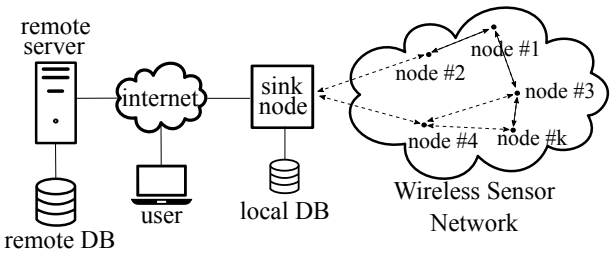

Fig. 1. General architecture of an IoT sensor network.

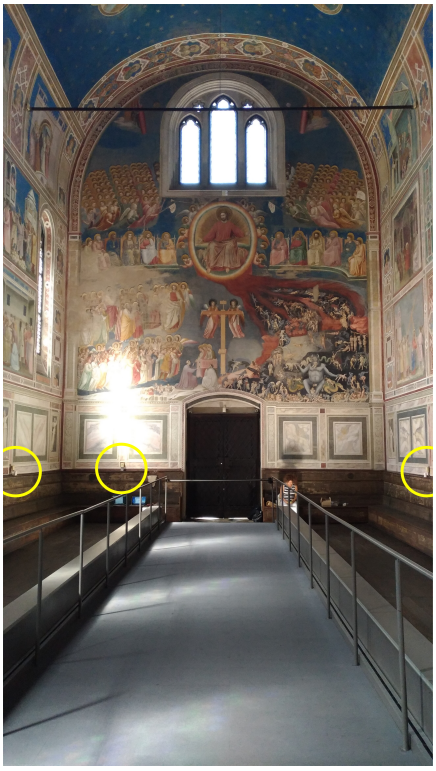

Fig. 2. Scrovegni Chapel (Padua, Italy): The Last Judgement. Three IoT nodes (circled in yellow) mounted on metal supports: the first on the left-side, the second on the left of the door, the third on the right-side.

To realize the IoT architecture for lighting monitoring and controlling inside the Scrovegni Chapel [8] (Fig. 2), a database for storing the collected data is implemented. Fig 3 shows a snapshot of the web application of the monitoring system, where are depicted the RGB components sensed by one of the IoT device inside the Chapel and stored into the sink node. This special site imposes severe restriction on the sensor nodes (number of nodes, positioning, energy supply, *etc.*), and a specific design for this IoT system was required. In fact for this specific application, the customer has requested a Wireless Sensor Network (WSN) composed of 5 sensor nodes and one sink node, that is able to sample the lighting inside the Scrovegni Chapel every 5 minutes. The use of radio channel (IEEE 802.15.4) for data communication was necessary in

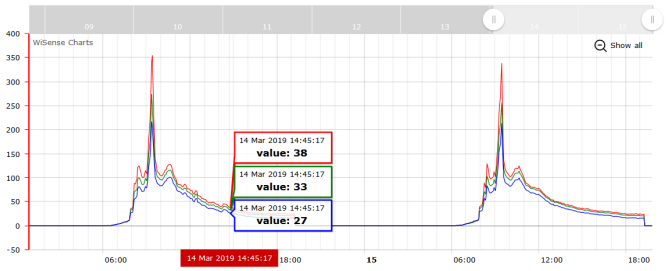

Fig. 3. Chart snapshot of the web application; RGB components of light inside Scrovegni Chapel.

order to minimize the wiring and simplify future nodes moving and adding. Moreover the wiring of the sensors and the installation of the hardware could damage or jeopardize the conservation of frescoes. The use of a self-configuring routing protocol, like Routing Protocol for Low power and Lossy network (RPL) makes the WSN dynamic and scalable. This allows to reduce the interventions of technicians on-site, thus to operate directly from remote. Nevertheless the proper choice of the best Data Base management Systems (DBMS) solution for storing the sensed data represents the key point, in fact this can make the system ready for successive upgrade of the sensor nodes or the IoT network architecture. The purpose of this work is to identify general comparative criteria between DBMS in order to make the best design choice in complex contexts such as the Scrovegni Chapel.

A. *Related works*

Related papers are focused on the comparison of different NoSQL DMBS through benchmarking tools, as in [9], or the performance evaluation of SQL versus NoSQL solutions on cloud environment using sensing data [10], and an overview of the current data storage systems in cloud computing and surveys of the state-of-art of data processing is discussed in [11]. Similarly to our work, Van Der Veen [12] compares the performance of a subset different from ours of SQL and No-SQL databases for the sensor network scenario, evaluated over physical and virtual machines limited to server environments. Meanwhile, Nyati [13] compared the performance between MongoDB, running on a cluster of four machines, and MySQL on a single machine. Other database solution for IoT applications are given by a distributed database [14], where each node of the network is able to store measurements and transmit sensed data when requested by the user, and a RFID repository based on MongoDB for sensor data source [15]. Recently are also appearing in literature Time-series DBMS for IoT applications [16]. This kind of DBMSs are well suited for the management of data associated with timestamp information, that are the measurements a WSN sensor node. In [17] are investigated the performance of TritanDB Time-series DBMS.

As integration of the previous described literature, our work consists in the objective quantification of relational and non-relational databases performances over embedded devices, using better hardware machines as a reference (see Table II). Especially we are considering an application scenario where data are collected and stored for improving the color rendering of Giotto's frescoes of the Scrovegni Chapel cultural heritage site.

The present paper is organized as follows. Section II gives a brief introduction to SQL and No-SQL DBMS and how data is stored inside these databases. Section III describes the implemented client-side scripts finalized to interact with the databases and the different types of queries used to quantify the performance of the examined systems. Section IV furnishes a brief description of the experimental simulation setup. Section V provides results of the performed tests with graphical and table support. Finally, Section VI presents the conclusions concerning the measured performance and the general inferable guidelines for the designer.

TABLE I
COMPARISON OF SQL AND NOSQL DOCUMENT-ORIENTED TERMINOLOGY

SQL		NoSQL
database	↔	database
table	↔	collection
row	↔	document
column	↔	field

II. SQL VERSUS NOSQL

Basically, two kinds of DBMS can be installed into a sink node, namely relational and non-relational database. In the first case, structured data (table) and language (SQL) with Atomic, Consistency, Isolation and Durability (ACID) properties are used, while in the latter a more flexible schema (i.e. key-value, document or column-oriented, Graph DB) and a non-structured language (NoSQL) are used in order to get better performances at the cost of ACID. Table I summarizes the principal data structures of relational and document-oriented NoSQL databases. For these DBMS, the CAP theorem must be considered, which states that only two of the three properties of a distributed system (Consistency, Availability and Partition tolerance) can be provided. In general, the partition tolerance adoption is preferable and then consistency or availability are alternatively chosen.

Relational databases use a rigid structure to store data, allowing a detailed vision of the managed data type. Each table is a set of homogeneous data, which can be related to other tables by a specific relation (key). In this way, new tables can be defined allowing relations (join) among data by specific requests. On the other hand, non-relational databases allow heterogeneous data storage into the same collection, enabling a dynamic expansion of the database's data nature, according to the new requests of an evolving application.

The present paper aims to furnish guidelines for choosing the proper DBMS that better fitting the specific IoT's architectural constrains. Therefore, we have analyzed the performance of three different DBMS on three distinct hardware devices, usable to implement a sink node, representing a not exhaustive subset of different computational and storage capabilities. Moreover for setting up the tests over the three DBMS, we also have to take into account the amount of data that can be

generated by the WSN. Since the network is composed of 5 nodes sampling every 5 minutes, and the data are encapsulated in the Constrained Application Protocol (CoAP) [18] (up to 96 Byte are available for data [19]), the number of messages sent per day is 1440 and per year is 525600, and the respective dimensions in byte are 138.2 KB and 50.5 MB.

The first analyzed database is MariaDB, representing a relational database exemplum and was choosen because of its open source patent and the high compatibility with MySQL. Indeed, the same client can be used to access both to Maria and MySQL databases (the port, socket and API are equal), moreover the binary files representing the tables are compatible. Finally, MongoDB and CouchDB represent non-relational databases, with the appealing characteristic of the open source license and a widespread use. MongoDB is an open source non-relational database, where data are stored as Binary Script Object Notation (BSON) documents, gathered in collections. The BSON object is an extension of the Java SON (JSON), which is a standard data format [20] constituted of "key-value" pairs elements, in an easy to read and write composition by humans, and be parsed and constructed by machines. A general representation of a JSON object is:

$$\{key_1 : value_1, key_2 : value_2, ..., key_n : value_n\}. \quad (1)$$

Moreover, MongoDB has replication and distribution features, and a rich query language supporting Create, Retrieve, Upload and Delete (CRUD) operations.

CouchDB is the second non-relational database used in our test. Similarly to MongoDB, data are stored like documents as JSON objects, but a particular feature of this non-relational database is the ability to perform queries through HTTP requests. CouchDB also implements a dynamic aggregation method, named View, that speed up queries using prepared statements. Of course there are many other possible NoSQL database solutions (column, key-value, graph, etc.), but for this paper we choose to evaluate only document oriented family as NoSQL because they are the best choice for small and medium size IoT application [12].

In order to compare the performances of relational and non-relational database on different hardware setups, the tests were conducted on three different devices implementing the sink node functionalities: a Raspberry board model B, a personal computer and a virtual machine running on a server (the respective characteristics are shown in Table II).

The hardware constrains of the sink node of a IoT system (see Fig. 1) depend on a variety of factors such as number of nodes, sensing area, type and number of sensing data, number of transmission, etc. and, in summary, on the suitable (costs/performance) rate for the specific application (e.g. in [2] an underwater vehicle is used to gathering data from underwater sensors). In most of IoT deployments, the sink node functionalities can be implemented in low-cost embedded devices with limited processing and storage capabilities, nevertheless adequate to manage the network and store data locally. Different deployment strategies can be adopted with the increase in the network's dimension. In fact, it is usual to overcome high numerosity of nodes with multiple sinks per network (horizontal scaling), otherwise, the hardware capability of the sink node can be potentiated (vertical scaling) to support the increasing network load. Therefore, different architectural solutions require diversified hardware resources for the sink node, each of which providing specific performance. Therefore, the need of fast analysis resources, responding to project specifications, for the combined choice of hardware and software solutions emerge. The work presented in this paper has exactly the previous purposes, providing reports of performance measured on different hardware platforms with various DBMS. Although the tested devices represent only a limited subset of possible combinations of hardware and database options, our tests provide significant support for the design and development of real solutions.

TABLE II
HARDWARE CHARACTERISTICS

Machine	Architecture	Max Clock Speed	Core	RAM	OS
Personal Comp.	x86_64	3100 MHz	4	8 GB	Ubuntu
Virtual Server	x86_64	2660 MHz	4	4 GB	Debian
Raspberry	armv6l	700 MHz	1	0.5 GB	Raspian

III. CLIENT-SIDE SCRIPTS

The performances of the DBMS under test are evaluated by running Python scripts measuring the query time needed to write and read sensing data on the database. The Python client libraries (MySQL [21], pymongo [22] and couchdb [23]) are used to perform the respective connections to the DBMS. Since an IoT system collecting information from a sensing area is the application scenario, the most interesting functions to be evaluated are multi-clients write operations, where a single sensor node writing one data into the database is simulated by a thread, and bulk reads from the database, to export the stored data into a remote server.

The series of queries to the database, generated by just as many scripts, are summarized below.

- One Client Operations:
  - One sensed data is written into the database 10,000 times;
  - One stored data is read from the database 10,000 times;
  - A dataset of 100 sensed measures is written into the database 1,000 times;
  - A dataset of 100 stored data is read from the database 1,000 times.
- Multiple Clients Operations:
  - One sensed data is written into the database, by 1 to 15 concurrent clients;
  - One sensed data is read from the database, by 1 to 15 concurrent clients;
  - A dataset of 100 sensed data is written into the database, by 1 to 15 concurrent clients;
  - A dataset of 100 sensed data is read from the database, by 1 to 15 concurrent clients.

In [10], [12] the number of concurrent threads for the multiple write operation is 16, and since the WSN deployed inside the Scrovegni Chapel have to be composed of 5 sensor nodes, we

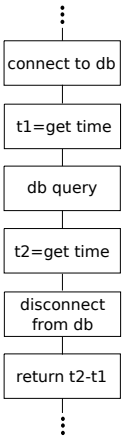

Fig. 4. Flow chart of the Python script for query latency measurement.

have chosen to use 3 times that number of nodes as upper limit for the multiple clients operations to test the different databases for this specific WSN case of use.

In Fig. 4 is shown the code flow used to calculate the latency time of the performed read or write queries on the selected database. The execution time is thus evaluated as the time required $(t_2 - t_1)$ to receive the ACK from the database after the write instruction ending, or the time waited to receive the queried data from the database. In case of queries executed by concurrent clients, each thread, which represent a single client, performs the operations reported in Fig. 4. The value $dt = t_2 - t_1$ is then written on a file for further evaluation.

IV. Test Setup

The Python script is saved and ran on each under test device, and connects to the chosen database which is installed on the same device to avoid network latency. Therefore, sensing data are stored into the non-relational databases according to the schema in (1), which takes the following form:

$$\{'sensor_tag' :' sensor1','sensor_value' : 27.0123456789, \\ 'sensor_time' : 1526891381.160871\} \tag{2}$$

where $value_1$ is a string used to identify the specif sensor measuring data on the network, while $value_2$ and $value_3$ are floating numbers representing the sensed value and the sensed time respectively. The same data are stored into the relational database as a table like that depicted in Table III. The Python script is then used to read and write the described values on the different databases, and save into a file the resulting latency time measured according to the flow chart of Fig. 4. Moreover each test is repeated n times and the average latency over the n simulations is evaluated.

TABLE III
Sensed Data on MariaDB

Column Name	Data Type	Example
$sensor_tag$	$var_char(10)$	sensor1
$sensor_value$	float	27.0123456789
$sensor_time$	float	1526891381.160871

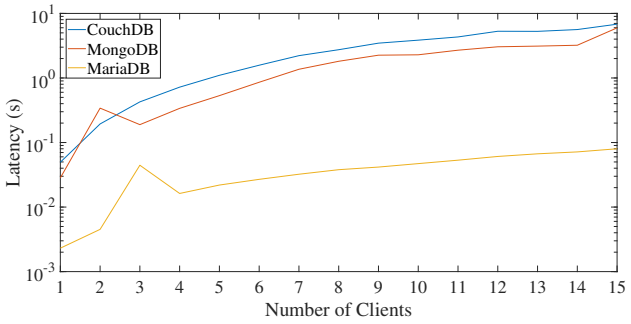

Fig. 5. Multi clients: latency of single write operations on Raspberry.

V. Result and Discussion

As presented in Section IV, the results related to a single write operation from concurrent clients are shown in Figs. 5, 6, 7, and those referred to a bulk read from a single client in Figs. 9, 10, 11.

Regarding the results displayed in Figs. 5, 6, and 7, the latency time of the write operations increases with the number of concurrent clients as expected, and the database latency has about the same trend for the different testing devices. The better performance is furnished by MariaDB, with an average latency time per client of 5 ms, 0.923 ms, 0.28 ms, with reference to the outcomes depicted in Figs. 3, 4, and 5 respectively, followed by MongoDB and CouchDB. Nevertheless, CouchDB seems to have only slightly inferior performance with respect to MongoDB when running over Rapsberry or Vitual Machine (see Fig. 3 and Fig. 5). Furthermore, the performance on the embedded device is lower than that on the other machines, in fact the latency of write operations over the relational MariaDB in Fig. 5 is about 6.5 times higher than that in Fig. 6 and is 18 times higher than that in Fig. 7. The same considerations can be done for the two NoSQL databases, indeed CouchDB on the embedded device is about 9 times slower respect to the PC and 8 times slower the virtual machine, while MongoDB on the embedded device is about 40 times slower respect to the PC and 7.5 times the VM.

In addition, the databases performance on PC and virtual machine depicted in Fig. 6, 7 can be more effectively compared evaluating the difference between their latency times. In fact, this comparison shows an almost linear trend for MariaDB and CouchDB, as presented in Fig. 8 where the vertical axis indicates the differences in the latency times.

This trend, which is almost superimposed for the PC and the VM, shows that the latency gap between the databases (MariaDB and CouchDB) on PC and VM grows linearly and is about the same up to 9 concurrent clients. The trend changes slightly for a number of clients above 9, so the performance remains almost unchanged as the underlying hardware varies, at least up to the number of competing clients considered in our simulations. Moreover, the performance of CouchDB on the PC increases and the latency gap reduced accordingly, while on the VM it continues to grow.

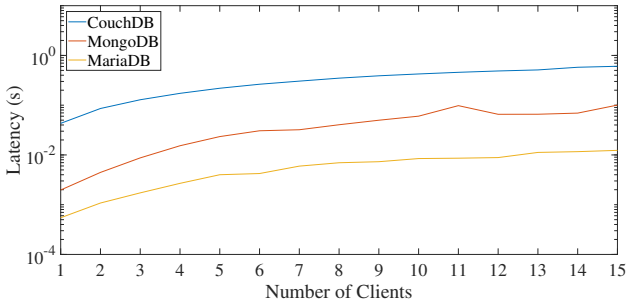

Fig. 6. Multi clients: latency of single write operations on PC.

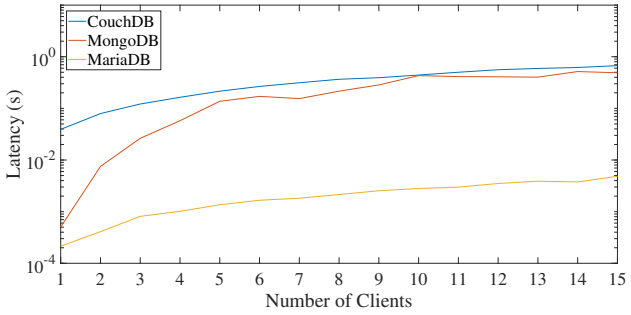

Fig. 7. Multi clients: latency of single write operations on Virtual Machine.

The next group of figures, Fig. 9, 10, 11, represents the latency time of bulk read operations. Also from these figures is possible to identify a similar behavior, in fact for all three devices the average latency time trend is almost constant, and for these devices is presented the same performance order of the databases. The considered non-relational databases demonstrate better performance respect to the relational one, MariaDB. Comparing the average latency of the faster database, CouchDB, the outcome for the different devices are: 0.917ms for Fig. 9, 0.032ms for Fig.10, and 0.034ms for Fig. 11, followed by MongoDB and MariaDB. The same behavior described above is also confirmed in this test, the embedded device offers significantly lower performance than PC and VM performance. In fact, CouchDB is about 28.6 times slower than the PC and 27 times respect to the VM, while MongoDB is 33 times slower than the PC and 19 times slower than the VM.

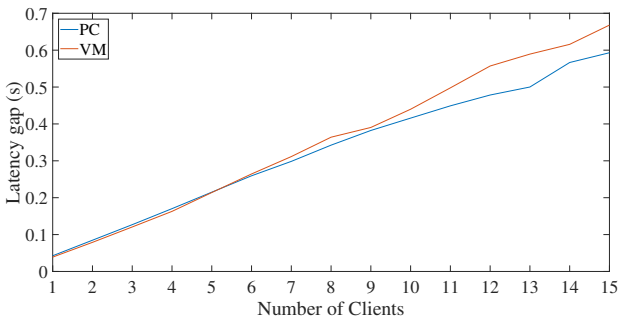

Fig. 8. Latency times difference between CouchDB and MariaDB on PC and VM for multi clients single write operations.

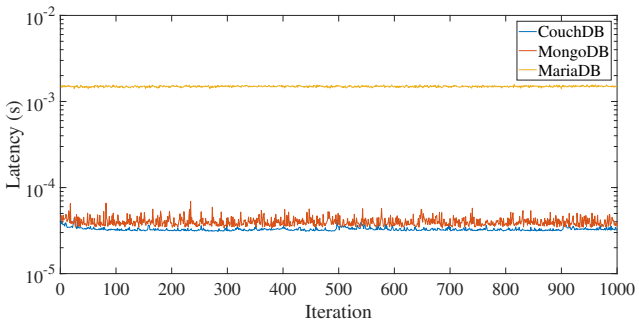

Fig. 10. Single client: latency of bulk read operations on PC.

The complete characterization of the databases performance is obtained through the execution of a series of tests simulating the most frequent operations over a database whose results are summarized on Table IV and Table V. The best performances of each devices are highlighted. Table IV collects the average latency time of single client operation while Table V shows the average latency time per client for the multiple client queries. These outcomes lead to say that the relational database, represented by MariaDB, has the lower write latency time, but, on the other hand, non-relational databases, MongoDB and CouchDB, have the best reading performance. Furthermore, comparing the results for the three devices, the virtual machine and the personal computer have almost the same latency time, while the embedded device has slower query time. In fact it is about 40 time slower then the PC and 60 times slower then the virtual machine. These performances of the embedded device respect the other two machines were expected, because of the different capacity of the hardware installed.

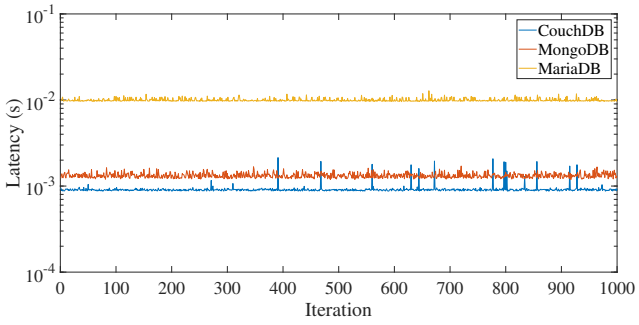

Fig. 9. Single client: latency of bulk read operations on Raspberry.

VI. Conclusion

This paper compares 3 DBMS running on machines with different hardware characteristic, and the performances of such databases are evaluated in the context of a IoT data storage scenario in a site with cultural heritage constrains. Results shown on Section V point out that the relational database MariaDB has better write speed than the non-relational MongoDB and CouchDB, but the latter offer faster read operations.
A good solution for sensor network applications is given by a database used to store sensor measurement temporarily, which

TABLE IV
SINGLE CLIENT RESULTS

Operation	DB	Rasp. (ms)	P.C. (ms)	V.M. (ms)
single write	Mongo	57.65	1.8125	0.482
	Maria	2.493	0.713	0.6285
	Couch	6.966	47.14	3.900
single read	Mongo	1.209	0.051	0.071
	Maria	134.6	13.14	4.242
	Couch	0.094	0.034	0.004
bulk write	Mongo	589.5	1.923	2.725
	Maria	122.0	4.700	1.414
	Couch	670.6	85.18	41.67
bulk read	Mongo	1.326	0.040	0.070
	Maria	9.900	1.500	0.450
	Couch	0.917	0.032	0.034

TABLE V
MULTIPLE CLIENT RESULTS

Operation	DB	Rasp. (ms)	P.C. (ms)	V.M. (ms)
single write	Mongo	233.7	5.548	30.97
	Maria	5.065	0.769	0.281
	Couch	364.0	41.83	44.56
single read	Mongo	2.472	0.093	0.070
	Maria	6.037	1.427	0.361
	Couch	3.878	0.109	0.051
bulk write	Mongo	233.7	11.46	7.352
	Maria	5.065	170.9	21.66
	Couch	1092	42.24	47.06
bulk read	Mongo	24.47	0.08	0.069
	Maria	6.037	181.7	77.67
	Couch	3.878	0.098	0.051

allows fast single write operations and fast bulk read to load the data to the remote database. The simulations performed haven't found a valuable database for both operations, thus the solution depends on the requirements of the sensor network's tasks. However the chances of use schema-less databases (non-relational) is really attractive to store heterogeneous sensor data, indeed the nature of a IoT application is dynamic and the kind and number of sensor data to store may change during the application lifetime, leading to chose NoSQL database solution for such applications. In conclusion, the results obtained suggest us to use MongoDB as database solution for the IoT application developed for the Scrovegni Chapel, and others heritage sites IoT systems.

For the future works we are planning to test TimeSeries DB on a real use case to evaluate its performances on a WSN application.

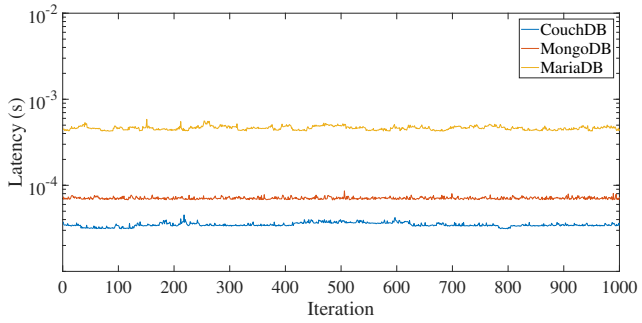

Fig. 11. Single client: latency of bulk read operations on Virtual Machine.

CONFLICT OF INTERESTS

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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MIMIC: a Cybersecurity Threat Turns into a Fog Computing Agent for IoT Systems

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***Abstract*—Fog and cloud computing are very attractive enabling technologies for Internet of Things applications. The virtualization of smart devices which compose the Internet of Things network is a promising field of research, leading to the design and development of new services and uses. To the best of our knowledge, this paper presents the first attempt to use a cybersecurity attack to realize a fog computing agent for Internet of Things systems. In particular the Man-In-The-Middle attack will be use to show the foundation of the proposed Man-In-the-Middle-Iot-Computing tool, namely MIMIC, and through the examples and tests performed we will show its potentialities.**

***Index Terms*—Internet of Things, Man-In-The-Middle, Man-In-the-Middle-Iot-Computing (MIMIC), Fog Computing, Cloud Computing, IPv6.**

I. Introduction

Internet have gained a key role in the research and development of new enabling technologies, and the Internet of Things (IoT) has become one of the most interesting fields of application of this century. The ongoing reduction in cost of the required hardware for the deployment of embedded devices, have allowed the widespread diffusion of millions of connected smart object. In fact is foreseen that on 2020 there will be more than 50 billion devices connected to the Internet. IoT fields of application are the more different, such as Industry 4.0 [1], home automation [2], Ambient Assisted Living (AAL) [3], health-care [4], automotive [5], smart-grid [6], cultural heritage [7], smart-city [8] and more. All these field of applications have in common the gathering, storing and later the elaboration of data, to acquire knowledge (and even to make decisions or perform actions). This feature can be managed in several ways. Every node of the IoT network may perform these operations (sensing, storing and elaboration), the nodes send the data to an edge node that perform such operations (From cOre to edGe (fog) computing [9]), or finally, the nodes may send the collected data into a remote server for successive elaboration (cloud computing).

New promising technologies are emerging close to fog and cloud computing namely Software Defined Network (SDN) [10]–[12] and Network Function Virtualization (NFV) [13], which are currently appearing in the IoT scenario [14]. Virtualization is the key role played in the disruptive technologies above. These new virtual architectures are well suited for the IoT, since in most IoT application are used constrained devices (with battery supply) to build and manage the network, acquire data from the environment, process sensed data, and to send data to the user. Thus the concept of fog computing combined with the cloud environment, represent an attractive solution for the IoT to increase the performances and services offered by the network. In fact many companies are investing in IoT cloud platforms such as Amazon (AWS), Cisco (Cisco IoT), IBM (Watson), Microsoft (Azure) and more.

Cloud computing is the technology which makes available virtual resources on a remote data center for the storing, processing and using the data sent to the cloud. On the other hand, the fog, is the availability of virtual resources close to the data source, in other words is an extension of the cloud. In the IoT scenario fog computing is used to manage the data on the so called edge node, creating new services for the user and reducing the impact of sensor nodes heterogeneity. When fog computing is combined with a remote cloud infrastructure, it is used to select and filter data that require high computational resources and large storage systems, in order to be sent to the remote cloud platform. Otherwise for low latency applications, the data are forwarded to the client by the edge bypassing the cloud. Hence the fog and cloud computing are two paradigms aimed to create virtual services for deployed networks. Instead, the other two virtual paradigms (SDN and NFV) are specific for network management.

The aim of SDNs is to centralize the network control in order to increase the performance of the system by decoupling control and forwarding plane. The SDN controller spreads the rules to the forwarding plane composed of routers and switches of the network. These devices use the rules to correctly route the packets over the network, and unmatching packets are sent back to the controller to create new rules. A well known protocol implementation of SDN is OpenFlow [15] which allows the remote management of the layer 3 forwarding tables of network devices. NFV is the other concept behind the virtualization of network functionalities, in fact is complementary to SDN but is not necessary to have both together. Moreover, with NFV is possible to virtualize network resources reducing the costs and the time to market for the service providers, creating energy efficient IoT network, allowing network stack customization, and increasing Quality of Service (QoS).

With this paper we want to show the foundations of an innovative virtual architecture to aid and support the management of IoT IP-oriented network, that have to be installed

into an edge node of the IoT network (fogging). This proposed software agent on the edge node is able to sniff and even catch the incoming IP traffic from the Wide Area Network (WAN), that is the mainly task of the cybersecurity attack known as Man-In-The-Middle (MITM), and then it makes complex decision based on the application purpose. Different tests of the proposed tool were carried out on a real IPv6 IoT network, with a sub-GHz IEEE 802.15.4 radio channel, IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) adaptation layer, and ContikiOS operative system on nodes. In section II we present the Man-In-the-Middle-Iot-Computing (MIMIC) tool, and to the best of our knowledge is the first attempt to use of a cybersecurity attack as fog computing agent for supporting IP networks. In this section is described how it works, and through three tests are compared its performances against real IPv6 IoT nodes. Section III shows the architecture composed of the MIMIC and the IoT network, describing how the virtualization is achieved and how users request are processed by the MIMIC. On Section IV are briefly introduced privacy challenges in fog computing applications.

A. Related Works

Many researchers are working on the exploit of virtual technology for IoT applications, combining the above mentioned promising virtual solutions to increase the efficiency of IoT networks. In [16] Mahmud *et al*. have used the OpenFlow protocol [15] on a IoT architecture to split data and control flow in order to allow resource sharing between different networks, and they have evaluated the reachability, packet sent and simulation time of different topology size. IoT energy management is investigated in [17], where the authors propose the software-defined Wireless Sensor Network (WSN) framework for 6LoWPAN (SD_WSN6Lo). With this framework, based on SDN paradigm, Lasso *et al*. have calculated an average energy saving of about 15% on the ContikiOS nodes simulated with Contiki network simulator Cooja [18]. Other works are focused on the energy savings given by the fog computing. In [19] are used "virtual resources" on an intermediate IoT device to relocate slice of the application. With the use of virtual resources on IoT scenario is achieved an improvement of about 40% in energy consumption and 60% in control loop latency. Whereas in [20] is proposed a framework based on Mixed Integer Linear Programming (MILP) and supported by cloud computing to reduce the energy consumptin of IoT networks up to 36%. Morabito [21] has evaluated the performance of Docker containers on different Single-Board Computers (SBCs) as edge nodes of an IoT network. The results obtained by Morabito show that the container-based virtualization represent a promising solution for building efficient IoT edge devices. A work very close to our is proposed in [22] by Abeele *et al*., where is presented the concept of Sensor Function Virtualization (SFV) as enabling technology for IoT systems. An aspect that is highlighted in our and in their work, is the key role played by the transparency of the virtual system for the end users, otherwise it may results annoying for the users point of view. Abeele *et al*. solution is also mainly deployed on cloud infrastructure, whereas our is deployed at the edge of the IoT network, implementing the so called fog computing. Instead, Bonomi *et al*. in their work [23] explained that the fog computing, respect to the cloud, represent a appealing solution for IoT composed of constrained sensor nodes that require: low latency, real time interactions, heterogeneity, wireless access, and more. Thus the fog computing can deliver new breeds of services and applications in the IoT scenario.

II. The MIMIC agent

The MITM attack [24] is a well known security threat in the communication between two end-points. In this kind of attack a third party start passively, with no chance to be detected, to sniff the traffic between two legitimate users over their communication channel. The goal of the MITM is not only to look the whole traffic, but it can also modify, replace and reply, the target's victim messages while staying concealed. Is possible to use this behavior of the MITM to work as fog computing agent in a IoT scenario, where it can be deployed on the edge node of a IoT network to control and manage the traffic of "victim" users. The MIMIC operates as the MITM attack. In fact, MIMIC is not IP addressable and is not identified by any Uniform Resource Identifier (URI), it is concealed while sniffing the traffic to the target network. The ability of the MIMIC to stay concealed to users is based on the IP-Spoofing attack [24], which exploits the header of the IP packet to edit the source address field for impersonating the real sensor node. In this fashion, when it detects a request that it knows how to manage, it removes the packet from the data flow and generates a proper reply or performs operations on the destination IoT node.

This behaviour is described on Fig.1, that shows a client that is performing GET request (2) to one node of the IoT network identified by its own global IPv6 address, and the MIMIC do

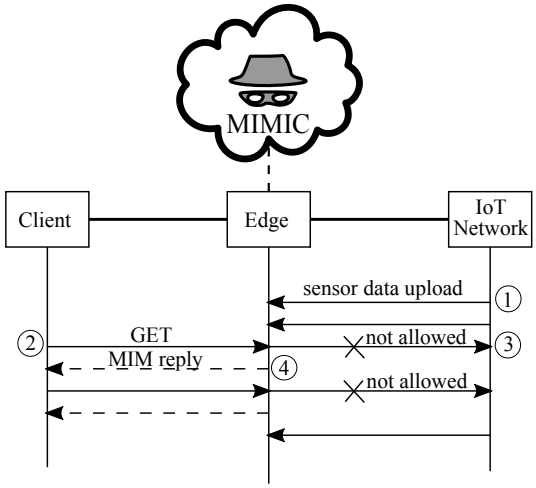

Fig. 1. Sensor data are uploaded by IoT nodes and stored on the edge (1); GET request (2) from the "victim" client are replayed back (4) by the MIMIC agent working on the edge of the IoT network; no client forwarding (3) to the IoT network is allowed.

not require any specific URI to be invoked for managing that request. At the edge of the IoT network the MIMIC agent is sniffing the traffic flow, has seen the incoming request and has captured it for blocking its forwarding to the IoT network. The MIMIC thanks to the fog computing (see Section III) has knowledge of the data sensed by the IoT network (1), since all the data are stored on the edge node. Thus it can reply to the client the information requested by forging *ad hoc* packets (4). In that case the MIMIC agent is no more a MITM attacker, but instead it became an active component of the system, that is a fog computing agent at the edge of the IoT architecture. The MITM cybersecurity attack is now used to help the remote clients to get information about the sensed data. Hence, in such system the goal of the MIMIC is to capture incoming packets, and then reply to the user requests with forged packets, making appear the packets generated by IoT nodes. This feature of the MIMIC, make the responses appear as generated by the real IoT nodes, and the system results to be totally transparent for the users experience. For the point of view of the users this is a very attractive feature, because users do not have to install additional software, use specific URI or any Application Program Interface (API) to let the MIMIC working.

Solutions that offer services similar to the novel MIMIC tool are proposed by AWS IoT Core and Hub IoT of Microsoft Azure, and are respectively the Shadow Device [25] and Digital Twin [26]. These solutions use JavaScript Object Notation (JSON) documents to store the state and data of the IoT devices connected to the cloud service. Clients may use HyperText Transfer Protocol (HTTP) methods or Message Queue Telemetry Transport (MQTT) topics to communicates with the virtual version of the IoT devices. MQTT is a publish/subscribe communication model, therefore both AWS and Azure implement a set of reserved topics to enable applications and devices to get, update, or delete the state information for a device (shadow/twin). For example in order to retrieve the latest state stored, it is possible to send a MQTT subscribe request to the reserved topic or use a HTTP GET request, that takes one of the following forms:

- https://endpoint/things/thingName/**shadow** (AWS)
- https://fully-qualified-iothubname.azure-devices.net/**twins/**id?api-version=2018-06-30 (Azure)

Clients have to use specific URIs to communicate with virtual devices. Instead our solution exploiting the MITM cybersecuirty attack creates transparent smart virtual IoT devices, that in addition to storing data and device state, are able to process incoming packets as real IoT devices.

```
PING 2001:760:2e0d:130:3035:3230:5234:740a(2001:760:2e0d:130:3035:3230:5234:740a) 56 data bytes
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=1 ttl=52 time=194 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=2 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=2 ttl=50 time=197 ms (DUP!)
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=3 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=3 ttl=50 time=195 ms (DUP!)
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=4 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=5 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=5 ttl=50 time=200 ms (DUP!)
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=6 ttl=52 time=101 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=7 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=7 ttl=50 time=200 ms (DUP!)
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=8 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=8 ttl=50 time=195 ms (DUP!)
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=9 ttl=52 time=100 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=10 ttl=52 time=109 ms

--- 2001:760:2e0d:130:3035:3230:5234:740a ping statistics ---
10 packets transmitted, 10 received, +5 duplicates, 0% packet loss, time 9012ms
rtt min/avg/max/mdev = 100.663/140.011/200.227/46.875 ms
```

Fig. 2. Example of MITM agent packets replication. The duplicated packets (DUP!) are the reals packets sent by the IPv6 node.

```
PING 2001:760:2e0d:130:3035:3230:5234:740a(2001:760:2e0d:130:3035:3230:5234:740a) 56 data bytes
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=1 ttl=52 time=1727 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=2 ttl=52 time=803 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=3 ttl=52 time=841 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=4 ttl=52 time=985 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=5 ttl=52 time=211 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=6 ttl=52 time=660 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=7 ttl=52 time=217 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=8 ttl=52 time=107 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=9 ttl=52 time=823 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=10 ttl=52 time=275 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=11 ttl=52 time=353 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=12 ttl=52 time=453 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=13 ttl=52 time=133 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=14 ttl=52 time=260 ms
64 bytes from 2001:760:2e0d:130:3035:3230:5234:740a: icmp_seq=15 ttl=52 time=546 ms

--- 2001:760:2e0d:130:3035:3230:5234:740a ping statistics ---
15 packets transmitted, 15 received, 0% packet loss, time 14004ms
rtt min/avg/max/mdev = 107.034/560.013/1727.742/417.346 ms, pipe 2
```

Fig. 3. Example of MITM agent packet replication with random delay. No packets forwarding to the IoT network.

In the next figures (Fig. 2 and Fig. 3) are shown two examples of the MIMIC agent behavior on the Internet Control Message Protocol Version 6 (ICMPv6) Echo Requests and Constrained Application Protocol (CoAP) GET Request performed by a Linux client to one IPv6 sensor node of the 2001:760:2e0d:130::/64 network. Fig. 2 shows the output of the ping6 command to the IoT node identified by the global IPv6 address 2001:760:2e0d:130:3035:3230:5234:740a, with the MIMIC agent running on the edge and the packet forwarding to the IoT network enabled. This means that in this particular example, both the MIMIC virtual node and the real IoT node receive the ICMPv6 request and both reply. A total of 10 ICMPv6 request are sent to that node, but 15 replies are received: 10 replies and 5 duplicates. The 5 duplicates are sent by the real IoT node (5 packets are lost) and all the 10 replies are forged by the MIMIC agent. The 5 duplicates from the real IoT node are received because in this example the forwarding to the IoT network is still enabled. Is important to notice that the forged replies have the same Round Trip Time (RTT) of 100ms (except the first, because of ARP cache filling), while the packets sent by the real IoT node have an average delay of about 197ms. In order to have a complete characterization of the 6LoWPAN network under test, in Tab. I is listed the average RTT and packet loss obtained by the ping6 tool used on each one of the 7 nodes of the network. A total of 1000 ICMPv6 request were sent to each IPv6 node, and referring to the table, the node #3 is the one identified by the address 2001:760:2e0d:130:3035:3230:5234:740a. In this example (Fig. 2), the MIMIC agent that is controlling the edge of the IoT network, has replayed to the ICMPv6 request with a better RTT and a lower packet loss respect to the IoT node on the 6LoWPAN network. This result show that the MIMIC is able to virtually augment the QoS of the IoT node, that is a valuable feature for fog computing applied to IoT networks. In fact one of the motivation of fog computing is the user satisfaction (QoS) [14], [27].

On Fig. 3 is shown the ping6 test on the same node, but in this case the packet forwarding to the IoT network is disabled (the real node do not receive the ICMPv6 request, thus no duplicated packets can occur) and a random delay between 0 to 1 sec is added to reply. The random delay is

```
$python coapclient.py get 2001:760:2e0d:130:3035:3230:5234:740a /test/rssi
Tx Power-> -0dBm
RSSI-> -72.500000dBm
$
$python coapclient.py get 2001:760:2e0d:130:3035:3230:5234:740a /test/rssi
Coap MiM Response
$
$
```

Fig. 4. MIMIC agent forging piggybacked CoAP response.

an example of QoS customization per client. This example shown the MIMIC tool at work, it captures the packet from the data flow and forges the proper packet for the user. The two test performed on the virtual IoT node, managed by the MIMIC agent, characterize the necessity and the potential of fog computing solution. Raising the QoS of the IoT network is not only the main aspect of the virtualization and the usage of the MIMIC.

MIMIC agent can also impersonate IoT node services. In fact, the first rows of Fig. 4 shows the CoAP server response of the IoT node (#3). The resource identified by the URI "/test/rssi" on the CoAP server, returns the transmitting power and the last Received Signal Strength Indicator (RSSI) of the target node. The first GET request is executed by a custom Python script on a Linux Desktop-Pc as shown on Fig. 4, and is responded by the real node giving the expected information. Whereas the second GET request, executed by the same script, is responded by the MIMIC agent with a forged IPv6 packet containing the CoAP payload: "Coap MiM Response" (of course the aim of the MIMIC is not to modify the content of the message, but instead to reply to users requests with the right data, see Section III). The ability of MIMIC to impersonate IoT node services gives the opportunity to move the application layer from the real nodes to the virtual nodes, thus reducing the memory requirement of the IoT (constrained) device.

In this last test performed are compared the goodput of the virtual node of the MIMIC agent versus the real IoT node, and the results are depicted on Fig. 5. As shown on the figure it is clear that the goodput performances of the MIMIC virtual node are better than the IPv6 node of the IoT network. This outcome is obviously expected, since the IEEE 802.15.4 standard [28] uses a Physical Service Data Unit (PSDU) of 127 Byte, hence at network layer for the ICMPv6 data field are available only 37 Byte. Referring to the red curve of Fig. 5 as the payload increase, IP fragmentation occur and the goodput performances degrade down to 0 bps at a payload size of 116 Byte. Whereas the blue curve describes a monotonically increasing function, and has a goodput value of about 26 Kbps at 160 Byte of payload (a goodput of 125 kbps was achieved for the payload size of 1.2 KB). The IoT network under test operates at the ISM frequency of 868 MHz, that permits a data rate of 20 Kbps. The previous outcome states that the virtual nodes can overcome the limitations of the standard, making available new kind of services that before were not conceivable. The feature of the MIMIC agent to be transparent for the users, can be used to create virtual services on the edge node of the IoT network, as proved by the test of Fig.4. Nevertheless, each node of the IoT network is virtualized inside the MIMIC agent, and on the virtual nodes can be added resources and services not present in the real node (HTTP Server, CoAP server, DB, and more) with better QoS, breaking the concept of constrained device in the virtual space.

TABLE I
RTT MEASUREMENT

Node	Packet loss (%)	$< RTT >$ (ms)
#1	62	276.2
#2	13	191.5
#3	38	191.2
#4	47	275.2
#5	29	272.3
#6	30	279.3
#7	1	188.7

III. Virtual IoT Architecture

Fog computing is an extension of the cloud computing but close to the edge of the network. The first definition of fog is given by Bonomi *et al.* [23] as: "Fog Computing is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network". Many researchers have found a strictly connection between fog computing and IoT systems. The possibility to have low latency, heterogeneity, geographical distribution, access to wireless devices, computing, storage, and more at the edge of the network, is a very attractive solution for IoT applications [9]. In the context of our application, fog computing is used to store and process data gathered by the IoT sensor nodes (Fig. 1 (1)), and with the assistance of the MIMIC tool, is possible to have virtual IoT devices with high computing power and additional services for managing users requests.

In the previous section, we have seen that the MIMIC agent is able to capture the IPv6 traffic of the "victim" users, and reply to them by forging *ad hoc* packets. The agent is deployed on the edge node of the IoT network (Fig. 6), which results to be the best position for a MITM attacker who want to sniff and capture all the incoming traffic.

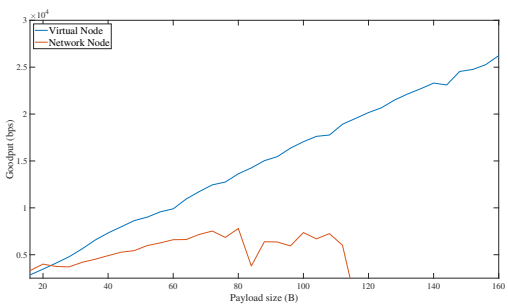

Fig. 5. Goodput comparison in bps for the virtual and real IPv6 nodes.

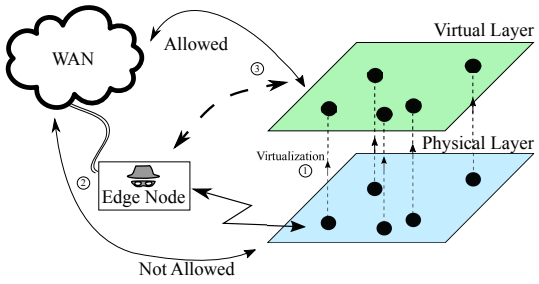

Fig. 6. Proposed architecture for the virtualization of the sensor nodes, from the physical layer to the virtual. A virtual copy of the nodes is created on the Virtual Layer (1), the MIMIC on the edge controls incoming requests (2) and it process the packets according to virtual nodes information (3).

Sensing nodes are placed in the Physical Layer on Fig. 6 and are virtualized by the MIMIC agent (1), which creates virtual twin nodes with the same resources (and even more) on the Virtual Layer. This proposed system is used to separate remote users from the real IoT environment, letting them to query only the virtual space created on the edge node. As depicted on the Fig. 6, the transmission from the WAN to the IoT Physical Layer is not allowed, because the MIMIC working at the edge of the network is the responsible of the packets capturing on the incoming IP traffic (2). This software agent, through the virtual IoT nodes, makes decisions on the response to be sent to the users, and then sends them the information requested, if they got the right privileges. Thus, the remote user that wants to communicate with one or more IoT nodes, instead communicates with the MIMIC virtual nodes (3).

The usage of this solution gives many advantages to an IoT system. Each user request, that is IP encapsulated, is managed by the virtual system on the edge node and no more by the constrained IoT nodes. The nodes of the network have to sense the surrounding environment and upload the measures to the edge, making them available to the MIMIC agent. In this way, the effort of the IoT nodes is reduced. In fact, the nodes no longer have to take into account the management of incoming users requests, so reducing the number of transmissions required, and the energy consumption of the radio transceiver. In fact, one of the advantages of this solution is the energy saving of the IoT nodes [17], [19], [20], specially for wireless IoT architectures where packets retransmissions occur. This solution should not be limited to energy saving purposes, but also to latency and retransmissions reduction due to packets loss. Therefore the MIMIC agent is able to raise the QoS of IoT systems as demonstrated by the tests.

IV. Privacy challenges

In literature there are several researches focusing on the privacy issues, challenges, and solutions on fog computing applied to IoT [29]–[31], but actually the research is still on a very early stage. In fact these issues are mainly investigated for cloud computing environment, and are not suitable in the context of fog computing [30] due the heterogeneity of the IoT network devices. These challenges are focused on the privacy of the data collected by the IoT sensor nodes that may expose sensitive information about the users and/or the monitored environment. Thus is required to give authentication, authorization and data protection to the fog environment. These privacy challenges and security issues will be studied and implemented on future works of the MIMIC tool.

V. Conclusion

This work presents the innovative usage of the cybersecurity threat known as Man-In-the-Middle attack as fog computing agent for IP-oriented IoT networks. This agent, namely MIMIC, has to be deployed at the edge node of the network to exploit all of its full potential, because the edge positioning makes possible easy sniff, capture and reply to all incoming IP packets. The MIMIC agent is also able to create virtual nodes of the IoT network under control, as shown on the tests of Section II, and moreover is able to implement services like a CoAP server. The tests performed on the MIMIC have proven the better performance of the virtual nodes with respect to the QoS of the IoT nodes, so furnishing a valuable results for fog computing applications. In addition, one of the most important features of the MIMIC is its ability to stay concealed to the end users, implementing a transparent service that does not require any API for the connected clients.

In our future works on the MIMIC tool we are planning to implement HTTP server and security features for the virtual nodes of the fog computing environment.

Conflict of interests

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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FREQUENCY SPECTRUM AND ANTENNAS

Optimizing Mobile Radio Access Network Spectrum Refarming Using Community Detection Algorithms

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Abstract - Radio spectrum refarming is a cost-effective way to increase capacity for UMTS/LTE without the need to acquire new spectrum. Therefore, it is an important process for today's mobile operators. As radio access networks (RAN) became more complex, the process of choosing which radio sites to refarm has become complex and time-consuming if done manually. This paper proposes the use of community detection algorithms for automating the process of RAN spectrum refarming. The problem of RAN spectrum refarming can be modeled as a graph in which one needs to isolate nodes which are densely connected. In RAN spectrum refarming it is crucial to keep the interference between sites and technologies at a minimum. Several community detection algorithms were tested for RAN spectrum refarming. Girvan-Newman algorithm showed most accurate results and was used for implementation of optimization solution. In this paper, the authors provided a benchmark of various network and cluster sizes. Result showed that RAN spectrum refarming can be optimized from one to several weeks to roughly few hours per cluster.

I. INTRODUCTION

Over the past few decades the telecommunications industry has evolved from second generation (2G) networks, to third generation (3G) networks, to 4th generation (4G) networks. As the upcoming fifth generation (5G) mobile radio system is being developed, many believe it will drastically challenge the existing communication infrastructure and network topologies [1]. In order to facilitate the use of new radio technologies, a mobile operator has to carefully use the spectrum it has purchased. Since different generations of radio networks use the spectrum in a specific way, it is often required to reorganize the frequency plan in order to use the new radio technology efficiently. This process is called spectrum refarming and it is a cost-effective way to increase capacity for radio networks without the need to acquire for new spectrum.

A radio access network (RAN) is the technology that connects end-user devices, or terminals, to other parts of a network through radio connections. Spectrum refarming refers to the process of managing radio resources in order to support different generations of cellular networks and enable them to operate in the same radio spectrum [2]. As RAN networks grew larger due to an increasing need for coverage, spectrum refarming has become a complex task. When done manually on a large network, it is not uncommon for the refarming process to span over several months. One of the main reasons why spectrum refarming is a complex process is the key requirement that refarmed cells need to keep the interference levels between their neighboring cells at a minimum [3], [4].

The goal of this paper is to model spectrum refarming as a graph problem and automate the process of finding an optimal plan by using community detection algorithms. A graph consists of edges and vertices or nodes. In the proposed method, the nodes are the telecom sites which make up the RAN network, while the edges are an arbitrary distance function.

This paper proposes and tests a solution for creating refarming plans on real world RAN networks. The following chapters provide an overview of the developed system, as well as an analysis on the use of various community detection algorithms for the spectrum refarming use-case. The developed solution has been tested on several large RAN networks located in Europe and South America.

II. RELATED WORK

Community structures have been found to exist in various types of networks. For example, social and biological systems [5], information networks [6], musical compositions [7], network analysis [8] and many other domains have found a use for community detection algorithms. The reason for its widespread use can be explained by the fact that community structures widely exist in so many real-life systems [9]. A majority of existing studies have been focused on defining, measuring and detecting community structures in complex systems. The studies of Newman et al. [10]–[12] are amongst the first studies in detecting community structures by measuring their modalities. As pointed out by [9], currently there is no general statistic model capable of describing all kinds of community structures. Therefore, various models have been proposed, each of which typically trying to reveal a certain aspect of the community structures. Some studies have been conducted to reveal community structures of real-life networks [6], [13], while some focus on random network models with community structures [14]. Other studies have focused on using statistic models such as powerlaw distributions [15], [16].

Although there are extensive studies on detecting community structures, it is believed that the current perception of the importance of community structures and how their existence benefits the systems remains to be rather limited. This paper studies the effects of community

structures on spectrum refarming in RAN networks. The goal of this paper is to leverage community detection algorithms in automating the spectrum refarming process. The authors hypothesis is that, by detecting community structures in graphs which were created based on RAN site relations, one can create a refarming plan which has the least amount of interference.

The rest of the paper outlines the proposed solution for automating spectrum refarming and provides an analysis of the use of various community detection algorithms for the spectrum refarming use-case.

III. System Overview

This section provides an overview of the developed solution for optimizing RAN spectrum refarming using community detection algorithms.

In this paper, the problem of spectrum refarming is modeled as a graph in which the distance between each node is modeled to take into account the interference between each node. An efficient spectrum refarming plan aims to minimize the interreference between refarmed nodes. Therefore, the distance function should be modeled to take into account several factors which indicate how much two nodes interfere with each other. The definition of the distance function is out of scope for this paper since it can vary on real-world needs and the reframing strategy. The proposed solution is independent of the distance function used.

A. Data Collection

The operator is required to collect input data which can be mapped to RAN sites and their locations. Depending on the distance function used, additional data may be required in order to calculate the weight for the graph edges. An average operator may have up to 30000 relations, or around 3000 sites. Section IV contains a benchmark which indicates how the algorithms perform based on the size of the input. From a data collection perspective, the format depends on the operator's internal processes and equipment. However, in most cases a textual input file (e.g. CSV) is available.

B. Architecture

Figure 1 shows the architecture of the developed solution. The refarming solution consists of three steps:

- Input parsing and data preparation: input.csv files are parsed and stored to SQLite database. Few SQL queries calculate values from stored data and filter out data that is below thresholds provided from the operator. Calculated values are then used to filter sites (nodes) and connections (edges) that will form a graph as well as calculate weights that are applied on created edges.
- Clustering: calculated nodes, edges and weights are added to Graph object. Graph is then analyzed by Girvan-Newman algorithm. Algorithm runs as many iterations needed to get maximum cluster size that is defined by the operator. After algorithm is finished, script runs calculation and recommends sites that should be shut down in order to minimize interference between two clusters while being refarmed.
- Report creation: clusters are written to .xlsx file that contains a sheet for each cluster with list of sites in cluster, number of cells on each technology and frequency per site and, optionally, relevant hardware data to calculate cost of cluster refarming. Report also contains map of all sites in the network colored in different colors depending on cluster they belong to and individual zoomed-in maps for each cluster.

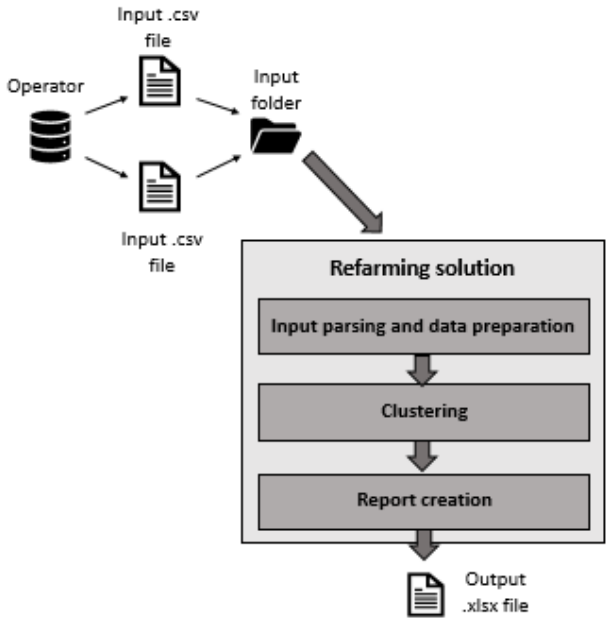

Figure 1 – Architecture of the developed solution

C. Community Detection Algorithm

This paper proposes community detection for automating the process of RAN spectrum refarming. The problem of RAN spectrum refarming can be modeled as a graph in which one needs to isolate nodes which are densely connected. In RAN spectrum refarming it is crucial to keep the interference between sites and technologies at a minimum.

Several community detection algorithms were tested for RAN spectrum refarming:

- Girvan-Newman Algorithm [5]: hierarchical method which defines the edge betweenness of an edge as a number of shortest paths between pairs of nodes that run along it. If a network contains groups that are only loosely connected by a few intergroup edges, then all shortest paths between different communities

must go along one of these few edges. By removing these edges, the groups are separated from one another and reveal the underlying community structure of the graph.

- Louvain Method [17]: heuristic method based on modularity optimization that is divided into two phases that are repeated iteratively. Different community is assigned to every node of the network. For each node i we consider the neighbors j of i and we evaluate the gain modularity that would take place by removing i from its community and placing it in the community of j. Node i is then placed in the community with maximum gain.
- Kerninghan-Lin Algorithm [18]: heuristic algorithm for finding partitions of graphs. The goal of algorithm is to partition set of nodes into two disjoint subsets A and B of nearly equal size in a way that minimizes the sum of the weights of the subset of edges that cross from A to B. The algorithm improves a partition in each pass by using a greedy algorithm to pair up nodes of A with nodes of B by moving nodes from one side of partition to other.
- Fluid Communities Algorithm [19]: algorithm initializes k fluid communities, each in a different and random node, with associated density (0,1] where density of a community is the inverse of the number of nodes composing the community. Algorithm operates through supersteps in which it iterates over all nodes in random order, updating community with goal to return communities with maximum aggregated density within the network.

IV. RESULTS

To evaluate the developed solution, a standalone workstation was used. The workstation was running a Windows 7 Professional operating system with a E3-1245v5 CPU, 32GB of RAM and 512GB solid-state drive (SSD). The solution was developed using the NetworkX library [20], which is a popular and often used library for testing and implementing network graphs in computer science [21]–[24]. Tests were conducted on input data that was collected from several operators from Europe and South America.

A. *Comparison of different community detection algorithms on RAN spectrum refarming problem*

To compare the results of different community detection algorithms on the spectrum refarming problem, this study used a network with 632 nodes and 2615 weighted edges. Throughout all tests, a cluster size of 300 nodes was used. This study notes that the size of the cluster may vary depending on the operational preferences of the network operator. A size of 300 nodes per cluster was chosen because it represents a maximum node size which is usually used in large RAN refarming operations. Figure 2a shows graph created using the network data before applying the community detection algorithms. Nodes are shown as red dots and edges as black lines. In figures 2b to 2e, black dots represent nodes (sites) that are placed between two clusters and need to be shut-down when refarming is taking place on its neighboring clusters. Once the refarming process for these clusters has been completed, those nodes can be refarmed and turned on again.

Figure 2b shows the resulting communities detected by Girvan-Newman algorithm [11]. This algorithm does not support setting a maximum cluster size. Therefore, the developed solution ran iterations until all communities had a nodes size less than 300, which was the size chosen for this benchmark. The results have a very small number of shut-down sites, which is desirable. The clusters are concentrated in a close geographical region and are of similar size. The downside of the Girvan-Newman algorithm is its computational complexity, described by $O(m^2n)$ where m is number of edges and n is number of nodes.

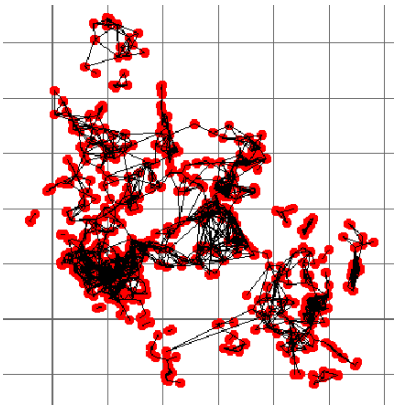

Figure 2a – Starting graph with its nodes and edges

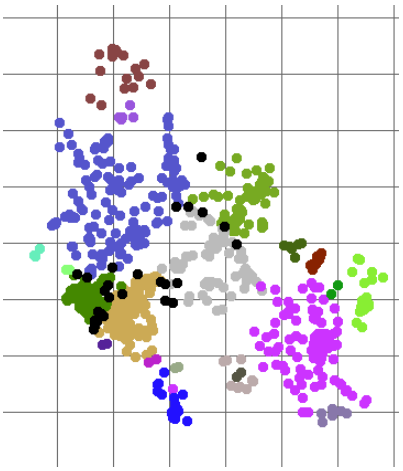

Figure 2b – Graph created by Girvan-Newman algorithm

Figure 2c shows the resulting communities detected by the Louvain Method [15]. For this method, there was no

way to configure maximum cluster size. The result is a graph that is divided into subgraphs that are mostly too small. Furthermore, this approach gives to many shut-down sites, which would make the refarming purposes too complicated in real-world scenarios.

Figure 2d shows the results obtained by applying the Kernighan-Lin algorithm [16] on the graph. This algorithm also does not support maximum cluster size limitation, so the same modification as with Girvan-Newman algorithm was applied. Result shows subgraphs that are scattered and thus not applicable for the refarming purposes.

Figure 2e shows a graph created by Fluid Communities algorithm [17]. As with the other algorithms, this method does not support maximum cluster size. However, the algorithm supports setting a maximum number of clusters which was used as replacement. In this test, a maximum of 10 clusters were used. The resulting communities are concentrated in a close geographical region. However, there are more shut-down sites compared to Girvan-Newman method.

Based on the results of the test, this paper concludes that the most applicable result was given by Girvan-Newman algorithm.

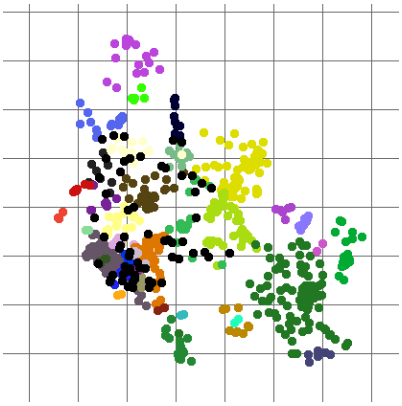

Figure 2c – Graph created by Louvain Method

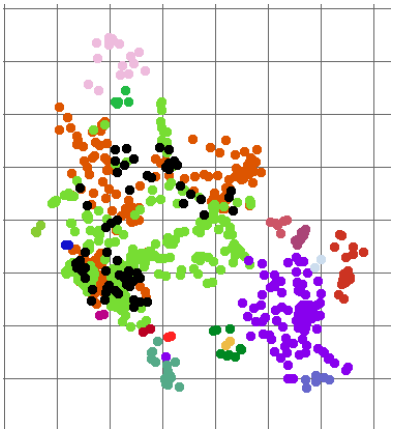

Figure 2d – Graph created by Kerninghan-Lin algorithm

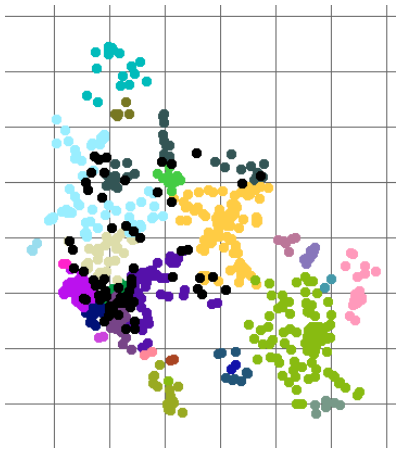

Figure 2e – Graph created by Fluid Communities algorithm

B. *Developed solution benchmark*

The results shown in this benchmark were achieved using data from a large network operator. To get different number of nodes and edges and not to artificially cut the network, different frequencies were used within the network which resulted in different number of nodes and edges. This is because not all frequencies are available on all sites. The results are shown in tables 1 to 3 and figure 3. As expected by the Girvan-Newman algorithm [5], computational complexity is approximately $O(m^2n)$ where m is number of edges and n is number of nodes.

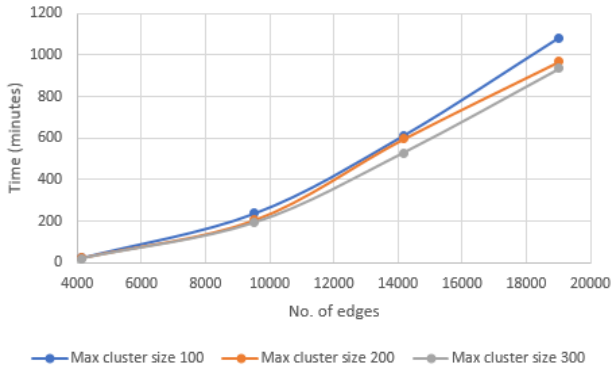

Figure 3 – Developed solution benchmark for 3 maximum cluster sizes

Different maximum cluster sizes were used throughout the benchmark to show its effects on execution time. Table 1 shows the benchmark results when maximum cluster size is set to 100 sites. Whereas Table 2 and Table 3 show the benchmark results when maximum cluster size is set to 200 and 300 sites respectively. The results for all three tables were achieved using the same dataset. Each table entry describes the number of nodes and edges that was used.

Based on the results, it can be concluded that the execution time is higher when smaller maximum cluster size is chosen. That is because smaller maximum cluster size requires more iterations of the Girvan-Newman algorithm. Number of iterations will also be dependent on network density. Having more edges between nodes will increase the number of paths that will have to be traversed in the search of isolated communities within the graph.

This can be seen in the increased execution time in cases where the number of nodes and edges is higher.

TABLE 1. DEVELOPED SOLUTION BENCHMARK WITH MAXIMUM CLUSTER SIZE OF 100 SITES

Number of nodes	*Number of edges*	*Execution time (in minutes)*
827	4116	23.18
1559	9516	237.22
2162	14168	611.55
2986	19013	1082.12

TABLE 2. DEVELOPED SOLUTION BENCHMARK WITH MAXIMUM CLUSTER SIZE OF 200 SITES

Number of nodes	*Number of edges*	*Execution time (in minutes)*
827	4116	21.5
1559	9516	204.22
2162	14168	595.23
2986	19013	968.28

TABLE 3. DEVELOPED SOLUTION BENCHMARK WITH MAXIMUM CLUSTER SIZE OF 300 SITES

Number of nodes	*Number of edges*	*Execution time (in minutes)*
827	4116	18.27
1559	9516	191.43
2162	14168	529.75
2986	19013	935.5

V. CONCLUSION

This paper studied the application of community detection algorithms on the spectrum refarming process in RAN networks. Specifically, the paper investigated the effects of various community detection algorithms for isolating clusters of sites that should be refarmed together. A performance analysis showed the estimated complexity of detecting communities in real-world scenarios. The analysis was conducted using real data obtained from a large European operator. Based on these results, this paper concludes that community detection algorithms can be used for automating and improving the spectrum refarming process. Further studies should focus on improving the execution time of the overall refarming process. In the current study, the execution time mostly depends on the complexity of the underlying community detection algorithms. Future studies should also consider the application of different weight functions when modeling the distance between nodes.

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Path loss model fitting for TV bands based on experimental measurements for urban environments in Kosovo

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***Abstract*- Signal attenuation due to path loss can significantly affect the quality of a wireless communication link. This makes path loss measurement and estimation an important aspect when designing wireless communication systems. However, accurate values for path loss are rarely readily available, as they heavily depend on a range of factors such as line-of-sight conditions, terrain, environment and transmitter and receiver positions and height. To this end, it is much more practical to use path loss models to estimate the expected value of path loss in a certain environment, instead of actual measured values. In this paper, we use experimental data of received power levels emitted by TV broadcasters in the UHF and VHF bands, and compare them to known and widely used path loss models such as Hata, Ericsson, COST and Egli, in order to identify which propagation models best fit our urban environment. Measurement locations were selected to represent various environments within the urban area of Prishtina, the capital of Kosovo. Our results show that for short distances (up to ~20 km), Hata model exhibits lower values of RMSE compared to measured values, while for longer distances (above ~20 km), Ericsson model is the better fit.**

Keywords - TV bands, UHF, VHF, path loss models, spectrum measurement

I. Introduction

With the exponential growth in smart wireless devices usage and their constant necessity for wireless connectivity, wireless cellular networks suffer from spectrum shortage. This imposes even more congestion in the already congested spectrum. In the other hand, research has shown that some frequency bands are underutilized. This is the case with the frequency band used by TV broadcasters especially now that many countries have switched to digital TV transmission which resulted in free spectrum known as TVWS (TV White Space). To overcome the spectrum congestion and efficiently use the underutilized spectrum, the idea of cognitive radios was presented as an efficient solution [1]. When planning a wireless communication system, the parameter that mostly affects the design of the network and quality of the communication link is the path loss. Path loss is the attenuation of signal between transmitter and receiver during transmission. Propagation models are used to predict the path loss at a given location in a certain environment. They depend heavily on a range of factors, such as: line of sight between transmitter and receiver, their position and height, terrain conditions and environment. There are many propagation path loss models used in wireless communications. However, choosing the appropriate model for a given area is not a straight forward task as it requires extensive measurements to determine the model that best fits the environment conditions.

In this paper, we use experimental data of received power levels emitted by TV broadcasters in the UHF band (470-860 MHz) and VHF band (174-230MHz) [2] and compare them to known and widely used path loss models such as Hata, Ericsson, COST and Egli, in order to identify which propagation models best fit our urban environment in Prishtina. We consider these models because these are the models that are mostly used in these cases [3, 4, 5, 6].

Even though, Kosovo has not yet fully transitioned to digital transmission, determination of the propagation model will provide a framework for the design of cognitive heterogeneous wireless network that are envisioned to coexist in TVWS in the future.

The rest of the paper is organized as follows: Section II describes the propagation models chosen to be used for analytical analysis. The details of the spectrum measurement process and the measurements results are presented in Section III. The results of comparative analysis are provided in section IV and conclusions are drawn in section V.

II. Propagation models description

The four propagation models used in this paper for comparative analysis, are described briefly below:

A. Hata Model

The Hata model is an extension of the Okumura-Hata model for distances 20 - 100 km, and covers a frequency range from 15-1500MHz. Hata's basic formulation for urban environments is given by:

$$PL_{50}(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_t) - a(h_r) + [(44.9 - 6.55)\log(h_t)]logd \quad (1)$$

where, f_c is the carrier frequency in MHz, h_t base station antenna height in meters, h_r is the receiver height and *d* is the distance between transmitter and receiver in km. The term $a(h_r)$ is the correction factor for effective receiver antenna height and depending on the type of environment. For small or medium size city the value of $a(h_r)$ is given by [7]:

$$a(h_r) = (1.1\log(f_c) - 0.7)h_{re} - (1.56log(f_c) - 0.8)\ (dB) \quad (2)$$

whereas for larger cities is given by:

$$a(h_r) = 8.29(log1.54h_{re})^2 - 1.1\ (dB);\ \ 150 \le f_c \le 200\ MHz$$

$$a(h_r) = 3.2(log11.75h_{re})^2 - 4.97\ (dB);\ \ f_c \ge 200MHz \quad (3)$$

Considering that Prishtina is a small city compared to Tokyo city where that model was built for, for our analysis we choose equation (2).

B. Ericsson Model

The Ericsson model is also derived from Okumura-Hata model but it allows adjusting the parameters based on the environment. The path loss in this model is calculated with the following formula:

$$PL_{Ericsson} = a_0 + a_1\log(d) + a_2\log(h_t) + a_3\log(h_t)\log(d) - 2(\log(11.75h_r))^2 + \mathrm{g(f)} \quad (4)$$

where, f is the carrier frequency in MHz, h_t base station antenna height in meters, h_r is the receiver height and *d* is the distance between transmitter and receiver in km. The g(f) parameter is defined as:

$$g(f) = 44.9\log(f) - 4.78(\log(f))^2 \quad (5)$$

The constants a_0, a_1, a_2, a_3 are model parameters and can be varied according to the propagation environment. For urban environment [8], the default values of these parameters are: $a_0 = 36.20, a_1 = 30.20, a_2 = 12$ and $a_3 = 0.1$.

C. Egli Model

The Egli model can be used for the frequency range 40 - 900 MHz and for distances up to 60 km. Even though the farthest TV broadcaster transmitter is located further than 50 km, the model serves our purpose. The propagation loss is calculated with [9]:

$$PL_{Egli} = \begin{cases} 20\log(f_{MHz}) + P_o + 76.3, & h_r < 10 \\ 20\log(f_{MHz}) + P_o + 83.9, & h_r > 10 \end{cases} \quad (6)$$

and,

$$P_o = 40\log(d) - 20log(h_t) - 10\log(h_r) \quad (7)$$

where, f is the transmission frequency in MHz, h_t and h_r are the base station and receiver antenna heights in meters and *d* is the distance between transmitter and receiver in km.

D. COST 231 Model

The COST 231 model is also an extension of Hata model and its designed to be used in frequency range from 500-2000 MHz. The expression for the path loss is given by [10]:

$$L = 46.3 + 33.9logf - 13.82logh_t - a(h_r) + (44.9 - 6.55logh_t)logd + c_m \quad (8)$$

where, *d* is the distance in meters, h_t and h_r are base station and receiver antenna height in meters and *f* is frequency in MHz. Parameter c_m is defined as 0 dB for suburban and rural environment and 3 dB for urban environment. For medium size city, the parameter $a(h_r)$ is defined as:

$$a(h_r) = (1.1logf - 0.7)h_r - (1.56logf - 0.8) \quad (9)$$

Although the frequency range of this model is outside the frequency range of the measurements, the opportunity for factor correctness made it widely used in the bands of interest [11].

III. Spectrum measurement set up

The measurements were conducted at 8 different locations in Prishtina, using the NARDA Selective Radiation Meter SRM-3006 using Spectrum analysis mode of the device. MATLAB software was used to process and analyze the data. To have the picture of the different propagation environments, measurement locations are illustrated in Fig.1. Measurement locations were selected to represent various environments within the urban area of Prishtina, the capital of Kosovo. The description of each location is elaborately described in [12].

We have calculated the received power in dBm for each channel by summing all the individual powers detected in 70/80 bins of a 7/8MHz channel. Since we know the locations and the antenna characteristics of the TV broadcasters [2], we are able to calculate the distance and the measured path loss between each TV transmitter and location measurement. The distances between the TV transmitters (denoted as TX) and locations are shown in Table 1.

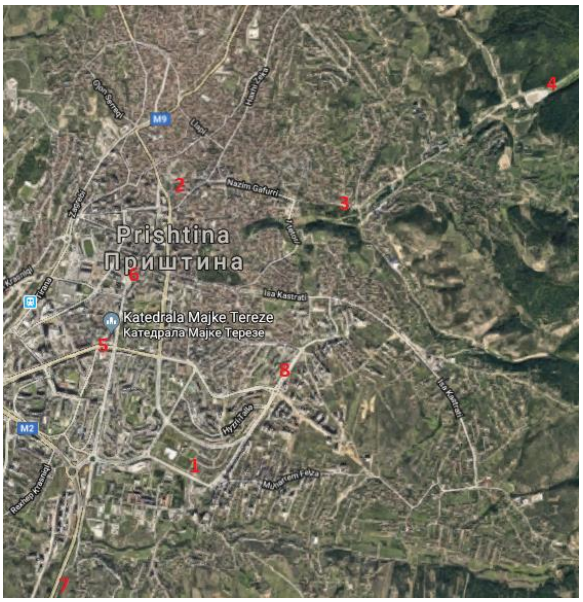

Fig.1. Measurement locations

Table 1. Distance in km for all locations from each transmitter

	Measurement Locations							
TX	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	50,2	48,3	51,1	53,1	50,0	76,9	48,4	51,2
2	33,4	34,1	31,7	32,7	32,4	57,1	34,2	33,4
3	28,8	29,2	29,9	28,3	29,7	11,5	29,2	28,4
4	50,2	48,3	51,1	53,1	50,0	76,9	48,4	51,2
5	32,6	33,6	32,9	30,9	33,2	3,2	33,6	31,8
6	3,05	5,1	1,4	0,9	2,6	28,6	5,0	2,2
7	50,2	48,3	51,1	53,1	50,0	76,9	48,4	51,2
8	60,2	58,2	61,6	63,4	60,4	83,4	58,2	61,2
9	30,4	28,7	32,5	33,0	31,2	41,7	28,7	31,0
10	0,7	2,7	1,6	2,4	1,0	29,1	2,7	0,3
11	32,6	33,6	32,9	30,9	33,2	3,2	33,6	31,8
12	50,9	49,0	53,0	53,8	51,6	62,8	49,0	51,7
13	0,7	2,7	1,6	2,4	1,0	29,1	2,7	0,3
14	42,9	43,9	43,4	41,4	43,6	13,8	43,9	42,2
15	28,9	29,3	29,9	28,3	29,7	10,9	29,2	28,4
16	30,4	28,7	32,5	33,0	31,2	41,7	28,7	31,0
17	36,0	36,5	34,3	35,6	35,0	60,7	36,5	36,0
18	28,9	29,2	30,1	28,6	29,8	13,0	29,1	28,5
19	33,4	34,1	31,7	32,7	32,4	57,1	34,2	33,4
20	42,9	43,9	43,4	41,4	43,6	13,8	43,9	42,2
21	13,8	15,9	12,3	10,6	13,6	24,4	15,9	12,8
22	37,7	37,7	39,1	37,8	38,7	20,8	37,7	37,5
23	33,4	34,1	31,7	32,7	32,4	57,1	34,2	33,4
24	42,9	43,9	43,4	41,4	43,6	13,8	43,9	42,2
25	59,0	56,9	60,6	62,2	59,3	79,3	56,9	60,0
26	28,6	29,1	29,7	28,0	29,5	10,5	29,0	28,2
27	13,8	15,9	12,3	10,6	13,6	24,4	15,9	12,8
28	27,8	28,2	28,9	27,4	28,7	11,9	28,1	27,4
29	60,2	58,5	60,7	62,8	59,90	88,5	58,6	61,1
30	13,8	15,9	12,3	10,6	13,6	24,4	15,9	12,8
31	59,0	56,9	60,6	62,2	59,3	79,3	56,9	60,0
32	38,6	39,1	37,0	38,2	37,6	63,1	39,2	38,7

IV. Results

The power received has been estimated using the above mentioned propagation models described earlier. The actual measured values of received power within each channel are shown in Fig. 2, with blue bars, whereas in different colors (purple, yellow, dark blue and green) is shown estimated power when using different propagation models for the same conditions.

As we can see from the figure, the estimated powers are lower than the measured values because we don't account for losses due to shadowing and multipath effects.

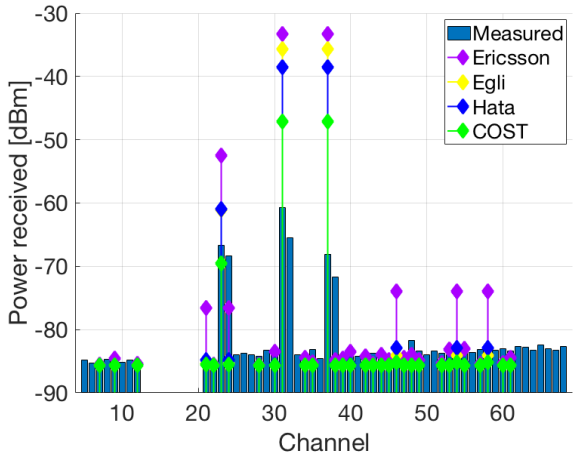

Fig. 2. Measured and estimated power received

Next we present the path-loss obtained from measurements and from using above mentioned propagation models as a function of distance. With red bars, we present the difference between maximal and minimal measured value. We have also included here the free space path-loss model just to have a better understanding on the crucial role of using a propagation model. It is clear from the figure that using free-space propagation model significantly underestimates the actual path loss value.

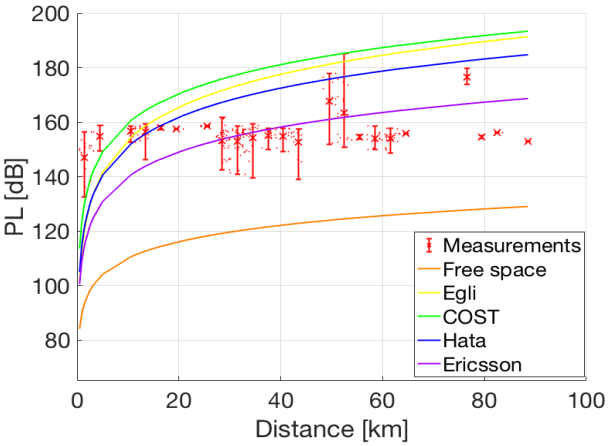

Fig. 3. Measured vs estimate path-loss

As we can see from the plot, the propagation model that best matches the measured values for short distances is Hata model (up to 20km), whereas for long distances is the Ericsson model.

The propagations model performance was also analyzed based on two metrics: prediction error and standard deviation, calculated by [13]:

$$\Delta x_i = P_{predicted} - P_{measured}$$

$$\Delta\bar{x} = \frac{1}{N}\sum_{i=1}^{N}\Delta x_i \quad (10)$$

Table 2. The average error probability for all locations and propagation models

$\Delta\bar{X}$, dB	COST231	HATA	EGLI	ERICSSON
1	28.681	10.725	-16.765	-1.342
2	31.567	-7.0532	-16.697	-4.1207
3	30.102	-6.395	-18.972	-3.5048
4	30.104	-6.07001	-18.581	-3.338
5	35.0075	-11.334	-12.467	-8.378
6	37.081	-10.475	-23.075	-7.572
7	31.199	-7.067	-15.825	-4.132
8	30.931	-7.317	-8.443	-4.392

$$\sigma = \sqrt[2]{\frac{1}{N}\sum_{i=1}^{N}(\Delta x_i - \Delta\bar{x})^2} \quad (11)$$

Table 3. Standard deviation for all locations and propagation models

σ, dB	COST231	HATA	EGLI	ERICSSON
1	14.46	19.853	13.249	10.315
2	16.444	16.644	17.886	14.038
3	16.569	18.206	19.707	15.45
4	15.913	17.625	19.253	15.051
5	14.851	16.001	16.803	13.842
6	13.848	16.482	17.569	13.884
7	15.2	14.201	14.918	11.82
8	14.611	15.331	16.204	12.846

It is clear from Table 2 and Table 3 that the Ericsson model has the lowest error probability and standard deviation value for each location.

We also present the RMSE (root mean square) of path-loss in dB, for all the measurements conducted in same distance. The RMSE value is calculated with [14]:

$$RMSE(d_{l,t}) = \sqrt{\frac{\sum(P_{l,t}^{m} - P_{l,t}^{p})^2}{N}} \quad (12)$$

where, $P_{l,t}^{m}$ is the measured path-loss from broadcaster t at location l, $P_{l,t}^{p}$ is the model predicted path-loss, and $d_{l,t}$ is the distance between the transmitter and the receiver. N is the number of samples.

We can see form the plot in Fig.4, that while Cost model overestimates the path-loss, the Ericsson model has the lowest RMSE value for most locations. The acceptable RMSE for a model is about 10–15 dB for suburban and rural areas [15] which is the type of environment that our measurement locations fit in.

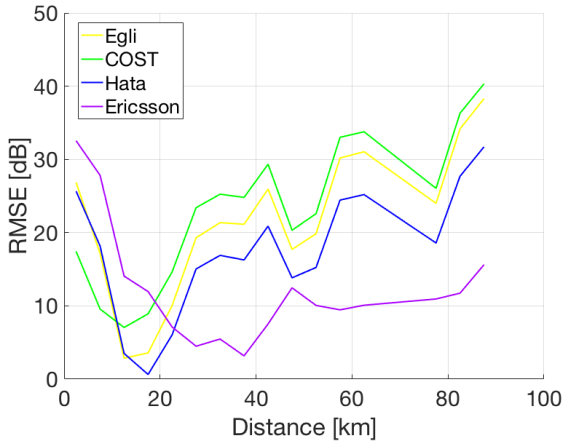

Fig. 4. RMSE of path-loss

V. Conclusions

The goal of this paper was to conduct studies on choosing the propagation model that best fits the type of urban environment in Kosovo. The measured data of received power and path loss values are compared to the predicted values generated from four propagation models for VHF and UHF frequency bands. From the analysis it is clear that that the propagation models that best fits for Prishtina type of environment is Hata model for short distances between transmitter and receiver and Ericsson model for larger respective distances. Future work is planned to extend the measurement campaigns over the entire territory of the country to obtain a comprehensive picture of country environment type and then with optimization of the factors decide on the propagation model that best fits the country terrain profile.

ACKNOWLEDGMENT

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Experimental assessment of electric field levels emitted by UHF TV broadcasters

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***Abstract* - Operation of high power broadcast transmitters in populated areas is accompanied with concerns regarding human exposure to emitted electromagnetic fields and related safety issues. In this paper we present the results of in situ measurements of electric field levels emitted by TV broadcasters operating in UHF frequency band. Measurements are conducted in far field zone, with calibrated spectrum analyzer NARDA SRM 3006, capable of capturing separately contribution of each transmitter/channel. Measurement locations are selected to include urban (mostly) and rural environments, indoor and outdoor spots, LOS and NLOS positions, and also different heights from the ground level. Software post processing of measured TV transmitter electric field samples in typical environments, reveal that highest averaged value of electric field is 102.73dBµV/m, captured in outdoor environment - LOS position. This corresponds to channel 31 transmitter, with Effective Radiated Power 15 kW, broadcasting in frequency 551.250 MHz. Most of measured electric field values for outdoor environments are in the range 70-80dBµV/m, while for indoor environments they range in 70-75dBµV/m. All measured samples of electric fields emitted by TV broadcasters are below the reference levels given by ICNIRP. The results of our measurement campaign are compared with results of similar studies conducted in different countries and results of comparative analysis are given in paper.**

Keywords - electric field, TV transmitters, UHF, measurement, spectrum analyzer, broadcaster

I. INTRODUCTION

Radio frequency (RF) and wireless communication systems are advancing at an unprecedented rate having noticeable impact in our daily lives [1].

The most important application of RF systems is providing telecommunication services such as: radio and television broadcasting, cellular telephony, personal communication services, cordless telephones, amateur and professional radio services, microwave point-to-point links and satellite communications, to name a few [2].

One of the parameters considered in the process of planning and exploitation of wireless systems and networks is inevitable human exposure to RF electromagnetic fields (RF-EMF) and possible related safety issues.

The results of experimental determination of RF-EMF of 2G, 3G and 4G cellular systems, up-link and down-link signals, Wi-Fi networks, DECT technologies and other RF technologies are presented [3-6], and in addition exposure levels are compared with safety standards given by International Commission on Non-Ionizing Radiation Protection – ICNIRP [7].

To date, based on our knowledge, there are limited number of studies presenting results of RF-EMF emitted by TV transmitters, whereas due to high power transmission the considered EMF strengths, in vicinity of broadcasters, may be expected.

Another factor to be investigated is RF-EMF levels emitted by TV broadcasters before and after analogue switch-off. The results of Ultra High Frequency(UHF) TV band spectrum and field strength measurements pre and post analogue to digital switching are given in [8]. Measurement of frequency occupancy levels in TV bands in urban environments in Kosovo are presented in [9] showing that spectrum utilization in these bands could be greatly improved by allowing the opportunistic use of spectrum by cognitive radios and other wireless communication technologies, such as future cellular networks. Therefore determination of signal strength, beside RF-EMF exposure determination, is important and for planning of network coverage for primary and secondary users and also for interference related issues in coexistence of heterogeneous networks scenarios at TV bands.

In this paper we present the results from measurements of electric field levels in Prishtina and suburb, emitted by TV broadcasters which operate in UHF band.

Measured values of electric field strength are compared to ICNIRP reference levels for occupational and general public exposure. To our knowledge, this is the first such study to be conducted in Kosovo, and one of the very few in the Western Balkans region. Applying study proprietary measurement protocol we performed a set of measurements over the UHF band with Selective Radiation Meter SRM- 3006.

The rest of the paper is organized as follows: Section II describes the details of the measurement campaign while the measurement results and comparative analysis

are presented in Section III. Conclusions are drawn in section IV.

II. MATERIALS AND METHODS

A. Measurement set-up and equipment

The analog terrestrial TV broadcasting in Kosovo is allocated in the following spectrum bands: VHF 174-230 MHz (8 channels, each 7MHz wide) and UHF 470-860 MHz (48 channels, each 8MHz wide). This paper is focused only on UHF band.

To assess the electric field levels in UHF band downtown Prishtina, measurements were performed at 23 different locations using the NARDA Selective Radiation Meter SRM- 3006 with a frequency resolution of 100 kHz.

The SRM-3006 is a spectrum analyzer equipped with a three-axis isotropic antenna that is able to detect signals from 9 kHz to 6 GHz. The device can be connected to a PC via RF cable. MATLAB software was used to process and analyze the data. The measurements were performed using the Safety Evaluation Mode of the device. A service table was created prior to starting of measurements. At each location, 2 measurements were performed, each lasting around 10min after approximately 1000 runs. Measurement parameters are set as shown in Table I.

B. Measurement Locations

The locations were chosen to represent the various types of environments present within the Prishtina urban area. The map of measurement locations is given on Figure 1. Where possible, in areas with taller buildings, measurements were taken in the ground floor and higher floors. Also at some locations where it was possible measurements were taken indoor, and if the terrain was not suitable only outdoor measurements were conducted. As shown in Table II., measurements were taken in three urban residential areas: at a school building (locations 16-19) situated in an uphill terrain and partially shadowed; at a residential area near the city center surrounded mainly by low-rise and little shadowing (location 1); and a residential area surrounded by high-rise buildings and shadowed by a hill (locations 20-23).

TABLE I. MEASUREMENT PARAMETERS

No.	NARDA SRM-3006 Configuration	
	Parameter	***Value***
1	UHF Frequency Range	467.75-851.25 [MHz]
2	Result type	Max, Min, Avg
3	RBW	100 kHz
4	Measurement Range	Automatic
5	Unit	dBµV/m

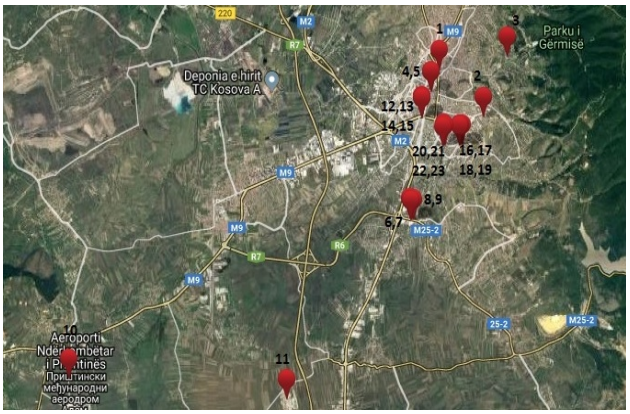

Figure 1. The map of measurement locations

Within the city center measurements were taken in two different locations: the main city boulevard (location 4, 5), which is a pedestrian street surrounded by medium-rise buildings (4-6 floors building); and at a high rise building in the city center (locations 12-15), surrounded by lower-rise buildings and situated in an uphill terrain. Measurements were also taken at two different parks, one within the city itself (location 2) and the other one in the outskirts of the city (location 3). Finally, measurements were also taken inside and near a shopping center (locations 6-9), outside of the city, situated on top of a hill, in a developing area planned to accommodate several upcoming residential neighborhoods, and in two rural areas also, one situated near Prishtina airport (location 10) and the other one at residential area surrounded by low-rise buildings (location 11).

TABLE II. MEASUREMENT LOCATIONS

No.	***Location***	***Type***	***Floor***	***Indoor/Outdoor***
1	RTK Building	Urban/Residential	Ground	Out
2	Taukbahqe	Park	Ground	Out
3	Vneshta	Park	Ground	Out
4,5	Sheshi	City Centre	Ground	In/Out
6,7,8,9	Gorenje Building	Shopping Center/Outside of the city	Ground,8th Floor	In/Out
10	Airport	Rural	Ground	In/Out
11	Marigona Residence	Residential/ Rural	Ground	Out
12,13, 14,15	KESCO Building	Urban/High-rise buildings	Ground, 13th Floor	In/Out
16,17,18,19	Faculty of Engineering	School/Residential	Ground, 4th Floor	In/Out
20,21, 22,23	Rruga B	Urban/High-rise residential buildings	Ground, 9th Floor	In/Out

The results of measurements, given in dBµV/m, are compared with ICNIRP reference levels for occupational and general public exposure.

III. RESULTS AND DISCUSSIONS

A. *Urban vs. Rural scenario*

In this scenario, a comparison between measurements of electric field strength levels at an urban area versus a rural area is conducted. A high rise KESCO building is chosen to represent our urban location and Marigona residence the rural. KESCO building is around 40m high. This specific measurement is made in terrace of this building situated at the 13th floor. Marigona residence is populated with houses up to 2 levels/floors.

Both measurements are made outside on the ground level. Maximum, average and minimum values on each UHF channel are shown in the Fig.2 for rural, and Fig. 3 for urban area respectively. As seen in Fig.3 at the urban area maximal value of field-strength, 106.77dBµV/m, is measured in channel 31. Also high values of signal strength are measured in channel 23 and 37. The values are 100.67dBµV/m and 100.34dBµV/m respectively. According to frequency plan issued by Kosovo Independent Media Commission these signal values are received from the transmitter situated in Prishtina that operates in those channels. Also from Fig. 2 and Fig.3 we can also see that on both locations there is an activity on channel 48. This comes from the transmitter situated on a hill in Cërrnushë 1006 m from ground, which is near both of our locations, with transmitting antenna height 27m, transmitting with Effective Radiated Power- ERP 5 kW on a frequency of 687.25 MHz [10].

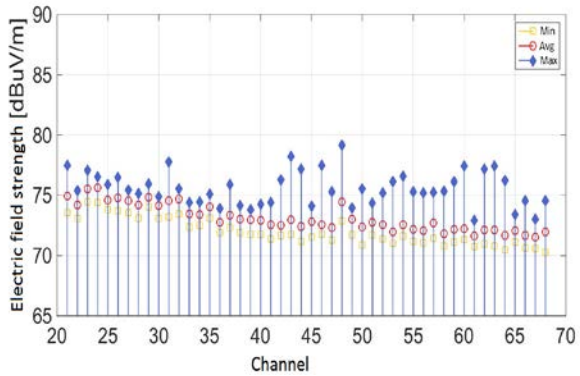

Figure 2. Electric field strength measured at a specific rural location

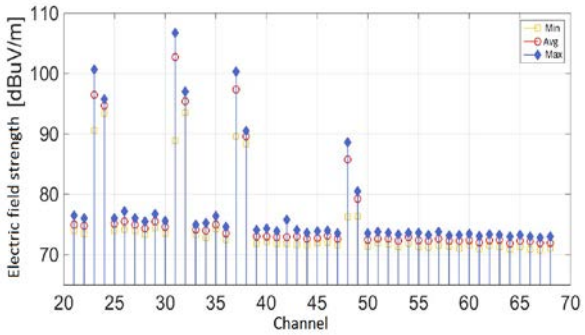

Figure 3. Electric field strength measured at a specific urban location

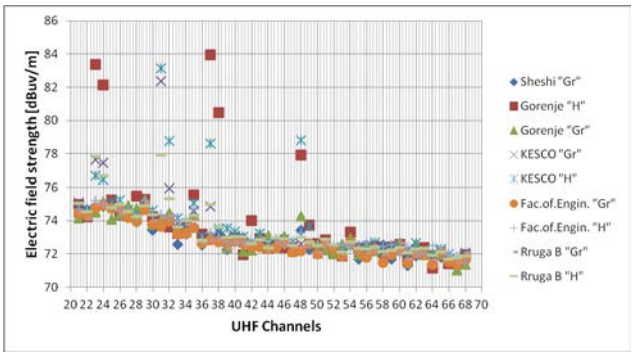

Figure 4. Electric field strength measured in indoor spots

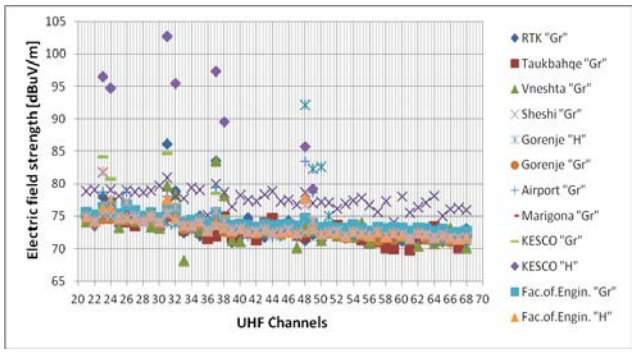

Figure 5. Electric field strength measured in outdoor spots

B. *Indoor vs. Outdoor scenario*

Another important observation noted from measurements is the difference in the levels of electric field strength between indoor and outdoor scenario. As expected the signal levels are smaller in indoor scenario than outdoor scenario. This could be due to attenuation because of the blocking effects of the walls. In Fig.4 the measured values of electric field strength for all indoor spots are shown and Fig.5 the values for all outdoor spots. While signal levels in UHF channels are concentrated in the range from 70-80dBµV/m in outdoor spots, on the indoor spots the concentration is on the range from 70-75dBµV/m.

The highest values of electric electric field strength were captured on the terrace of KESCO building on the 13th floor, outdoor scenario, Line–of-sight (LOS) position, in channels 23, 24, 31, 32, 37 and 37 followed by Gorenje shopping mall, in channel 48. For the indoor scenario in Gorenje shopping mall the highest values of signal strength were spotted on the 8th floor of the building in channels 23, 24, 37, and 38. While the highest measured value in indoor scenario is 83.97dBµV/m in channel 37, for outdoor scenario the highest value is 102.73dBµV/m

in channel 31. UHF TV broadcast transmitter which transmits in channels 31 and 37, is situated in Prishtina, operating in frequencies 551.25 MHz and 599.25 MHz, respectively. The transmitter is 725m from ground, operates at 15 kW ERP, with antenna height 42m.

C. *Electric field stregth at different heights*

Similar to indoor versus outdoor scenario an assessment of electric field values emitted on UHF band was made also for different heights, in locations where there was a possibility of performing measurements. Most of the measurements were conducted on ground level, and eight on different heights (around 20-40m from ground). Results are shown in Fig.6 for measurements made on the ground level, and Fig.7 for measurements on different heights.

As we assumed higher levels of electric field strength were obtained in the case of certain heights from ground

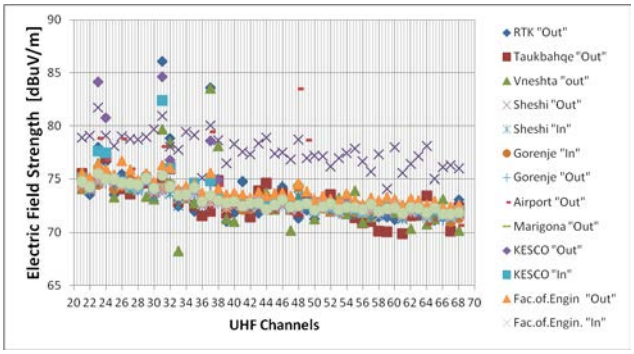

Figure 6. Electric field strength measured in ground level

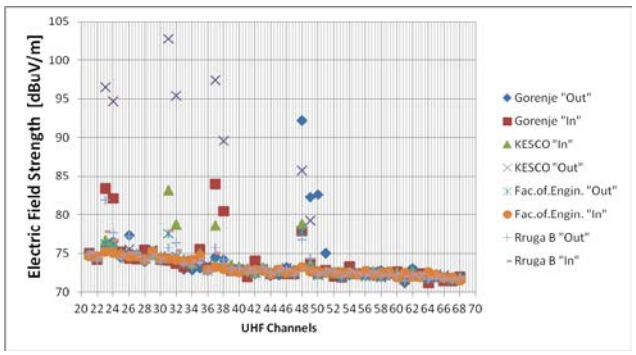

Figure 7. Electric field strength measured in different heights from ground

level, compared to measurements made in the ground level.

D. *Comparison to ICNIRP Reference Levels*

In this section we compare the values of our measurement campaign with ICNIRP occupational and general public limitations.

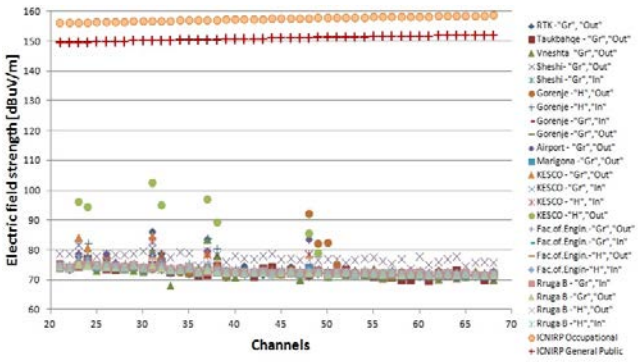

Figure 8. Comparison of measured values to ICNIRP reference levels

As seen on Fig.8 despite the location of our measurements, or the channel used by a TV broadcasting operator all the values of electric field strength are significantly below ICNIRP reference levels which range from 149.50-152.05dBµV/m for general public and 155.71-158.82dBµV/m for occupational exposure.

The highest value of average electric field strength, 102.73dBµV/m, again, was measured on the 13th floor of a building, which is still below the ICNIRP levels.

E. *Comparative analysis with similar measurement campaings*

Similar campaigns were conducted in Thessaloniki, Greece and Skopje, Macedonia [8]. The Measurement equipment consisted of a Rohde and Schwarz FSH-3 portable spectrum analyzer. UHF band spectra and electric field strength levels pre- and post- analogue switch- off were analyzed.

The measured UHF-TV band spectra in the cities of Thessaloniki and Skopje pre- and post-switch off clearly demonstrate the economies made on spectrum occupation by the passage to digital television. Additionally, for the same coverage area lower electric field strength values are required, thus leading to lower transmitted powers.

It should be noted that Kosovo has not yet transitioned to digital TV broadcasting [11]. In Table III are shown average values of electric field strength measured in Prishtina compared to average values of electric field strength in individual UHF channels of interest, measured pre- and post- analogue switch-off in the cities of Thessaloniki and Skopje. Since in Kosovo the process of transition from analog to digital has not been completed, the table contains values of electric field strength for cities of Thessaloniki and Skopje on individual channels regardless of prior or post switch off and they were compared to our measured values. The highest value of electric field strength in Thessaloniki was measured in channel 38 (104.80dBµV/m), while in Skopje the highest value was measured 101.50dBµV/m in

TABLE III. COMPARISON WITH SIMILAR CAMPAIGNS

Channels	*Prishtina*		*Thessaloniki*	*Skopje*
	Field strength (dBµV/m)			
	Min avg	Max avg	Avg	Avg
23	74.52	96.50	90.80	87.50
24	74.58	94.72	93.10	/
26	74.10	79.02	/	101.10
27	73.60	78.76	100.00	/
28	73.91	78.69	/	101.50
29	73.39	78.97	95.00	/
30	73.12	79.70	98.80	101.20
31	74.06	102.73	94.60	/
33	72.48	77.71	98.70	101.00
35	71.99	79.11	102.30	/
36	71.60	75.09	/	92.90
38	72.70	89.58	104.80	/
41	71.96	77.57	100.70	
43	71.83	78.36	/	99.10
45	71.97	77.35	102.30	/
46	72.84	77.48	94.50	/
47	71.83	76.85	/	95.10
50	71.26	77.20	90.60	95.00
51	72.21	77.12	99.60	/
52	71.99	76.16	/	84.70
53	71.62	76.93	/	95.20
55	71.42	77.85	/	97.30
56	70.91	76.67	92.00	/
57	71.06	75.66	/	99.70
59	70.08	74.14	86.90	/
63	71.49	77.16	/	98.10

channel 28 compared to our measured value of 102.73 dBµV/m in channel 31.

IV. CONLUSION

In this paper we present the results of the experimental evaluation of electric field levels emitted by TV broadcasters operating in UHF band.

Three measurement scenarios are included, urban vs. rural electric field strength, indoor vs. outdoor, and determination of exposure levels at different heights from the ground level. The obtained results are compared with ICNIRP reference levels and also with results of similar measurement campaigns.

While signal levels in UHF channels are mostly in the range 70-80dBµV/m in outdoor spots, on the indoor spots the concentration is on the range 70-75dBµV/m. The highest value of electric field strength is captured on 13 floor on city center location (102.73dBµV/m).

All measured values of electric field strength, regardless the location of our measurements, or the channel used by a TV broadcasting operator, are below ICNIRP reference levels.

After analog to digital switching process, the measurement campaign will be repeated and comparative analysis in terms of: exposure, coverage, coexistence of heterogeneous networks and interference in TV bands, will be presented.

ACKNOWLEDGMENT

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Analysis of Helix Turns Impact on Design of Helix Antenna Operated on 2.46GHz Proposed for FSO/RF Hybrid System

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Abstract – Motivation on the research in this area is still growing with regards on expanding demands on communication networks. We live in the ages of communication technologies. Users' demands are still growing. We need to develop new solutions to resolve the growing demand on multimedia streams in metropolitan networks. Current high speed communication systems are based on an optical fiber transmission. However, in densely populated areas an optical fiber cannot always be embedded. In these areas free space optics (FSO) is a perfect solution. With FSO system optical beams can be transmitted through free space. In the case when the primary optical link has the radio-frequency (RF) backup link, the system is named FSO/RF hybrid system. The RF backup link is used in outage cases. This paper is focused on improving availability of FSO system using RF link with appropriate type of antenna. In this research we consider helix antenna. Design is realized using professional designing tool FEKO. In the optimization process of the RF link we focused on the analysis of antenna properties depending on the number of helix turns. The operating frequency was chosen from non-licensed frequency range free available in Slovak republic. It is 2.46GHz. The main point of this paper is to find appropriate candidate for RF backup link which will be implemented in our experimental FSO/RF system.

Key words – antenna design, FSO/RF hybrid system, helix antenna, turns of helix

I. INTRODUCTION

Communication technologies were expanded through many areas of our lives. These technologies have dominant effect onto private and professional spheres of human lives. Fully digitalized system needs direct communication between all parts of system for sufficient operation. The demand on availability of services are still growing and it needs physical infrastructure which would be able to transmit full data stream. In recent years a lot of communication systems which are able to react on the users demands were invented. The main break point in the invention of communication was the invention of optical fibers. Optical fiber communication systems allow rates of about several Gbps. Nowadays, backbone networks are based on an optical fiber. Their implementation has some drawbacks which is conditioned to the next research. These drawbacks are: the higher building cost of the physical structure and the implementation time. The optical communication system which is able to transmit optical beams without the need physical fibers Free Space Optics system (FSO). This system minimizes drawbacks of fiber optical communication systems. On the other hand, the FSO system have the drawback too. It is the sensitivity to weather changes. The solution is in implementation of backup radio-frequency transmission link. This backup link makes redundancy in case of soft switching between links. In the case when the communication is realized synchronously using both links, we talk about soft switching. In the case when the communication is realized using primary link and the switching is realized when the primary link has an outage, we talk about hard switching. The experimental model of FSO/RF system is realized in the area of Technical University of Košice. Now we are interested in design of appropriate type of RF antenna operating on frequency from non-licensed frequency range. The main point of this paper is comparison of six helix antennas. Our previous research is published in [1-7].

II. DESIGN OF HELIX ANTENNAS

The design was realized in professional tool proposed to analysis of electromagnetic compatibility from Altair Company. This program suite called FEKO. FEKO is simulation software package for analysis of electromagnetic compatibility. We designed six models of helix antenna with the same dimensions, the difference was the number of turns of helix. The dimensions of antennas are in the TABLE I.

TABLE I. PARAMETERS OF DESIGNED HELIX ANTENNA

Label	Parameter	Values
f	***Frequency***	2.46 GHz
N	***Number of turns***	5
d_1	***Diameter of helix***	4.4 cm
d_2	***Diameter of conductor of helix***	0.2 cm
d_3	***Diameter of reflector***	6.2 cm
l	***Length of helix***	12.2 cm

These models operates on 2.46 GHz. The TABLE II. shows the assignment of the number of turns and label of antenna.

TABLE II. DIFFERENT VALUE OF KEY PARAMETER OF THE MODEL

Variable	Number of Turns - *N*
Antenna No.1	5
Antenna No.2	6
Antenna No.3	7
Antenna No.4	*8*
Antenna No.5	9
Antenna No.6	10

The structure of helix antenna model is given by Fig. 1. Parameters defined in the TABLE I. are also shown in Fig. 1. These values are given by equations in [8-15].

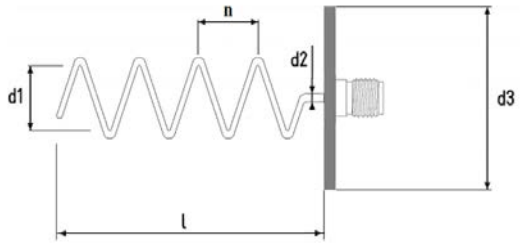

Fig. 1 The reference model of helix antenna

For design was chosen programme CAD FEKO from the package. Its environment is used to set the elements features. CAD FEKO used Mesh network which distributes element to the grid of same triangles. For these particular elements the Maxwell´s equations will be calculated using method of moments (MoM). The models of designed antennas are in the Fig. 2.

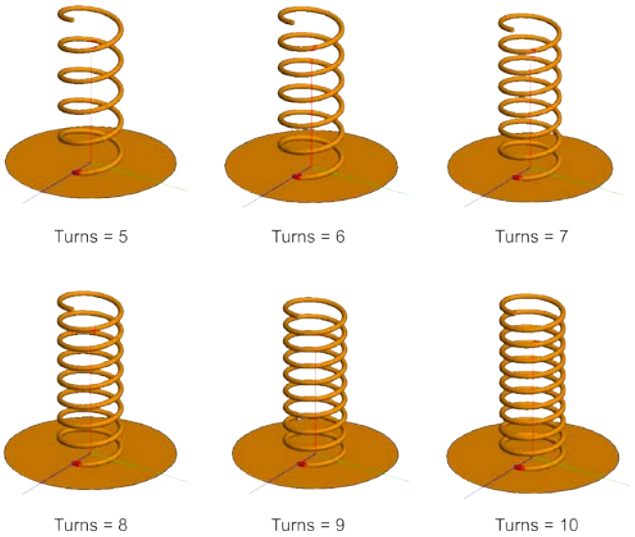

Fig. 2 Models of designed antennas in CAD FEKO

Requirements for analysis were chosen in CAD FEKO. The one of these requirements is FarField. The considered FarField consists from points placed around the designed model of antenna. In this case these points are placed on the surface of virtual sphere in uniform distances between points [16-21].

III. ANALYSIS OF DESIGNED HELIX ANTENNAS

The analysis of designed antennas was realized in program POST FEK. POST FEKO allows analysis of fundamental parameters of simulated antennas. The 3D radiation patterns of simulated antennas is illustrated in the Fig. 3.

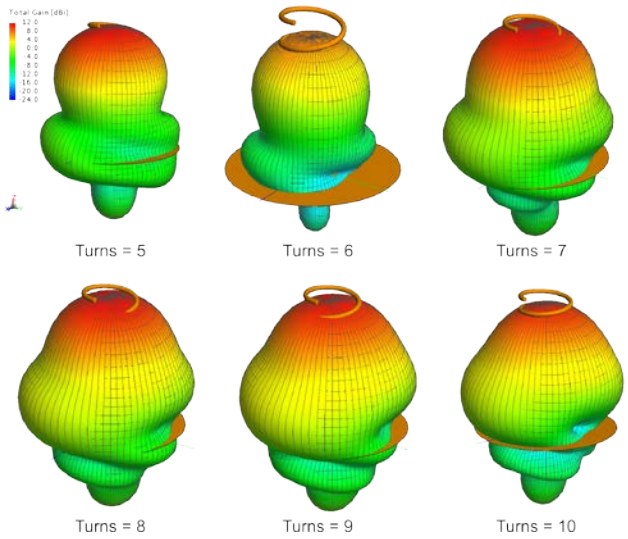

Fig. 3 Total gain of designed antennas operating on 2.46 GHz

These radiation patterns were obtained on operating frequency 2.46 GHz. The cut of these radiation patterns (Φ = 90°) could be seen in the Fig. 4.

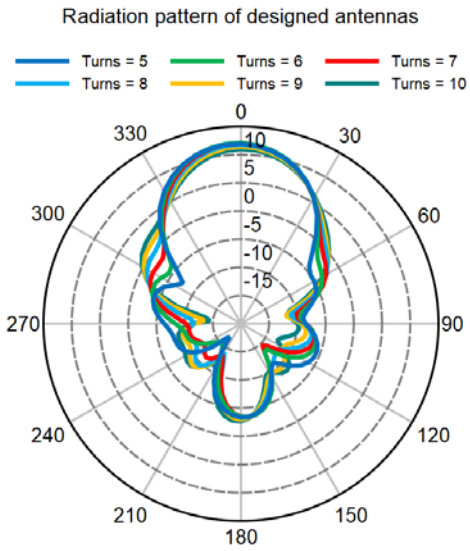

Fig. 4 Radiation of modelled antennas for Φ = 90°

The radiation patterns in the Fig. 4 are placed in the polar coordinates. The radiation patterns are in the [dBi] units which suggest increased value of gain in comparison

with the case when the radiation of considered antenna is isotropic.

TABLE III. VALUES OF TOTAL GAIN

Variable	Gain	Gain [dBi]
Antenna No.1	15.5079	11.9055
Antenna No.2	*16.022*	*12.0472*
Antenna No.3	15.8382	11.9971
Antenna No.4	15.0451	11.774
Antenna No.5	15.8281	11.4076
Antenna No.6	12.494	10.967

Obtained values of gain are recorded in the TABLE III. In this table, the maximal values of obtained gain denoted are by italic.

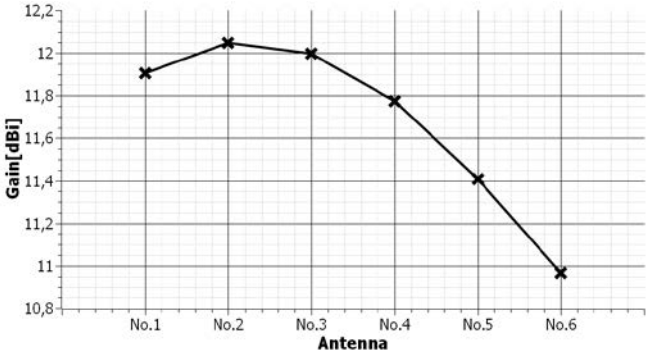

Fig. 5 Total gain of designed antenna operating on 2.46 GHz in dBi units

The Fig. 5 shows the dependence of obtained values of total gain of simulated antennas and change of number of turns. The maximum value of total gain was obtained for antenna No.2 with the value 12.0472 dBi.

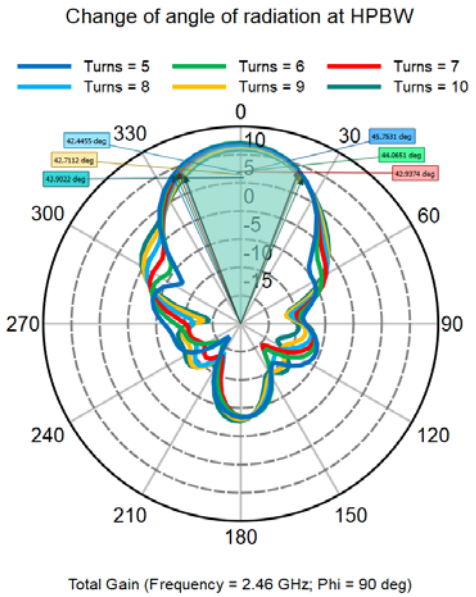

Fig. 6 Change of angle of radiation for $\Phi = 90$

The most important parameter of antenna is Half Power of Beam Width (HPBW). The HPBW of designed antennas is in the Fig. 6.

TABLE IV. VALUES OF CHANGE OF RADIATION ANGLES

Variable	HPBW - $\Phi = 0°$	HPBW - $\Phi = 90°$
Antenna No.1	46.2746°	45.7531°
Antenna No.2	44.6114°	44.0651°
Antenna No.3	43.6217°	42.9374°
Antenna No.4	*43.3116°*	*42.4555°*
Antenna No.5	43.7664°	42.7112°
Antenna No.6	45.2192°	43.9022°

The obtained values of angle of radiation could be seen in the TABLE IV. In this table, the minimal values of this angle are denoted by italic.

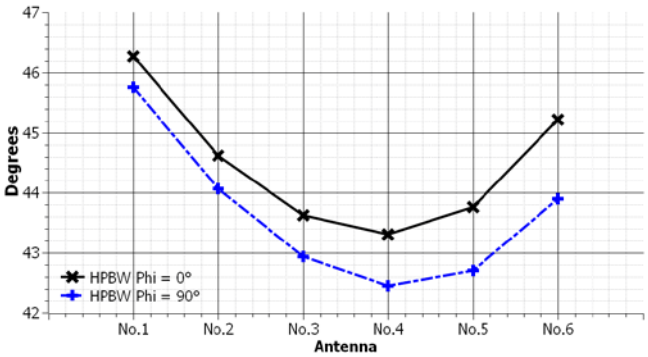

Fig. 7 Angle of radiation at Half Power of Beam Width (HPBW)

The Fig. 7 shows the dependence of obtained values of change of radiation angle of simulated antennas and change of number of turns. The HPBW value for antenna No.4 is the smallest: 43.3116° for $\Phi = 0°$ and 42.4555° for $\Phi = 90°$

TABLE V. VALUES OF MAXIMAL RADIATED POWER AND SIDE LOBE LEVEL

Variable	Power [mW]	Power [dBW]	SLL [dB]
Antenna No.1	10.0258	-19.9888	15.1271
Antenna No.2	*10.4748*	*-19.7985*	15.339
Antenna No.3	7.90759	-21.019	*15.4837*
Antenna No.4	6.46146	-21.8967	15.0803
Antenna No.5	6.9322	-21.5913	14.3799
Antenna No.6	10.0957	-19.9586	13.6126

The values of reached power are noticed in the TABLE V. In this table, the SLL parameter describes the ratio between maximal lobe and second maximum.

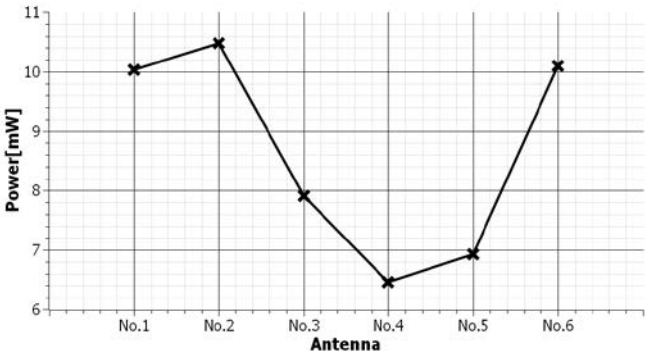

Fig. 8 Maximal radiated power of designed antennas

The Fig. 8 shows the dependence between obtained maximal power values in [mW] of simulated antennas and change of number of turns.

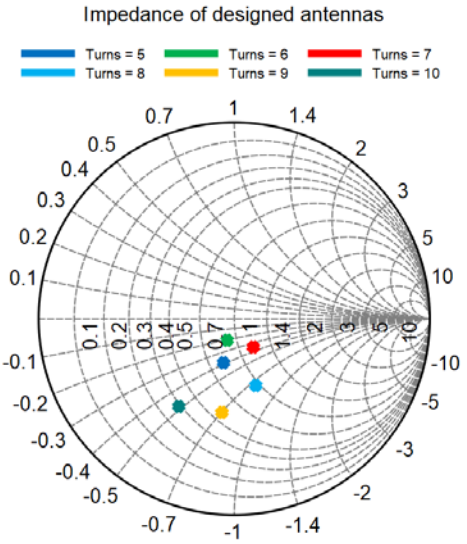

Fig. 9 The impedance of the designed antennas

The impedance points of designed antennas can be seen in the Fig. 9. In this figure, the points are placed on Smith chart.

IV. Conclusion

This paper is focused on examination of impact of number of helix turns on features of designed antennas. We are looking for appropriate RF antenna for FSO/RF hybrid system and on the base of this knowledge we chose the frequency of 2.46 GHz from non-licensed frequency range. The antenna No.2 had the maximal value of gain: 16.022 (12.0472 dBi). The most important parameter for direction oriented application is size of the angle of radiation. We consider the small value represent the direction of radiation into small spreaded beam. The HPBW of antenna No.4 for Φ = 0°is 43.3116° and 42.4555°for Φ = 90°. For non-licensed application the maximal value of radiated power into affected area is very important parameter. The threshold value for the given frequency (2.46 GHz) is 20 mW. The maximal value of radiated power was obtained for antenna No.2 with the value 10.4748 mW (-19.7985 dBW). The last examined parameter was side lobe level (SLL) which shows the ratio between main lobe and second maximal lobe. With regards on this knowledge the maximal value for antenna No.3 was 15.4837 dB. This paper shows that the trade-off is the need. From our point of view is antenna No.2 appropriate candidate for realization.

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Design and Analysis of Vivaldi Antenna for Measuring Electromagnetic Compatibility

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***Abstract* - The paper presents design and characterization of a pair of Vivaldi antennas in the frequency range from 0.5 to 4 GHz. The design procedure is described in details together with analysis of the antenna current density distribution and the operating mechanism. Simulated and measured relevant results are compared and discussed. The antennas are intended to be used for electromagnetic field measurements over wide frequency range (by which several narrow-band antennas can be replaced). It is shown that antenna exhibits stable characteristics and is relatively low-cost, so it can be considered as a suitable solution for high frequency component of the electromagnetic compatibility (EMC) measurement system currently being developed within Department of Electrical Engineering Fundamentals and Measurements at University of Zagreb, FER.**

Keywords* - *Ultrawideband antenna; Vivaldi antenna; antenna factor; Electromagnetic compatibility measurements

I. INTRODUCTION

The wearable electronic and computing devices have been largely developed within last decade with promising applications in health monitoring, general safety together with general entertainment and augmented reality. Such development has naturally led to merging the traditional microwave communication technology with developments in textile materials. As a result, variety of methods for construction of textile antennas and transmission lines has emerged, together with new textile materials made of conductive polymers, which are suitable for unobtrusive integration in clothing, resistant to washing and mechanical deformations, while at the same time retaining desirable electrical properties (see e.g. [1– 3]). Furthermore, there is an increasing trend to use the conductive properties of newly developed textile materials in protection of electromagnetic interference [4, 5] since these materials are typically light-weight, thin, flexible and low-cost. They can be easily mounted on walls, used in everyday clothing or used as a cover for electronic equipment. The principal issues in use of conductive textiles in antennas are their finite conductivity and possible anisotropy of electromagnetic properties which leads to need of their characterization [3]. Due to relatively high price for widespread commercial use there are proposals for developing conductive mesh-type textile grids for use both in communications [3] and shielding [5], to reduce the conductive textile material consumption.

This work has been fully supported by Croatian Science Foundation under the project IP-2018-01-7028 Shielding from electromagnetic fields with electrically conductive textile materials.

In this paper we propose a pair of Vivaldi antennas which can be used for characterization of various conductive and mesh-type textile materials in terms of shielding efficiency and conductivity. The Vivaldi antenna itself is a planar broadband traveling wave antenna with exponentially tapered slot which serves as a quasi-transverse electromagnetic (i.e. quasi-TEM) transmission line which provides smooth and continuous transition from the feeding line to the free space, thereby acting as two-dimensional horn antenna [6–8]. It possesses capability of ultrawideband (UWB) operation with high gain over large frequency range and, since it is planar, it is easy to manufacture and integrate with electronic circuitry which makes it a good choice for use in electromagnetic compatibility (EMC) measurements and wideband characterization of conductive textile materials. Furthermore, its design allows for further modifications and optimizations, as well as convenient integration in arrays [6, 7]. Here we present the design of Vivaldi antenna version with simple coaxial feeding together with its characterization in terms of gain and antenna factor in the frequency range from 0.5 GHz and 4 GHz, since this is at the moment the supposed range of its application in textile material characterization. We also show that the developed antenna has however even larger bandwidth so its applications can be extended readily when needed.

II. THE VIVALDI ANTENNA DESIGN

Using the commercial software CST Microwave Studio [9] we have optimized the Vivaldi antenna (Fig. 1) for operation between around 0.5 GHz and 4 GHz, as shown in Fig. 1. Each arm of the antenna (i.e. the exponential taper) is given by the equation:

$$y = A \cdot e^{px}, \tag{1}$$

where A is the opening half-width at the antenna narrow end and p is the taper rate. The initial parameters A and p are chosen according to the prescription in [8], which basically requires that the total length and width of the antenna are comparable to the wavelength at lowest operating frequency.

We have chosen to excite the antenna directly via coaxial cable which has considerably simplified the design of the antenna feeding and in final design has enabled some reduction in total antenna dimensions compared to the ones arising from [8]. The used antenna substrate is FR408HR [10]. Although the lowest frequency of operation has been initially chosen as 1 GHz, we have managed to optimize the lowest operating frequency to

500 MHz with reasonable total dimensions. The relevant parameters of the antenna geometry after optimization are summarized in Table I.

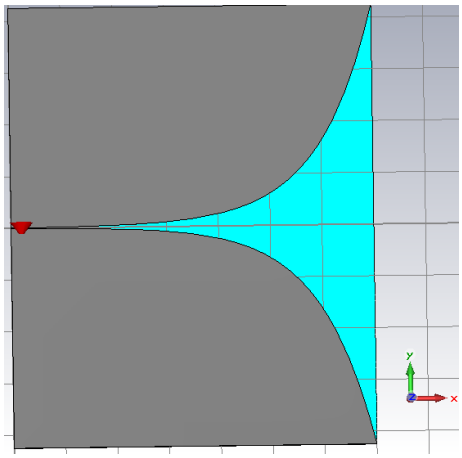

Figure 1. The sketch of the proposed Vivaldi antenna

TABLE I. ANTENNA GEOMETRY AFTER OPTIMIZATION

Parameter	Value
Half-opening *A*	0.1
Taper rate *p*	0.0482
Antenna dimensions	14 cm × 17 cm
Feeding position	4 mm from the narrow opening
Substrate thickness	1.5 mm
Substrate permittivity	3.69

The antenna radiation mechanism is illustrated in Fig. 2, where the snapshots of electric field tangential component in the antenna plane are shown for several frequencies. It can be seen that the tapered slot acts as a transmission line with smooth impedance transition towards free space, which makes the radiation mechanism similar to the one in the horn antenna [8] (hence Vivaldi antenna can be considered as 2D horn antenna). The calculated radiation patterns (Fig. 3) exhibit maximum at the direction of the antenna opening at all the considered frequencies, while the maximum gain (Table II) and radiation pattern shape are relatively stable at higher considered frequencies. Although there is some discrepancy in radiation pattern shape at frequencies of 1 GHz and 2.45 GHz, this possesses no major relevance for the envisaged application in electromagnetic compatibility measurements, as the maximum direction is stable at all frequencies.

A. The manufactured prototype

Based on the described simulation results two prototypes of the Vivaldi antennas are manufactured. Both prototypes (Fig. 4) are excited with 0.5 m section of the 50 Ω commercial coaxial RG174 cables [11], for which the measured loss characteristics up to 10 GHz (using R&S ZVA 40 network analyzer) is given in Fig. 5. It can be seen that the cable introduces losses of less than 2 dB for frequencies up to around 6 GHz and up to 3.25 dB for frequencies up to 10 GHz. At this stage the losses can be considered low enough for the antenna application, while the use of relatively long cable enables practical integration of the antennas into the measurement system and keeps the low overall cost of the structure. Since the antenna is to be used as a measurement antenna, the introduced losses are not expected to degrade measurement system performance and are compensated with relatively high gain of the antenna itself (of course, at any stage in the future the cable can be easily replaced or shortened if needed).

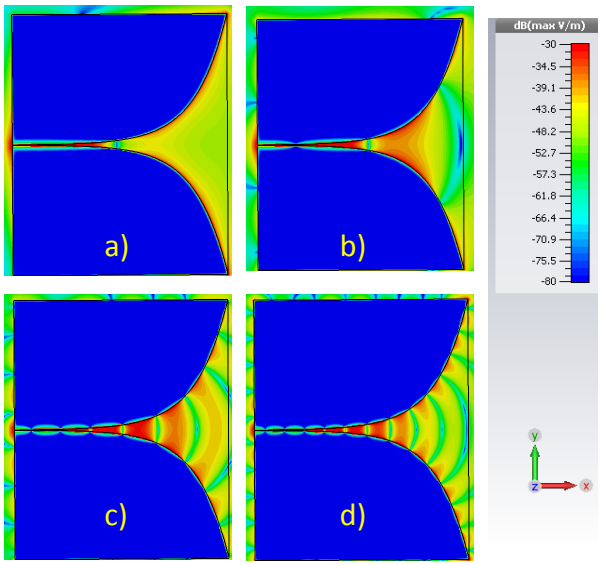

Figure 2. Snapshots of tangential (*x*- and *y*-) components of the electric field at the antenna plane: a) *f*=1 GHz; b) *f*=2.45 GHz; c) *f*=5.8GHz; d) *f*=8.5 GHz

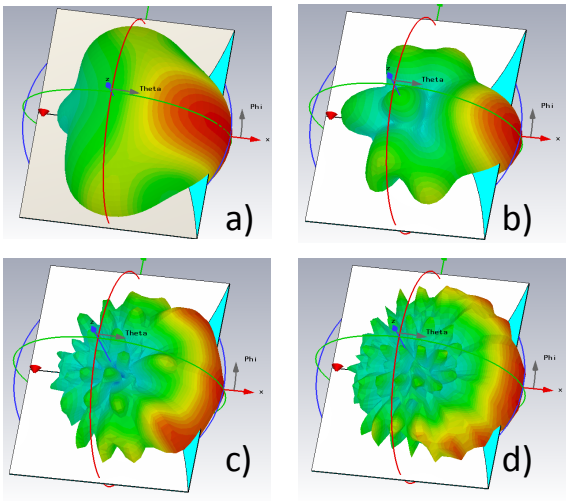

Figure 3. Qualitative 3D plots of the calculated antenna radiation patterns at: a) *f*=1 GHz; b) *f*=2.45 GHz; c) *f*=5.8GHz; d) *f*=8.5 GHz

TABLE II. THE CALCULATED ANTENNA GAINS AT REPRESENTATIVE FREQUENCIES

Frequency [GHz]	Calculated gain [dBi]
1	3.15
2.45	8.36
5.8	7.42
8.5	6.55

The antenna measurements have been performed using R&S ZVA 40 and Keysight FieldFox N9913A network analyzers. The first analyzer was used for measurements up to 10 GHz, to analyze the antenna and cable behavior at frequencies somewhat beyond upper operating range (and find possible improvements for future), while the second analyzer is used for measurements from 500 MHz to 4 GHz since this is the range the measurement system with Vivaldi antenna is supposed to operate. The frequency characteristics of measured and calculated magnitudes of the input reflection coefficients are compared in Figs 6 and 7 both for range up to 10 GHz and (more detailed) up to 4 GHz, respectively. In addition, in Fig. 7 the measurements on the second prototype are also shown, and here it can be seen that the second prototype exhibits similar frequency behavior as the first one. From these results it can also be seen that very good correspondence between measured and simulated results has been obtained (note that some minor discrepancies arise mostly due to cable losses), while the manufacturing procedure is generally robust and reproducible.

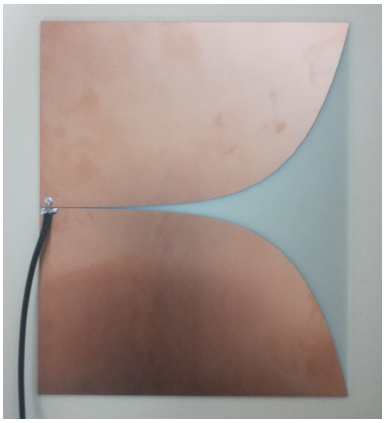

Figure 4. The manufactured antenna prototype

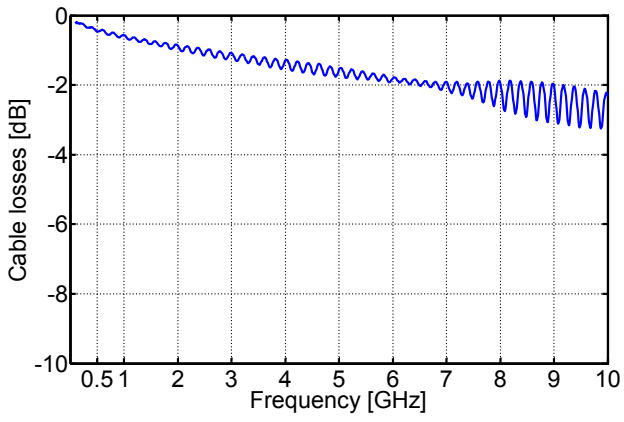

Figure 5. Measured losses of the used RF-174 coaxial cable section

B. *The antenna gain*

In the next measurement campaign two Vivaldi antennas have been put at the distance of 2 meters and oriented to the same polarization. The magnitude of transmission coefficient has been measured in order to find the total gain (antenna plus cable) and eventually the antenna factor. The results are shown in Figs 8 and 9. The measured total gain in [dBi] is calculated from the transmission coefficient as:

$$G_{TOT,dB} = \frac{1}{2}\cdot\left(|S_{21}|_{dB} - 20\log\left(\frac{\lambda}{4\pi d}\right) - M_{dB}\right), \qquad (2)$$

where $|S_{21}|$ is the measured magnitude of transmission coefficient, $|S_{11}|$ is the measured magnitude of antenna input reflection coefficient (linear), λ is the wavelength and d is the distance between antennas. The mismatch factor M in [dB] is given as:

$$M_{dB} = 10\cdot\log\left(1-|S_{11,T}|^2\right) + 10\cdot\log\left(1-|S_{11,R}|^2\right), \qquad (3)$$

where $|S_{11,T}|$ and $|S_{11,R}|$ are measured (linear) magnitudes of reflection coefficient of the transmitting and receiving antennas, respectively (Fig. 7). Note that in (2) we assume that the gains of the antennas are the same, which is the fair and standard assumption in antenna measurements with two basically the same antennas [8].

By subtracting the cable losses from Fig. 5 one obtains the gain of the structure itself. It roughly corresponds to the gain predicted by simulation (Table II). The realized antenna gain is thus in line with similar Vivaldi antenna realizations [6-8], and in line with the expectations (as mentioned before, total gain can be somewhat improved by replacing the cable with one having lower losses if needed).

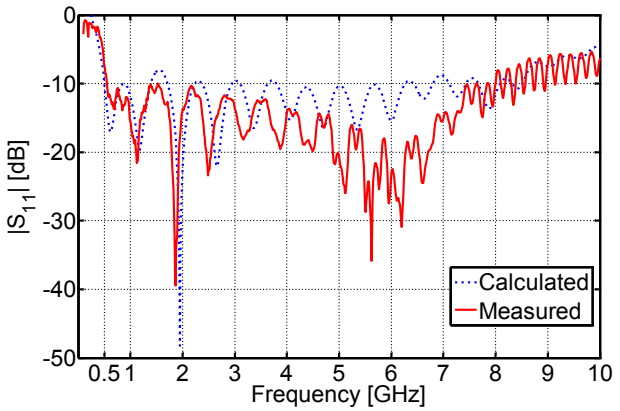

Figure 6. The calculated and measured magnitudes of the input reflection coefficient at full operating range (antenna 1)

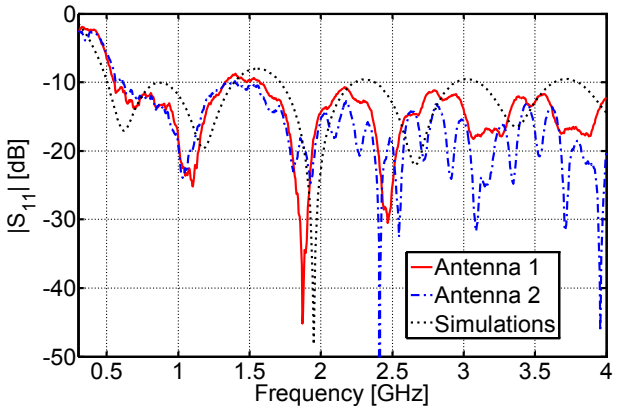

Figure 7. Comparison of magnitudes of the input reflection coefficient for the two manufactured antennas at the range up to 4 GHz

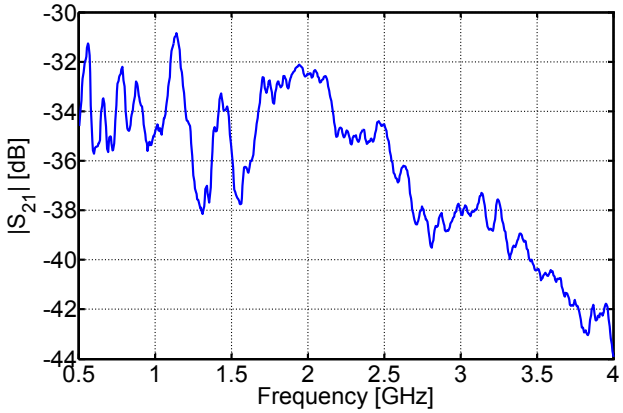

Figure 8. Measured magnitude of transmission coefficient between two Vivaldi antennas at the distance of 2 meters

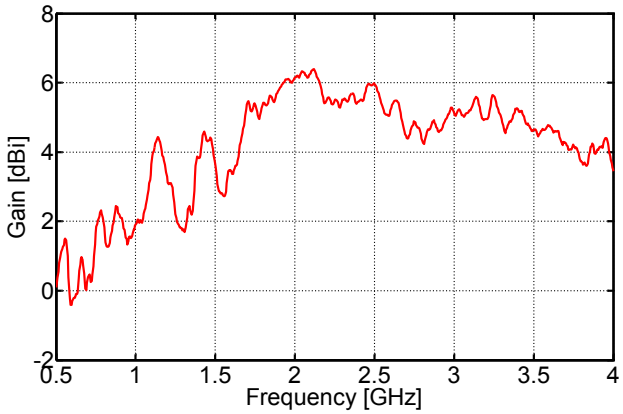

Figure 9. The measured total gain of proposed Vivaldi antenna

C. *The antenna factor calculation*

Since the antenna is intended to be used in electromagnetic compatibility (EMC) measurements, we also characterize its performance via the parameter termed antenna factor [12]. By knowledge of the antenna factor one can readily obtain the field value at some point in space by measuring the received voltage, which makes the antenna de-embedding convenient (hence its use in EMC). By assuming that the characteristic impedance of the system is 50 Ω, the antenna factor (in [m^{-1}]) is calculated from the antenna gain as [12]:

$$AF = \frac{E_r}{V_r} = \frac{\sqrt{2 \cdot S_r \cdot \eta_0}}{\sqrt{2 \cdot S_r \cdot A_{ef} \cdot 50}} = \frac{9.73}{\lambda \cdot \sqrt{G}}, \quad (4)$$

where E_r and V_r are the peak values of incident electric field and received voltage, respectively, while S_r, A_{ef}, η_0 and G are received power density, effective antenna area, free space intrinsic impedance and (total) gain, respectively. Here we note that the antenna gain and effective antenna area are related via reciprocity relation [8]:

$$\frac{A_{ef}}{G} = \frac{\lambda^2}{4\pi}. \quad (5)$$

The calculated antenna factor for the proposed Vivaldi antenna is given in Fig. 10, while the values of the antenna factor at representative frequencies are given numerically in Table III. The values of the antenna factor in [dB/m] are eventually obtained as:

$$AF\left[\frac{\text{dB}}{\text{m}}\right] = 20 \cdot \log AF\left[\frac{1}{\text{m}}\right] = 20 \cdot \log\left(\frac{9.73}{\lambda \cdot \sqrt{G}}\right). \quad (6)$$

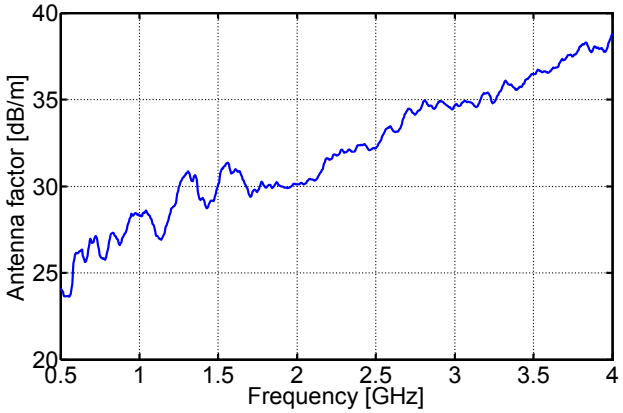

Figure 10. The obtained antenna factor

TABLE III. THE ANTENNA FACTOR – DETAILED

Frequency [GHz]	Antenna factor [dB/m]
0.5	24.04
1	28.3
1.5	30.07
2	30.09
2.5	32.25
3	34.64
3.5	36.47
4	38.81

III. CONCLUSION

In this paper we have proposed a simple Vivaldi antenna for electromagnetic compatibility measurements and characterization of conductive textile materials. The antenna is shown to operate between 500 MHz and around 6 GHz, while more detailed characterization is performed for frequencies up to 4 GHz since this is the envisaged operating range of the measurement system to be developed. The good correspondence of simulated and measured results is obtained, while the antenna is shown to possess high gain, reasonably small dimensions and is cost-effective for implementation in measurement system since it is capable of replacing several narrow-band antennas. The obtained antenna factor is in line with commercial antenna realizations for electromagnetic compatibility (EMC) measurements.

The future work will comprise the integration of the antenna into an EMC measurement system and development of method for measuring shielding efficiency and conductivity of conductive textile materials. In addition, the proposed design will be adapted for textile

version of Vivaldi antenna for use in body-centric ultrawideband systems. The methods for integration of textile Vivaldi antennas into an array will also be considered.

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PAPERS

Proširenje mrežnih usluga emulacijom hardvera u GNS3

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Sažetak **- Primjenom adekvatnih softverskih alata za emulaciju mrežnog hardvera i simulaciju računalnih mreža na postojećoj infrastrukturi lokalnih računalnih mreža obrazovnih institucija i manjih poduzeća omogućuje se proširenje skupa dostupnih usluga u domeni hibridnih resursa. U radu je predstavljen primjer konfiguracije emuliranog Mikrotik usmjeritelja s funkcijom vatrozida kao komunikacijskog i sigurnosnog sučelja između virtualnog HTTP poslužitelja i vanjske mreže te integracija simulacijske okoline s produkcijskom mrežom. Za emulaciju mrežnog hardvera i HTTP poslužitelja odabran je besplatni grafički mrežni simulator otvorenog koda - GNS3, koji se ovim primjerom pokazao kao praktično povoljan alat za savladavanje tematskih cjelina u nastavnim kolegijima s naglaskom na računalne mreže kao i u stručnim primjenama fleksibilne alokacije postojećih računalno-komunikacijskih resursa.**

Ključne riječi – GNS3, MikroTik, simulacija, mreže

I. UVOD

Suživot koncepata virtualizacije i emulacije u kontekstu primjene fizički manifestiranih računalnih mreža omogućio je poboljšanje i proširenje već postojećih usluga i sustava u nastavnim, laboratorijskim i produkcijskim primjenama. Iako su navedeni koncepti apstraktni i često nedostupni krugu krajnjih korisnika, na tržištu se učestalo pojavljuju proizvodi koji predstavljaju kompromis između jednostavnosti i dobrobiti korištenja te pozadinske složenosti svih uključenih tehnologija i načela potrebnih za rad takvih sustava. Grafički mrežni simulatori stekli su svoju popularnost najprije u profesionalnim okruženjima mrežnih stručnjaka, no sve je više prepoznat i njihov akademski potencijal pa se koriste kao pomoćni alati pri svladavanju teorijskih i praktičnih načela računalnih mreža i mrežnih usluga [1]. Njihovo intuitivno i parametarski bogato okruženje korisnicima omogućuje emulaciju, parametrizaciju i testiranje virtualnih i stvarnih računalnih mreža različitih stupnjeva složenosti i namjena u realnom vremenu bez potrebe posjedovanja mrežnog hardvera, uz mogućnost emuliranja mrežne opreme renomiranih proizvođača te stvaranja hibridnih okruženja spajanjem virtualnih i realnih mreža [2]. Uvodnim pregledom osnovnih svojstva i mogućnosti poznatog grafičkog mrežnog simulatora GNS3 rad se osvrće na praktičnu primjenu proširenja usluga lokalne računalne mreže uspostavom virtualne instance HTTP poslužitelja u GNS3 okruženju te pokazuje potencijal primjene kako u produkcijskim scenarijima tako i u uvjetima svladavanja nastavnih tema računalnih mreža.

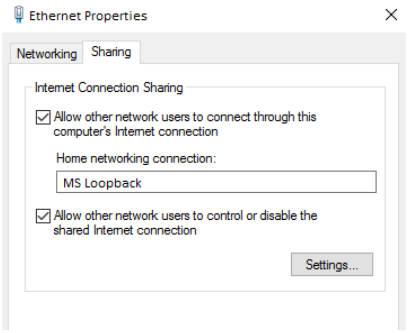
II. EMULACIJA MREŽNOG HARDVERA U GNS3 SIMULATORU

U osnovi namjene navedenog simulatora ujedno su prisutne i njegove glavne prednosti što uključuje mogućnosti simulacija računalnih mreža u realnom vremenu uz integraciju s fizičkim mrežama bez potrebe za stvarnim posjedovanjem posredničkog mrežnog hardvera te lake dostupnosti njihovih softverskih reprezenata u obliku emuliranih sustava.

Slobodnom distribucijom pod GNU GPLv3 licencom te lakom dostupnošću putem centralne web lokacije [3], uz inicijalnu korisničku registraciju, omogućeno je preuzimanje instalacijske datoteke GNS3 simulatora te pristup tzv. *marketplace* web portalu namijenjenom preuzimanju besplatnih ili komercijalnih mrežnih softvera, dodatnih simulacijskih komponenti i slika sustava emuliranih uređaja, pripremljenih laboratorija i mrežnih tečajeva realiziranih u okruženju GNS3 simulatora. Za potrebe rada preuzeta je posljednja inačica simulatora u izdanju 2.1.8 te je postavljena na računalo s Windows 10 operacijskim sustavom s performansama sukladnim minimalnim tehničkim zahtjevima samog simulatora. Uz osnovnu komponentu simulatora tijekom instalacijskog postupka odabrane su i dodatne komponente neophodne za realizaciju konačne ideje rada. S obzirom da se u središtu simulirane topologije nalazi emulirani sustav Mikrotik usmjeritelja, dodana je komponenta QEMU u predloženoj inačici 2.4.0. Radi se o softverskoj komponenti otvorenog koda namijenjenoj hardverskoj emulaciji i virtualizaciji kojom se omogućuje pokretanje sustava i aplikacija pisanih za određene procesorske arhitekture (x86, x86-64, PowerPC, ARM i dr.) na različitim platformama primjenom dinamičke translacije koda [4].

Neophodan korak inicijalne konfiguracije odnosi se i na postavljanje Microsoft KM-TEST Loopback mrežnog softverskog adaptera koji ima ulogu posrednika između fizičkih mrežnih resursa i parametara računala te simulacijskog okruženja. Kako je navedena komponenta sastavni dio Windows operacijskog sustava, instalacija se provodi putem čarobnjaka za dodavanje novog hardvera u sklopu sistemske aplikacije „Device manager“ te se po završetku postupka pojavljuje u popisu mrežnih adaptera pod nazivom MS Loopback. U TCP/IPv4 svojstvima dotičnog adaptera naknadno su definirane proizvoljne vrijednosti parametara IP adrese 10.0.0.1 te maske podmreže od 24 bita (255.255.255.0). Kako bi se omogućila funkcija posredovanja u dijeljenju mrežnih resursa fizičkog Ethernet adaptera te simulirane mreže u

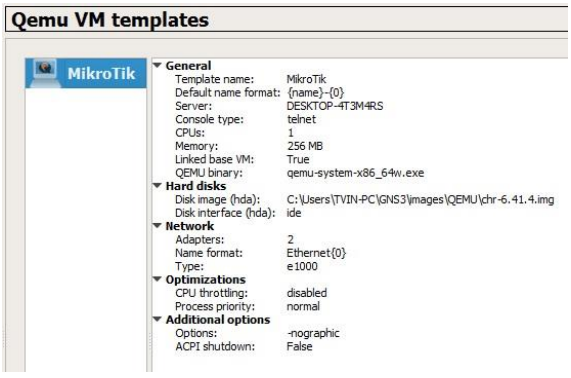
svojstvima fizičkog adaptera aktivirana je opcija „Internet Connection Sharing“ u postavkama samog fizičkog adaptera prema slici 1.



Slika 1. Postavke dijeljenja mrežnih resursa fizičkog mrežnog adaptera s Loopback adapterom

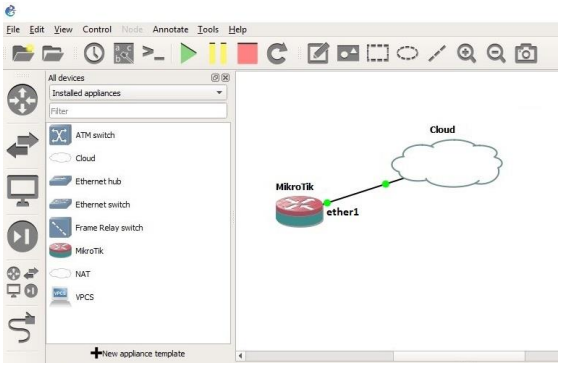
Preliminarna provjera povezivosti i općenitog funkcioniranja simulatora ostvarena je generiranjem testne topologije koja je u potpunosti realizirana unutar GNS3 simulatora. To podrazumijeva upravljanje simulacijom putem lokalne instance GNS3 poslužitelja integrirane u samom simulatoru koja se predefinirano dodjeljuje svakom novom projektu. Prije pokretanja novog projekta te kreiranja početne topologije u GNS3 simulator dodan je element mrežnog usmjeritelja proizvođača Mikrotik. S obzirom na postojeće praktično iskustvo s fizičkim proizvodima ovog proizvođača te slobodno dostupnim slikama sustava kompatibilnih s korištenim softverom za emulaciju, za potrebe simulacije odabrana je slika sustava „Mikrotik Cloud Hosted Router“ u inačici chr-6.41.1 preuzeta sa službene lokacije GNS3 simulatora [5].

Kreiranje virtualne instance Mikrotik usmjeritelja posredstvom QEMU emulatora integriranog u aplikativni dio GNS3 simulatora provedeno je kroz personalizaciju parametara predloška, uz minimalnu potrebu za izmjenom ponuđenih parametara, osim u dijelu prilaganja odgovarajuće datoteke slike sustava te odabiru broja mrežnih adaptera, odnosno sučelja [6]. Ostali parametri, poput količine radne memorije te procesorske alokacije odgovaraju minimalnim hardverskim zahtjevima samog usmjeriteljskog uređaja (slika 2).



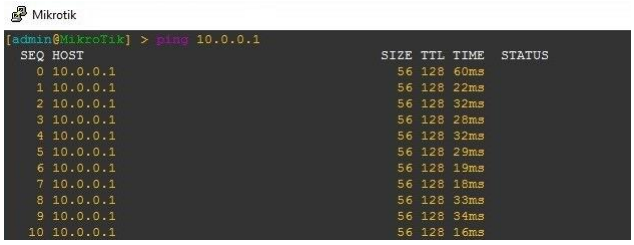
Slika 2. Parametri komponente Mikrotik usmjeritelja definirane posredstvom QEMU VM predloška

U prozor radne površine novog projekta GNS3 simulatora dodana su i povezana dva elementa početne topologije: prethodno definiran Mikrotik usmjeritelj te element Cloud. Oba elementa povučena su iz kolekcije raspoloživih mrežnih komponenti simulatora katalogiziranih s lijeve strane glavnog prozora radne površine te su ispuštena na željeno mjesto zamišljene topologije kao što je prikazano slikom 3.



Slika 3. Početna topologija s Mikrotik usmjeriteljem te elementom Cloud

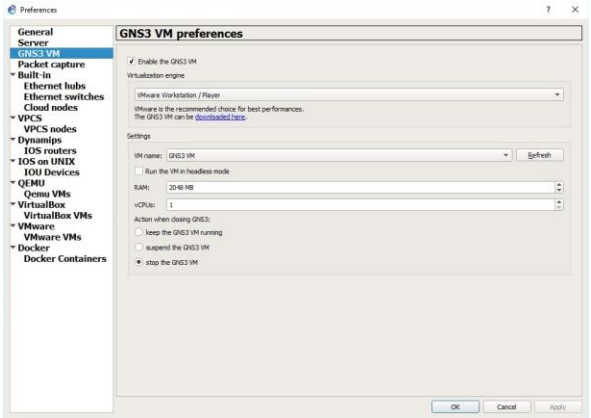
Ulogu sučelja simulirane mrežne topologije prema MS Loopback adapteru, odnosno posredno prema fizičkom Ethernet sučelju simulacijskog računala, preuzima element Cloud kojemu je u konfiguracijskim postavkama jednostavnim odabirom predloženih adaptera podešena veza Ethernet sučelja s nazivom Loopback adaptera. S obzirom da je simulator postavljen u operacijskom sustavu Windows 10, prije provjere povezivosti dva elementa početne topologije u aplikaciji „Windows Firewall With Advanced Security“ omogućena je lokalna propusnost „ICMP Echo Request“ paketa u oba smjera aktivacijom predefiniranih pravila „File and Printer Sharing (Echo Request - ICMP) - Domain/Public“. Drugim riječima, aktivacijom navedenog pravila Windows vatrozida omogućena je dozvola odgovora na dolaznu naredbu ping. Samim povezivanjem sučelja elementa početne topologije pomoću ponuđenog grafičkog alata za kreiranje veza, sučelje *ether1* Mikrotik usmjeritelja, prema slici 3, logički je pripalo podmreži 10.0.0.0/24 u kojoj je smješteno i sučelje elementa Cloud, odnosno MS Loopback adapter. Da bi provjera dostupnosti sučelja *ether1* s pozicije naredbenog retka simulacijskog računala bila uspješna, emulirana komponenta Mikrotik usmjeritelja prethodno je upaljena jednostavnim pokretanjem funkcije Start iz pripadajuće kartice opcija alatne trake grafičkog sučelja simulatora. Pokretanjem funkcije „Console“ iz pripadajuće kartice opcija usmjeritelja te kratke automatske inicijalne instalacije CHR operacijskog sustava virtualne komponente, pristupilo se naredbenom sučelju operacijskog sustava unosom predefiniranog korisničkog imena “admin” i lozinke bez znakova. Unosom i izvršenjem naredbe “*ip address add add=10.0.0.2/24 int=ether1*” inicijalizirano je sučelje *ether1* te je uspostavljena funkcionalna veza s MS Loopback adapterom. Provjera ICMP Echo dostupnosti prema MS Loopback adapteru izvršena je iz naredbenog sučelja usmjeritelja naredbom “*ping 10.0.0.1*” te je prikazom na slici 4 pokazana uspješna komunikacija između navedenih elemenata.



Slika 4. Prikaz uspješne ICMP Echo provjere s Mikrotik usmjeritelja prema MS Loopback adapteru

III. PROŠIRENJE USLUGA LOKALNE MREŽE USPOSTAVOM HTTP POSLUŽITELJA U GNS3

Za potrebe realizacije finalne topologije koja je po iskorištenju hardverskih resursa složenija od prethodno prikazane testne verzije te zahtijeva stabilnost u radu, poslužiteljska GNS3 instanca izdvojena je od aplikacije grafičkog sučelja te je implementirana kao virtualni stroj u VMWare Workstation Player virtualizacijskoj platformi. Navedenim virtualnim strojem omogućeno je posluživanje usluga simulacije gotovog Docker kontejnera Nginx HTTP poslužitelja [7] čime je u okolini GNS3 aplikacije postignuta funkcijska podjela konačne topologije na dvije instance GNS3 poslužitelja. Uz postojeću VMWare Player aplikaciju, na simulacijskom računalu omogućena je i BIOS opcija za podršku hardverskoj virtualizaciji te je dodan VMWare VIX API paket [8] neophodan za posredovanje pristupa virtualnim strojevima ugošćenih u VMWare okruženju putem drugih vanjskih aplikacija. U konkretnom slučaju, VMWare virtualnom stroju GNS3 poslužitelja generiranog na temelju GNS3 OVA datoteke u inačici 2.19 [9] pristup se obavlja iz lokalne inačice grafičkog sučelja GNS3 simulatora, uz prethodno omogućeno svojstvo korištenja GNS3 virtualnog stroja u radu samog simulatora (slika 5).

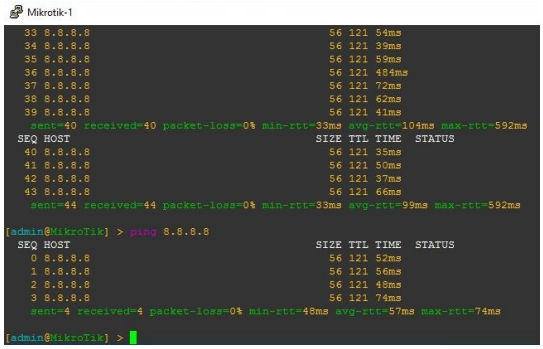


Slika 5. Dodavanje instance GNS3 virtualnog poslužitelja u GNS3 simulatoru

S obzirom da priključenje HTTP poslužitelja realnom mrežnom okruženju u uvjetima zadane topologije zahtijeva uspostavu funkcionalnosti NAT mehanizma u sustavu Mikrotik usmjeritelja, navedeni je mehanizam realiziran primjenom naredbi u prethodno otvorenom naredbenom sučelju Mikrotik usmjeritelja. Uz prvobitno kreirano vanjsko sučelje usmjeritelja, s dodijeljenom IP adresom 10.0.0.2/24, naredbom "*ip address add address 192.168.0.1/24 interface=ether2*" definirana je IP adresa sučelja *ether2* smještenog na strani lokalne mreže simulirane topologije. Ovime je ujedno kreirano sučelje podrazumijevanog izlaza za sve uređaje iz domene zadane lokalne mreže 192.168.0.0/24, a podrazumijevana ruta navedene podmreže, koja odgovara sučelju elementa Cloud, odnosno Loopback adaptera, definirana je izvršenjem naredbe "*ip route add gateway 10.0.0.1 prefsrc=10.0.0.2*". Provedbom sljedećih izvorišnih i odredišnih pravila vatrozida uspostavljena je funkcionalnost NAT mehanizma pretvorbe privatnih IP adresa iz podmreže 192.168.0.0/24:

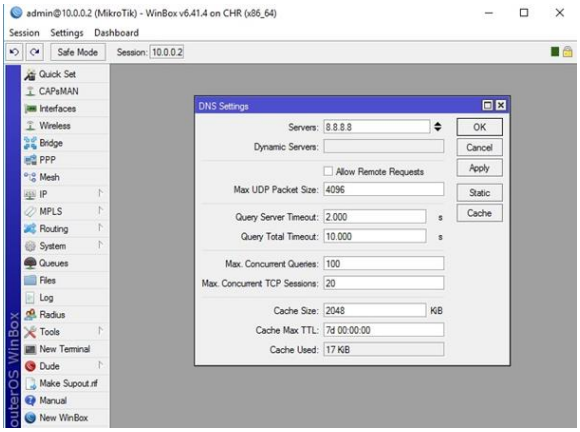
- "*ip firewall nat add action=dst-nat chain=dstnat dst-address=10.0.0.2 to-address=192.168.0.1*"
- "*ip firewall nat add action=src-nat chain=src-nat src-address=192.168.0.0/24 to-address=10.0.0.2*".

Kontrola valjanosti NAT mehanizma izvršena je provjerom dostupnosti javnog Googleovog DNS poslužitelja 8.8.8.8 ICMP Echo porukom s lokacije naredbenog sučelja Mikrotik usmjeritelja. Slikom 6 prikazana je uspješna provjera dostupnosti poslužitelja čime je ujedno ostvaren otvoren pristup Internetu potreban za ispunjenje lokalne i globalne dostupnosti usluge budućeg HTTP poslužitelja.



Slika 6. Prikaz provjere valjanosti NAT mehanizma slanjem ICMP Echo poruke prema poslužitelju 8.8.8.8

Dodatnom konfiguracijom adrese DNS poslužitelja u postavkama Mikrotik usmjeritelja osigurana je dostupnost simboličkih računalnih adresa. Pristupom postavkama kroz grafičko sučelje Mikrotik usmjeritelja uz pomoć uslužne aplikacije Winbox prikazana je i druga realno primjenjiva mogućnost upravljanja i konfiguracije dotičnih uređaja. Tako je IP adresa DNS poslužitelja određena unutar IP grupe postavki pod kategorijom DNS u prozoru s postavkama podešenih na IP adresu javnog Google DNS poslužitelja prema slici 7.

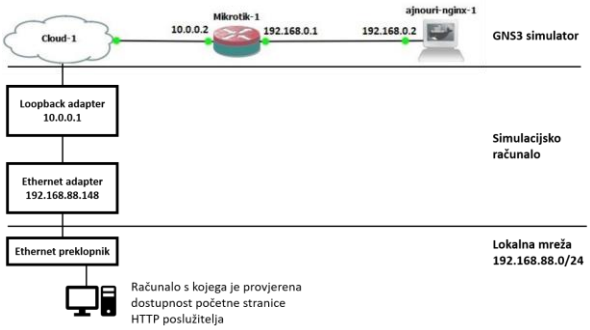


Slika 7. Prikaz grafičkog sučelja usmjeritelja i definiranje IP adrese DNS poslužitelja

Slanjem ICMP Echo poruke iz naredbenog sučelja usmjeritelja prema simboličkoj adresi *www.google.com* ponovno je provjerena uspješna povezivost prema internetu te ispravan rad dodane funkcionalnost zapisa DNS poslužitelja.

A. Uspostava usluge HTTP poslužitelja

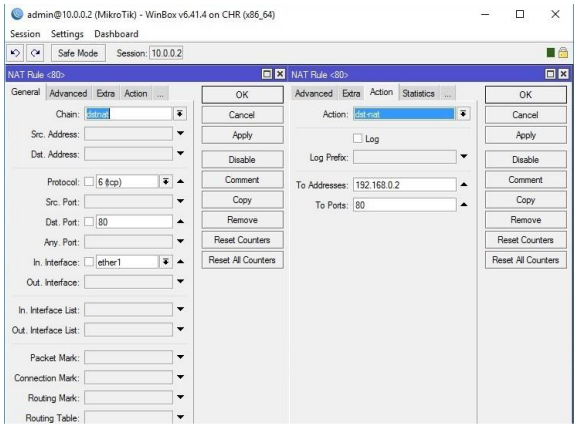
Usluga HTTP poslužitelja u simuliranoj mrežnoj topologiji realizirana je iskorištenjem podrške za kontejnersku virtualizaciju Linux operacijskog sustava unutar GNS3 okruženja, postavljanjem predefiniranog Docker kontejnera. Tako je za potrebe demonstracije HTTP poslužitelja odabran *ajnouri/nginx* Docker kontejner, koji je potom implementiran u lokalnoj virtualnoj mreži iza sučelja *ether2* Mikrotik usmjeritelja. Automatizirana instalacija slike sustava s predpodešenim Nginx HTTP poslužiteljem realizirana je unosom navedenog naziva github repozitorija Docker kontejnera unutar GNS3 opcije „Docker Containers“ te jednostavnim ubacivanjem novodefinirane komponente iz repozitorija dostupnih uređaja u područje prozora simulacije. Spajanjem uvezene komponente poslužitelja sa sučeljem *ether2* Mikrotik usmjeritelja kreirana je konačna topologija mreže nakon čega su provedeni dodatni konfiguracijski postupci kako bi se omogućio pristup sadržajima HTTP poslužitelja s bilo kojeg računala iz mreže u kojoj se nalazi mrežni adapter simulacijskog računala gdje je dotični poslužitelj ugošćen (slika 8).



Slika 8. Prikaz komponenata konačne realizacije simulirane mreže

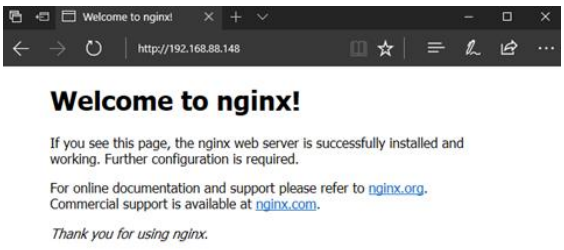
Na javnom (vanjskom) sučelju Mikrotik usmjeritelja podešeno je prosljeđivanje HTTP prometa prema poslužitelju koji je prema prikazanoj shemi smješten na „privatnoj“ strani usmjeritelja iza sučelja *ether2*. Funkcija prosljeđivanja HTTP paketa omogućena je konfiguracijom parametara u sklopu grafičkog sučelja Mikrotik usmjeritelja posredstvom aplikacije Winbox. Unutar izborničke grupe IP, pod funkcionalnosti vatrozida definirani su sljedeći parametri pridruženi konfiguracijskoj grupi NAT mehanizma (slika 9):

- u kartici General: *Chain=dstnat;Protocol=6(tcp); Dst. Port=80; In. Interface=ether1*
- u kartici Action: *Action=dst-nat; To Addresses=192.168.0.2; To Ports=80*.



Slika 9. Postavke prosljeđivanja HTTP prometa

Dodatnim postupkom isključenja HTTP servisa grafičkog sučelja u postavkama samog usmjeritelja oslobođena su TCP vrata 80 čime su ostvareni uvjeti slobodnog pristupa uslugama Nginx poslužitelja na standardnom broj TCP vrata bez potrebe za dodatnim konfiguriranjem samog poslužitelja. Primjenom usluge *portproxy* Windows operacijskog sustava simulacijskog računala, omogućena je dostupnost HTTP usluge klijentima iz mreže simulacijskog računala. Svi dolazni TCP paketi s brojem vrata 80 koji dolaze na Ethernet sučelje simulacijskog računala prosljeđuju se vanjskom sučelju *ether1* Mikrotik usmjeritelja s adresom 10.0.0.2 sa standardnim TCP brojem vrata 80. Navedeno je ostvareno izvršenjem sljedeće naredbe u naredbenom retku simulacijskog računala pokrenutog pod administratorskim ovlastima: „*netsh interface portproxy add v4tov4 listenport=80 listenaddress=192.168.88.148 connectaddress=10.0.0.2 connectport=80“*. Parametrom *listenaddress* određena je IP adresa mrežnog adaptera simulacijskog računala smještenog u mreži 192.168.88.0/24 te se pozivom web lokacije http://192.168.88.148 s proizvoljnog testnog računala iz prethodno specificirane mreže pokazuje konačan prikaz početne web stranice HTTP servisa.



Slika 10. Prikaz početne stranice uspostavljenog HTTP servisa

IV. ZAKLJUČAK

Prikazanim postupcima sinteze elemenata i konfiguracijskih postupaka u realnim i virtualnim mrežnih topologijama pružen je obrazac primjene grafičkih mrežnih simulatora izvan isključivo simulacijskog konteksta. Uvođenjem emuliranih hardverskih komponenti stvoreno je sučelje prema fizičkom mrežnom okruženju kao i elementi zaslužni za proširenje samih usluga unutar domene lokalnih mreža. Osim što je pružen konkretan i poučan primjer implementacije jednog tipa mrežnog usmjeritelja s integriranom funkcijom vatrozida, pokazana je i idejna platforma za primjene Docker kontejnera u obliku HTTP poslužitelja kao i drugih mogućih funkcionalnosti. Prikazanim spojem različitih koncepata i tehnologija otvoren je prostor za daljnja proširenja u primjenama učenja, poučavanja te profesionalnih, odnosno stručnih primjena u području računalnih mreža.

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Stavovi roditelja i učenika o korištenju sustava e-Dnevnik u osnovnom obrazovanju

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I. SAŽETAK

Primjena informacijskih i komunikacijskih tehnologija u nastavi, odnosno informatizacija škola proces je koji se odvija u hrvatskim školama već godinama. Kako se tehnologija kontinuirano i neprestano razvija, tako je potrebno razvijati i sam sustav obrazovanja, to jest sve sastavnice koje ga sačinjavaju. Jedna od tih sastavnica je vođenje razrednih knjiga koje se od školske godine 2011./2012. odvija u elektroničkome obliku, u pojedinim osnovnim i srednjim školama. CARNet je upravo te školske godine izradio aplikaciju e-Dnevnik, elektroničku razrednu knjigu, čiji su korisnici učitelji i nastavnici, ali i učenici i roditelji. Aplikaciju danas koristi više od 1160 osnovnih i srednjih škola. U veljači 2018. godine provedeno je istraživanje na ukupno 700 ispitanika (407 učenika i 293 roditelja) čiji je cilj bio utvrditi koliko roditelji i učenici koriste aplikaciju e-Dnevnik i na koji način, imaju li problema s njenim korištenjem, što im se sviđa u aplikaciji te ispunjava li aplikacija e-Dnevnik svoju svrhu.

II. UVOD

Hrvatska akademska i istraživačka mreža – CARNET školske je godine 2011./2012. pokrenula sustav e-Dnevnik. To je informacijski sustav namijenjenu vođenju razredne knjige u elektroničkome obliku. Informacijski sustav e-Dnevnik je Web baziran sustav koji omogućuje pristup nastavnicima, učenicima i njihovim roditeljima svim relevantnim podacima tijekom školovanja učenika. Postepenim uvođenjem u osnovne i srednje škole danas se njime koristi više od 1160 osnovnih i srednjih škola.

Informacijski sustav ima sve funkcionalnosti kao i fizička razredna knjiga uz dodatne mogućnosti koje pruža uporaba informacijsko-komunikacijskih tehnologija. Neke prednosti korištenja e-Dnevnika u odnosu na tiskani dnevnik i imenik su jednostavnije vođenje razredne evidencije, mogućnost detaljne analize statističkih podataka iz razredne nastave, brzi pristup svim važnim informacijama vezanim uz pojedini razred ili pojedinog učenika kao i preglednija cjelokupna evidencija nastave. Uz prednosti, sustav također ima i svoje nedostatke, a neki od njih su sljedeći: budući da se aplikacija koristi putem računala (stolna ili prijenosna) i tableta, kvarom uređaja nastavnik nije u mogućnosti pristupiti e-Dnevniku te mora naknadno upisati podatke vezane za dan kada nije bio u mogućnosti pristupiti aplikaciji.

Nadalje, nemogućnost pristupa aplikaciji može biti uzrokovana i nestankom električne struje kao i nestankom internetske veze ili kvarom u mrežnom sustavu te u tome slučaju treba pričekati da stručnjaci otklone kvar, a za to vrijeme sve potrebno zabilježiti u pisanom obliku. Aplikaciju danas koristi više od 1160 osnovnih i srednjih škola. U veljači 2018. godine provedeno je istraživanje na ukupno 700 ispitanika (407 učenika i 293 roditelja) čiji je cilj bio utvrditi koliko roditelji i učenici koriste aplikaciju e-Dnevnik i na koji način, imaju li problema s njenim korištenjem, što im se sviđa u aplikaciji te ispunjava li aplikacija e-Dnevnik svoju svrhu.

III. ISTRAŽIVANJE

A. *Metodologija istraživanja*

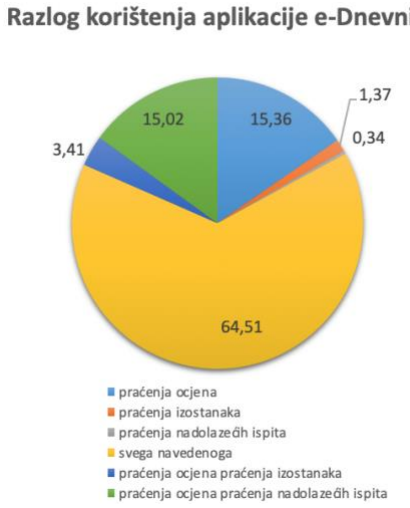
Istraživanje je provedeno u tri osnovne škole na području Grada Zagreba i jednoj osnovnoj školi u Zagrebačkoj županiji metodom ankete. Za potrebe istraživanja napravljene su dvije ankete, anketa za roditelje sastojala se od 16 pitanja (12 pitanja zatvorenog tipa, 4 pitanja otvorenog tipa), a anketa za učenike od 13 pitanja (10 pitanja zatvorenog tipa, 3 pitanja otvorenog tipa), a ispitani su učenici sedmih i osmih razreda. Podatci su obrađeni u programu PSPP, besplatnoj verziji programa SPSS *(Statistical Package for Social Sciences)*. U ovome će članku biti prikazani rezultati za pojedina pitanja iz obiju anketa.

B. *Rezultati istraživanja*

U istraživanju je sudjelovalo 293 roditelja, od toga je njih 78,84% ženskog spola, a 20,82% muškog spola. Najviše roditelja pripada dobnoj skupini od 40 do 50 godina (54,27%) te od 30 do 40 godina (32,76%). Od 407 učenika koji su sudjelovali u istraživanju, 47,17% su bile učenice i 52,83% učenika. Od toga je bilo 53,32% učenika, odnosno učenica sedmoga razreda te 46,68% učenika i učenica osmoga razreda.

C. *Rezultati anketa za roditelje*

Svi su se roditelji izjasnili kako su upoznati s činjenicom da se u školi njihovog djeteta koristi e-Dnevnik, ali su na različite načine upoznati s njihovima korištenjem. Naime, većina roditelja sama se upoznala s načinom rada aplikacije, neki su roditelji dobili ključne informacije na roditeljskim sastancima, dok je određeni broj škola za svoje roditelje organizirao radionice na kojima su roditelje upoznali s mogućnostima aplikacije e-Dnevnik. Roditelje se nadalje pitalo koliko često koriste aplikaciju. Najviše njih to čini svakodnevno (32,08%), malo manji postotak jednom tjedno (30,03%), odnosno do tri puta tjedno (24,57%). Najmanji postotak roditelja izjasnio se da aplikaciju koristi rijetko (13,31%). Pitalo se roditelje i koji je najčešći razlog korištenja e-Dnevnika gdje su birali između sljedećih ponuđenih odgovora: praćenja ocjena, praćenja izostanaka, praćenja nadolazećih ispita, svega navedenoga, ništa od navedenoga. Najveći broj ispitanika izjasnio se kako aplikaciju koristi zbog svega navedenoga (64,51% ispitanika), dok odmah iza toga slijede odgovori zbog praćenja ocjena te zbog praćenja ocjena i nadolazećih ispita. Rezultati su prikazani na slici 1.



Slika 1. Razlog korištenja aplikacije e-Dnevnik

Što se tiče pristupa aplikaciji, najviše roditelja to čini putem mobitela (42,66%), a najmanje putem tableta (2,73%). Roditelji također često koriste laptop ili računalo, to jest kombinaciju mobitela i laptopa što se detaljnije može vidjeti u tablici 1.

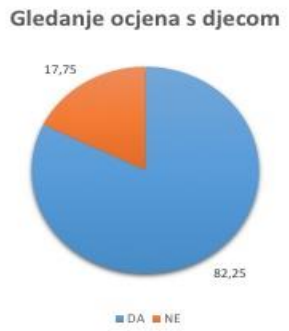
Tablica 1. Prikaz načina pristupanja roditelja aplikaciji

Nacin_pristupa

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
MOBITEL	1	125	42,66	42,66	42,66
TABLET	2	8	2,73	2,73	45,39
LAPTOP	3	44	15,02	15,02	60,41
RAČUNALO	4	49	16,72	16,72	77,13
MOBITEL TABLET	5	2	,68	,68	77,82
MOBITEL LAPTOP	6	18	6,14	6,14	83,96
MOBITEL RAČUNALO	7	22	7,51	7,51	91,47
TABLET LAPTOP	8	3	1,02	1,02	92,49
TABLET RAČUNALO	9	1	,34	,34	92,83
LAPTOP RAČUNALO	10	7	2,39	2,39	95,22
MOBITEL TABLET LAPTOP RAČUNALO	11	13	4,44	4,44	99,66
	33	1	,34	,34	100,00
	Total	293	100,0	100,0	

Šesto pitanje u anketi roditelja glasilo je: *Prijavljujete li se u sustav e-Dnevnik putem sustava e-Građani?* Iako je roditeljima namijenjeno da aplikaciji pristupaju putem sustava e-Građani, veliki broj korisnika (71,67%) aplikaciji pristupa na drugi način, tj. koristeći aplikaciju svoje djece. Na pitanje smatraju li da je aplikacija korisna, potvrdno je odgovorila većina ispitanika (99,66%). S obzirom da je ovo bilo pitanje otvorenog tipa u nastavku su odgovori nekih ispitanika koji su dali potvrdan odgovor: *povećava dostupnost informacija; brža komunikacija; zbog uvida u ocjene, profesorskih opaski i zapažanja o djetetu; roditelju omogućuje redovne kontrole; ne moram zapisivati ocjene; jednostavno korištenje; bolja komunikacija i brzina; korisna je jer se može planirati učenje za ispite; svakodnevno sam u toku događanja, ne moram ići u školu; smanjuje broj odlazaka na informacije*. Ispitanik koji je odgovorio kako aplikacija nije korisna napisao je: *„Relativno korisna. Daje samo djelomično uvid u sve nužno uz školovanje djeteta.“*

Nadalje, u anketi se roditelje pitalo gledaju li zajedno s djetetom ocjene i znaju li lozinku svoga djeteta za pristup aplikaciji. Na prvo je pitanje potvrdno odgovorilo 82,25% roditelja. Rezultati su vidljivi na slici 2.



Slika 2. Gledanje ocjena s djecom

Na pitanje koje se odnosi na lozinku potvrdno je odgovorilo 86,35% roditelja, dok njih 13,65% ne zna lozinku svoga djeteta. Jedno od pitanja bilo je i pokušavaju li djeca sakriti ocjene od svojih roditelja. Na njega je potvrdno odgovorilo 13,31% ispitanika što pokazuje da većina učenika ne skriva ocjene od svojih roditelja. *Dolazite li rjeđe na informativne razgovore u školu zbog e-Dnevnika? Zašto?* bilo je sljedeće pitanje gdje je 55,63% ispitanika odgovorilo kako rjeđe dolazi u školu otkako koriste e-Dnevnik, dok se to ne odnosi na preostalih 44,37% ispitanika. Analizom podataka ispitao se odnos učestalosti korištenja aplikacije i odlazaka u školu na informativne razgovore. Tablica 2. prikazuje rezultate statističke obrade (PSPP), odnosno korelaciju između varijabli Učestalost i Razlog korištenja. Pearsonov koeficijent korelacije pokazuje korelaciju r=-0,23 uz signifikantnost p<0,01 čime se pokazuje slaba negativna povezanost, odnosno što češće roditelji koriste aplikaciju e-Dnevnik, to rjeđe odlaze na informativne razgovore. Neki od odgovora na pitanje zašto dolaze rjeđe su: *sve informacije su dostupne na e-Dnevniku; uz*

redovne roditeljske sastanke i e-Dnevnik dolazim po potrebi ocjena i situacije; nije potrebno; ocjene su odmah dostupne i mogu ih prokomentirati zajedno s djetetom; putem e-Dnevnika dobijemo većinu potrebnih informacija. Primjeri odgovora roditelja koji su zaokružili ne: *usmena komunikacija je nezamjenjiva; u razgovoru s razrednicom saznam i ponašanje, odnos*

Tablica 2. Rezultati statističke obrade podataka – PSPP Pearsonov koeficijent korelacije

Correlations

		Učestalost	Razlog_koristenja
Učestalost	Pearson Correlation	1,00	-,23
	Sig. (2-tailed)		,000
	N	293	293
Razlog_koristenja	Pearson Correlation	-,23	1,00
	Sig. (2-tailed)	,000	
	N	293	293

prema radu i funkcioniranje cijelog razreda i mog djeteta unutar istog; smatram da su i razgovori s razrednikom vrlo korisni; volim o svome djetetu popričati s razrednicom; mislim da je izravan kontakt bitan, nisu ocjene jedino što me zanima u školovanju djeteta.

Sljedeća dva pitanja bila su otvorenog tipa, a neki od odgovora navedeni su u nastavku. *Što Vam se sviđa u aplikaciji? Brzina i efikasnost pristupa informacijama; ažurnost informacija; jednostavnost korištenja i ispis ocjena pojedinačnog predmeta; praktičnost i preglednost; brzi uvid u sve; logično je postavljena i jednostavna za korištenje; pregled svih ocjena i izračun prosječne ocjene; aplikacija je u redu, ali profesori ne znaju raditi s njom. Što Vam se ne sviđa i što biste htjeli promijeniti u aplikaciji? Ništa, ali uvela bi obvezne informacije unatoč aplikaciji; preglednost ocjena na mobitelu nije baš dobra, preglednost je bolja na stolnom računalu; ne želim ništa mijenjati; bilo bi korisno omogućiti komunikaciju profesor – roditelj kako bi mogli pitati što nas zanima; u aplikaciji ne treba ništa mijenjati osim što profesori trebaju redovito vršiti upis ocjena; nemogućnost povratne informacije profesoru; ako je blizu datum ispita da se ubaci neki crveni znak; što moram ulaziti u svaki predmet posebno; dodati „side menu" s predmetima umjesto „back" za odabir; možda ubaciti raspored i eventualne promjene rasporeda.* Roditelje pitalo i komuniciraju li s razrednikom putem službenog e-maila na što je potvrdno odgovorilo 39,93% ispitanika, dok većina ne vrši komunikaciju putem službenog e-maila. Posljednja dva pitanja postavljena roditeljima bila su: *Smatrate li da je aplikacija jednostavna za korištenje?* i *Biste li ukinuli e-Dnevnik i vratili klasični imenik? Zašto?* Na prvo je pitanje većina ispitanika odgovorila potvrdno (97,61%), dok je na posljednje pitanje pozitivno odgovorilo samo 2,39% ispitanika što znači da većina njih ne bi htjela da se ukine e-Dnevnik. Neki od odgovora zašto ne bili su: *samo ne vraćanje na klasični imenik; moramo pratiti moderne tehnologije; ovako je praktično; korisna aplikacija; mislim da olakšava rad profesorima, a također nama roditeljima (pravovremeni uvid u ocjene i ponašanje djeteta, kao i zbog manje mogućnosti mijenjanja ocjena na kraju školske godine, tj. manipuliranja); zbog lakše kontrole uspjeha i ponašanja učenika, osobito kada nisam u mogućnosti redovno osobno dolaziti na informacije; zato što pisanom imeniku u doba novih tehnologija više nije mjesto u školi; na početku korištenja sam bila malo opsjednuta svakodnevnim praćenjem ocjena i ispita, ali s vremenom sam našla granicu i vratila se sistemu da komuniciram s djetetom o ocjenama i ispitima, a e-Dnevnik s vremena na vrijeme pogledam.*

Primjeri odgovora zašto da: *zato što ima veliki pritisak na djecu; jer učenici mogu ispraviti ocjene na bolji način; zato što mogu pričati s razrednikom o ocjenama.*

D. Rezultati anketa za učenike

Prvo pitanje postavljeno učenicima bilo je vezano uz učestalost korištenja aplikacije e-Dnevnik. Rezultati su pokazali kako najviše učenika aplikaciju koristi do tri puta tjedno (38,33%), nešto manji postotak učenika to čini svakodnevno (24,08%). Ovime se potvrđuje kako veliki postotak učenika aplikaciju e-Dnevnik koristi kontinuirano, a rezultati su prikazani dijagramom na slici 3.



Slika 3. Učestalost korištenja aplikacije e-Dnevnik kod učenika

Sljedeće se pitanje odnosilo na najčešći razlog korištenja e-Dnevnika gdje su učenici birali između ponuđenih odgovora (gledanja ocjena, praćenja izostanaka, praćenja nadolazećih ispita, svega navedenoga, ništa od navedenoga). Najviše ispitanika izjasnilo se kako aplikaciju koristi zbog svega navedenoga, točnije 41,52%, isključivo zbog gledanja ocjena aplikaciju koristi 34,64% učenika, zbog gledanja ocjena i praćenja nadolazećih ispita 17,2% učenika, a samo zbog praćenja nadolazećih ispita 3,69% učenika. Zbog gledanja ocjena i praćenja izostanaka aplikaciju koristi 0,25% učenika, dok je ništa od navedenoga zaokružilo 2,7% učenika. Zanimljivo je primijetiti povezanost s odgovorima roditelja koji su se također izjasnili kako aplikaciju koriste ponajviše zbog svega navedenoga.

Sljedeće pitanje otvorenog tipa bilo je: *Misliš li da je aplikacija e-Dnevnik korisna? Zašto?* Potvrdno je odgovorilo 89,93% učenika.

Neki od potvrdnih odgovora na pitanje su: *za lakši pristup informacijama; lakše imam uvid u svoje ocjene; zato što mi roditelji svakodnevno mogu pratiti ocjene; možemo pratit kad imamo koji ispit; zato što onda roditelji ne bi dolazili u školu zbog gledanja ocjena; možemo vidjeti kad imamo ispite, lektiru te se bolje pripremimo; možemo vidjeti svoj prosjek te ga popraviti;*

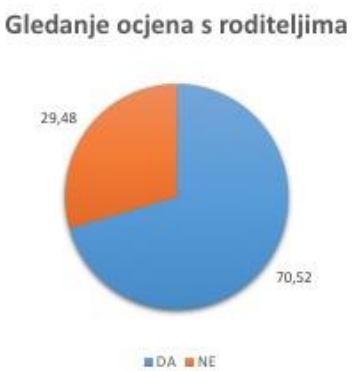
jer se ne treba tako često ići na informacije, korisna je dok roditelji ne znaju lozinku.

Primjeri odgovora na pitanje zašto ne: *zato što ne mogu lagati za ocjenu; jer profesori daju nenajavljene ispite pa praćenje ispita postaje beskorisno; jer ti roditelji imaju 5 puta stresniji život nego prije prateći svaki korak u mojoj školi; zato što nije dobro napravljena; to je najveća glupost što postoji; zato jer se ne znam koristit računalom; zato što nam roditelji cijelo vrijeme gledaju ocjene i ne sviđa mi se; bolji su obični dnevnici; zato jer ne mogu roditeljima ne reć ocjenu jer odmah vide.*

Sljedeća su dva pitanja također otvorenog pitanja, a neki odgovori navedeni su u nastavku. *Što ti se sviđa u aplikaciji? To što mi roditelji ne moraju ići u školu da mi pogledaju ocjene; to što možemo gledati ocjene; sviđa mi se to što je napisano lijepim fontom; što mogu pogledat kada je test; to što je plave boje; jednostavna je; što mogu gledati ocjene kad želim; što je dobro organizirana; sviđa mi se cijeli izgled e-Dnevnika i način na koji je raspoređen.*

Što ti se ne sviđa i što bi htio promijeniti u aplikaciji? Sve mi se sviđa i ništa ne treba promijenit; da mi mama ne može gledati ocjene, htjela bih da roditelji nemaju pristup aplikaciji; mogućnost promjene lozinke da bi ju lakše zapamtio; ne sviđa mi se što se u e-Dnevnik zapisuju gluposti, npr. da pričamo pod satom ili da smo zaboravili pribor; meni je sve u redu samo bih htjela promijeniti font slova; ne sviđa mi se to što onu ocjenu koju ispravimo je još upisana; preteške su lozinke; slučajan odabir; htjela bi da dođe obavijest kada imamo ispit; promijenio bih e-Dnevnik na mobitelu težak je i nepregledan trebao bi biti kao na kompu; da ne dolazi obavijest za novu ocjenu; htio bih da se negdje automatski izračuna ukupan prosjek; trebalo bi staviti raspored sati; dodao bi poruku dana – motivacijsku.

Šesto pitanje u anketi učenika glasilo je: *Znaš li svoju lozinku za pristup aplikaciji napamet?* Većina je učenika (63,14%) odgovorila kako zna svoju lozinku napamet. Sljedeća dva pitanja također su vezana uz lozinku. *Jesi li ikada promijenio svoju lozinku?* te *Znaju li tvoji roditelji lozinku za pristup aplikaciji e-Dnevnik?* Vrlo je mali broj učenika mijenjao svoju lozinku (8,35%), dok se veliki postotak njih izjasnio kako njihovi roditelji znaju lozinku za pristup njihovoj aplikaciji (87,22%) što se u velikoj mjeri poklapa s odgovorima roditelja. Naime, 86,35% roditelja izjasnilo se kako zna lozinku svoga djeteta.



Slika 4. Gledanje ocjena s roditeljima

Jedno je od pitanja za učenike bilo i gledaju li roditelji s njima ocjene preko aplikacije na što je 70,52% učenika odgovorilo potvrdno, a to se poklapa ponovo s odgovorima roditelja od kojih je njih 82,25% odgovorio isto tako potvrdno. Dijagram na slici 4. prikazuje rezultate odgovora učenika.

Na jedno se pitanje od učenika tražilo mišljenje o tome koliko često njihovi roditelji koriste aplikaciju e-Dnevnik. Rezultati su vrlo slični onima koji su se dobili analizom odgovora roditelja. Podjednak broj učenika odgovorio je svakodnevno (26,54%) i jednom tjedno (26,78%), dok je nešto manji broj učenika odgovorio je do tri puta tjedno (19,41%) što pokazuje da učenici znaju kako roditelji često koriste aplikaciju e-Dnevnik.

I učenike se također pitalo imaju li pristup e-Dnevniku te na koji mu način pristupaju. Tako je 99,26% učenika odgovorilo da ima kod kuće mogućnost pristupa aplikaciji. U tablici 3. prikazani su odgovori učenika, odnosno načini pristupanja aplikaciji. Najviše učenika e-Dnevniku pristupa putem mobitela što je u današnje vrijeme i očekivano budući da većina učenika posjeduje pametni telefon. Odgovori se ponovo u velikoj mjeri poklapaju s odgovorima roditelja jer dosta učenika aplikaciju koristi na laptopu ili stolnom računalu ili na kombinaciji jednog i drugog s mobitelom.

Nacin_pristupa

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
MOBITEL	1	198	48,65	48,65	48,65
TABLET	2	7	1,72	1,72	50,37
LAPTOP	3	29	7,13	7,13	57,49
RAČUNALO	4	31	7,62	7,62	65,11
MOBITEL TABLET	5	8	1,97	1,97	67,08
MOBITEL LAPTOP	6	54	13,27	13,27	80,34
MOBITEL RAČUNALO	7	38	9,34	9,34	89,68
LAPTOP RAČUNALO	10	1	,25	,25	89,93
MOBITEL TABLET LAPTOP RAČUNALO	11	41	10,07	10,07	100,00
	Total	407	100,0	100,0	

Tablica 3. Prikaz načina pristupanja učenika aplikaciji e-Dnevnik

Posljednje pitanje na koje su učenici odgovarali u svojoj anketi bilo je: *Koristiš li svoj školski e-mail (ime.prezime@skole.hr)?* Na to je pitanje potvrdno odgovorilo 53,56% učenika, dok ih je 46,44% odgovorilo kako isti ne koristi.

IV. ZAKLJUČAK

Temeljem provedenoga istraživanja i analizom prikupljenih podataka može se zaključiti kako su i roditelji i učenici zadovoljni sustavom e-Dnevnik, odnosno njegovom primjenom, mogućnostima, alatima i uslugama koje im on pruža. Posebno su zadovoljni roditelji koji sada mogu lakše nadzirati svoju djecu te im je sve što se događa u školi još pristupačnije. Ono što proizlazi kako negativno jest činjenica da roditelji puno rjeđe dolaze na informativne razgovore u školu jer smatraju kako je praćenje napretka njihove djece dovoljno samo putem aplikacije, no tu se gubi odnos roditelja i škole, prvenstveno odnos roditelja i učitelja, odnosno nastavnika. e-Dnevnik je odličan alat koji pomaže roditeljima kako bi bili konstantno u toku sa zbivanjima u školi, ali nikako ne bi trebao biti jedini kontakt sa školom.

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Suradnja roditelja i nastavnika u srednjoj školi i informacijsko-komunikacijska tehnologija koja se koristi u ovoj suradnji

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***Sažetak* - Kroz povijest se mijenjao odnos roditelja prema nastavniku i vlastitom djetetu. Nastavnici su stručnjaci za odgoj i obrazovanje, a roditelji bi trebali najbolje poznati svoju djecu. Za dobrobit djeteta, za njegov razvoj i napredak kroz što kvalitetnije obrazovanje potpomognuto korištenjem informacijsko-komunikacijske tehnologije važna je suradnja roditelja i nastavnika.**

U ovom radu opisan je pojam suradnje i važnost suradnje nastavnika i roditelja za dobrobit djeteta. Da bi se shvatilo zašto je suradnja roditelja i nastavnika važna, izrađen je kratki pregled dosadašnjih istraživanja vezanih za temu rada. U radu su također izdvojeni otvoreni izazovi i primjeri dobre prakse.

U istraživačkom dijelu rada prikazani su rezultati istraživanja suradnje roditelja i nastavnika u srednjim školama, po uzoru na prethodna istraživanja. Prema rezultatima provedenog istraživanja, roditelji i nastavnici smatraju međusobnu suradnju vrlo važnom za uspjeh i napredak učenika. Navode kako kroz zajedničku suradnju mogu pomoći učeniku da ostvari svoj maksimum. Iako su svjesni koje su njene prednosti, kroz intervju se nije stekao dojam da suradnju i njezine mogućnosti u potpunosti koriste za boljitak djeteta odnosno učenika, što ostavlja prostor za daljnji napredak i usmjeravanje ove vrste suradnje.

Informacijsko-komunikacijska tehnologija u mnogim segmentima pruža brži i učinkovitiji način komunikacije. U okviru istraživanja provedenog za potrebe ovog rada istraženo je u kojem obliku roditelji i nastavnici koriste ovu vrstu tehnologije u svrhu bolje i učinkovitije komunikacije i suradnje.

Ključne riječi – nastavnik; roditelj; suradnja; obrazovanje; informacijsko-komunikacijska tehnologija; srednja škola; školsko ozračje; etos škole

I. UVOD

Suradnja roditelja i nastavnika je važan pojam u suvremenoj pedagogiji. Sve češće se promišlja o suradnji roditelja i nastavnika za dobrobit djeteta. U školskoj ustanovi su nastavnici, kao kvalificirani stručnjaci, organizatori i rukovoditelji nastavnog procesa, odnosno oni kojima je zadaća odgajati i obrazovati učenike ostvarujući ciljeve i zadaće odgoja i obrazovanja [16; 18; 24]. Roditelji bi trebali doprinijeti „različitim, ali istovrijednim iskustvom i stručnošću“ [11]. Autori radova s tematikom odgoja i obrazovanja navode kako roditelj ne bi smio biti isključen iz procesa odgoja i obrazovanja [1; 3; 5]. Roditelj bi trebao postati suradnik nastavniku te se sa svojim idejama uključiti i doprinijeti nastavi [3; 5].

U posljednje vrijeme brojni autori ističu činjenicu da uz suradnju roditelja i nastavnika dijete može bolje razviti i iskoristiti vlastite potencijale te dati svoj maksimum [3; 17; 25]. Povećani interes roditelja za uspjeh djeteta, za događanja koja se održavaju u školi ili razredu, za pomoć djetetu u učenju ili pisanju domaćih zadaća, potiču dijete i utječu na njegov napredak [6]. S obzirom na navedeno, nastavnik i roditelj trebaju osvijestiti važnost suradnje i spoznati načine na koje mogu surađivati na obostrano zadovoljstvo roditelja i nastavnika, a za dobrobit djeteta.

II. SURADNJA RODITELJA I NASTAVNIKA

Prema zakonskim propisima Republike Hrvatske roditeljska dužnost je brinuti se za odgoj i obrazovanje svog djeteta [8; 14; 20]. Kroz povijest smo svjedočili da roditelji ne shvaćaju jednako svoju dužnost. U posljednjih nekoliko godina zamijećen je rast uključenosti roditelja u odgoj i obrazovanje vlastitog djeteta [17]. Sve više roditelja želi „uspostaviti suradnju s nastavnicima kako bi mogli adekvatno kontrolirati i usmjeravati rast i razvoj djeteta“ [9].

Suradnja je jedan od oblika socijalne interakcije. Ona je „temelj uspostavljanja dobrih međuljudskih odnosa i ostvarivanja timskog rada“ [19]. To je dugotrajan proces koji traži maksimalnu angažiranost i volju obiju strana koje žele surađivati [11]. Suradnja roditelja i nastavnika se smatra važnim čimbenikom osiguranja djetetova uspjeha i cjelovitog razvoja što nije sporno jer su nastavnici stručnjaci u području odgoja i obrazovanja, a roditelji su stručnjaci u poznavanju svoje djece [11; 25].

Pod njihovom suradnjom podrazumijeva se kontinuirano razmjenjivanje informacija i iskustava, suodlučivanje o različitim aspektima djetetova školovanja, ali i uključivanje u razne izvanškolske i školske aktivnosti s ciljem podupiranja djetetovog školskog uspjeha i cjelovitog razvoja [10]. Ona je važan segment uspjeha i zajedničkog zadovoljstva zainteresiranih i odgovornih za proces odgoja i obrazovanja [11].

Važnost suradnje roditelja i nastavnika potvrđuje i činjenica da je navedena tema posljednjih nekoliko godina u fokusu mnogih istraživanja [12]. Istraživanja pokazuju da je suradnja roditelja i nastavnika važna odrednica uspjeha djeteta [13; 25]. Kvalitetna suradnja nastavnika i roditelja omogućuje kontinuirano praćenje rada i napretka učenika i uočavanje teškoća i propusta. Ona pospješuje odgoj i obrazovanje te ima pozitivan utjecaj na školski uspjeh i ponašanje učenika [10]. Odnos nastavnika i roditelja se najčešće gradi kroz roditeljske sastanke, individualna informiranja, pisane informacije, volontiranja, radionice, školske akcije i slično [13; 15; 23; 25].

Većina roditelja i nastavnika shvaća da razni oblici suradnje olakšavaju njihovu međusobnu komunikaciju i informiranje o djetetu i da su, s obzirom na navedeno, važni za djetetov napredak [25]. Bez obzira na to, neki nastavnici i roditelji neprestano nalaze izgovore, ne trude se uspostaviti pozitivne odnose niti se žele međusobno konzultirati. Roditelji najčešće uspostavljaju kontakt s nastavnicima samo onda kada su primorani, zbog zakonskih propisa ili zbog pozitivnog/negativnog isticanja učenika [13; 15; 22; 23]. Razlog, ali i posljedica toga su tenzije koje se stvaraju u odnosu nastavnika i roditelja. Jedni druge često gledaju kao ugrozu i kao problem [13]. Umjesto na trzavice, međusobne svađe i optuživanja, svi akteri trebali bi svoju energiju usmjeriti na postizanje kvalitetne međusobne komunikacije, odnosno na postizanje suradnje za dobrobit djeteta [13; 22; 25].

III. METODOLOGIJA

Cilj istraživanja provedenog za potrebe ovog rada je kvalitativno istražiti percepciju roditelja i nastavnika o njihovoj suradnji. Za prikupljanje podataka korišten je polustrukturirani intervju koji se temelji na instrumentu korištenom u istraživanju koje je provela Žužić [25]. U okviru provedenog istraživanja istraženo je i u kojem obliku roditelji i nastavnici koriste informacijsko-komunikacijsku tehnologiju, a u svrhu postizanja što bolje i učinkovitije komunikacije i suradnje.

Prigodni uzorak obuhvaćen istraživanjem čini 30 nastavnika i 30 roditelja učenika iz četiri različite srednje škole. Svi ispitanici bili su upoznati sa sadržajem intervjua tri dana prije njegovog održavanja kako bi se pripremili za razgovor.

Intervju je obuhvaćao jedanaest komplementarnih pitanja koja su jezično prilagođena nastavnicima i roditeljima.

Intervju je provođen individualno sa svakim od ispitanika. Prosječno vrijeme trajanja intervjua bilo je 40 minuta.

IV. REZULTATI ISTRAŽIVANJA

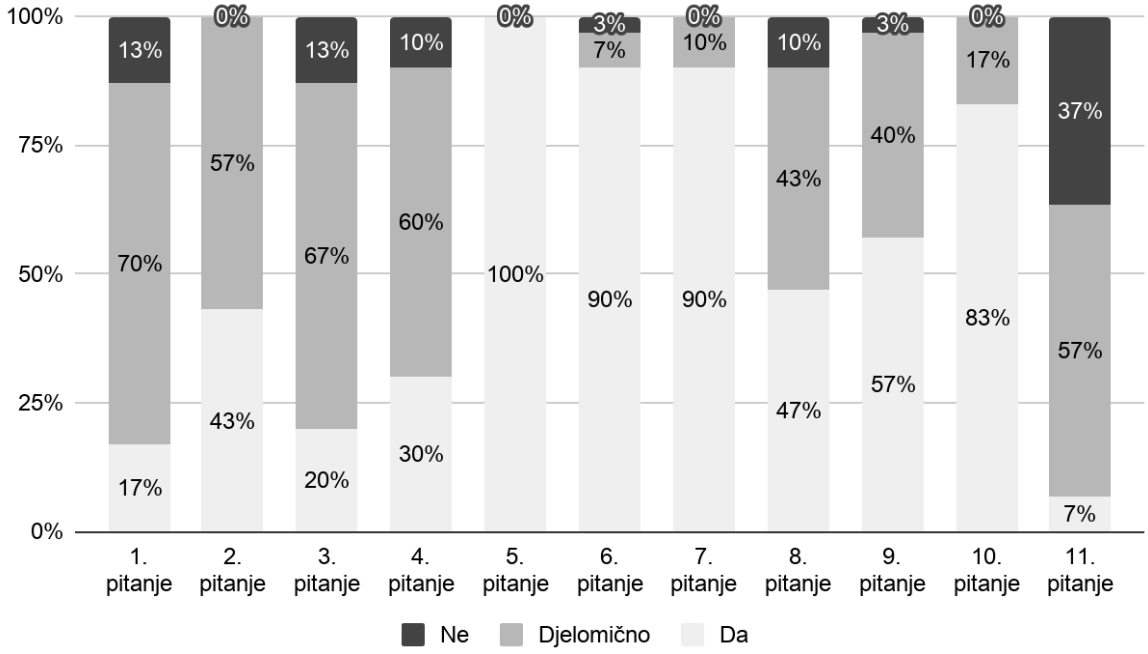
Zaintrigirani rezultatima kvantitativnog istraživanja autorice Žužić [25] odlučili smo otkriti koji se razlozi kriju iza odgovora ispitanika na tvrdnje iz ankete koju je provela spomenuta autorica. Kvalitativnim istraživanjem i dobivenim informacijama željeli smo dodatno doprinijeti njezinom istraživanju i zaključcima. Nastavnici i roditelji koji su pristali na intervju za potrebe ovog rada su zamoljeni da prokomentiraju sljedeće:

1. Sudjeluju li roditelji u donošenju odluka važnih za život i rad škole? ([25]; tvrdnja br. 7)
2. Informiraju li nastavnici dobro roditelje o ponašanju i napredovanju učenika? ([25]; tvrdnja br. 8)
3. Daju li nastavnici pravovremene informacije i jasne upute o tome kako roditelji mogu pomoći djetetu u vezi poteškoća u učenju i ponašanju? ([25]; tvrdnja br. 9)
4. Smatrate li da nastavnici uvažavaju mišljenje roditelja o pitanjima vezanim za školu? ([25]; tvrdnja br. 11)
5. Smatrate li da je suradnja roditelja i nastavnika izuzetno važna za uspjeh djece u školi? ([25]; tvrdnja br. 12)
6. Smatrate li da je dolazak roditelja na roditeljske sastanke i individualna informiranja izuzetno važan za napredovanje djeteta? ([25]; tvrdnja br. 13)
7. Održavaju li se roditeljski sastanci redovito i jesu li dobro organizirani? (Žužić, 2009; tvrdnja br. 14)
8. Postoji li u školi dobra suradnja između nastavnika i roditelja? ([25]; tvrdnja br. 16)
9. Smatrate li da roditelji s nastavnicima mogu otvoreno razgovarati o problemima vezanim za dijete i jesu li nastavnici spremni saslušati i uvažiti mišljenje roditelja? ([25]; tvrdnja br. 17 i br. 18)
10. Smatrate li da su roditeljima dostupne informacije o svim aktivnostima škole? ([25]; tvrdnja br. 19)
11. Jesu li roditelji uključeni u aktivnosti škole? ([25]; tvrdnja br. 20)

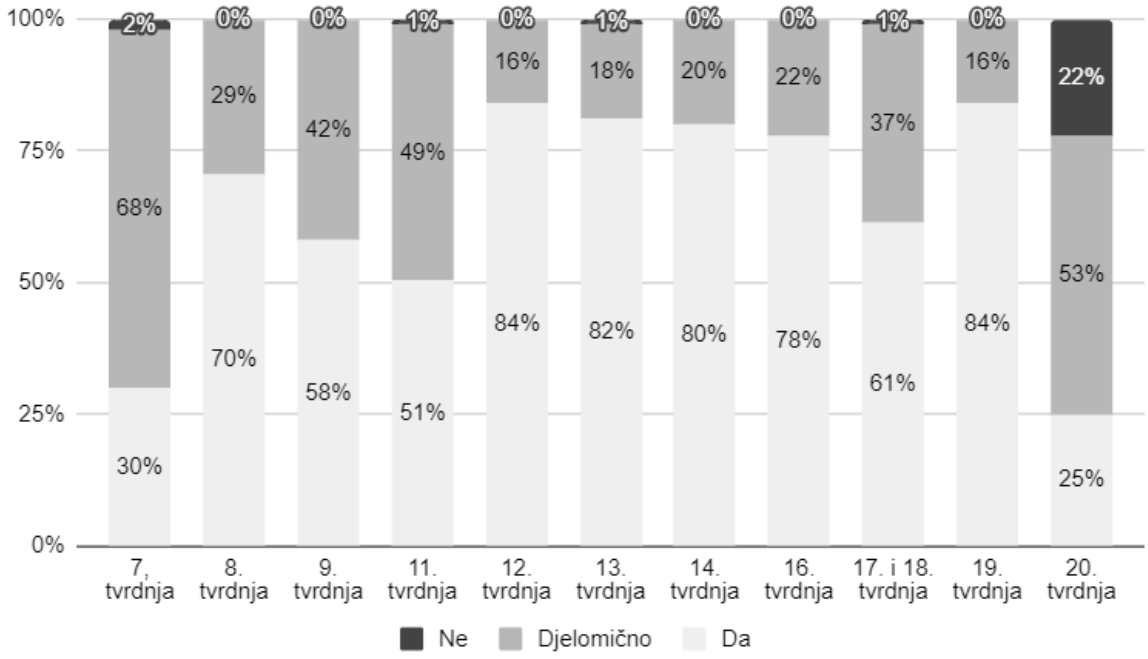
U istraživanju provedenom od strane Žužić [25] sudjelovali su samo roditelji, što odgovara stanju u području znanstvenih istraživanja vezanim za ovu i slične teme.

U mnogim slučajevima istraživanje i rezultati vezani za nastavnike i njihovo viđenje spomenute problematike nisu uključeni, iako istraživanja vezana za uvid u navedenu problematiku iz perspektive nastavnika postoje [4]. Zbog navedenog, u nastavku je dana usporedba rezultata Žužić [25] s rezultatima vezanima za roditelje koji su sudjelovali u istraživanju provedenom za potrebe ovog rada.

Rezultati su prikazani grafički kako bi se lakše usporedili. Svaki stupac prikazuje postotak određenog odgovora po pojedinom pitanju odnosno tvrdnji.



Slika br. 1: Rezultati dobiveni intervjuiranjem roditelja



Slika br. 2: Rezultati tvrdnji vezanih za roditelje dobiveni analizom podataka autorice Žužić [25]

Promatranjem frekvencija (slika br. 1 i slika br. 2) uočavamo da se rezultati djelomično podudaraju. Negativnih odgovora na pitanja/tvrdnje ima u najmanjem postotku po svakom pitanju, a najviše postotke uglavnom imaju potvrdni odgovori odnosno slaganja s tvrdnjama. U nastavku slijedi interpretacija rezultata.

Ispitanici iz oba istraživanja nisu mogli sa sigurnošću odgovoriti sudjeluju li roditelji u donošenju odluka važnih za život i rad škole. Kroz razgovor s našim ispitanicima saznali smo da roditelji koji nisu u vijeću roditelja nemaju izravan utjecaj na donošenje odluka, već svoja mišljenja najčešće iznose nastavnicima. Nastavnici u obzir uzimaju sva konstruktivna mišljenja koja doprinose razvoju škole i njezinom napretku, a time i boljitku učenika. Nastavnici imaju ograničenu slobodu u donošenju odluka vezanih za razna školska pitanja. Samim time roditelji nerijetko imaju osjećaj da ih se isključuje iz života i rada škole jer ne vide rezultate nakon iskazanog mišljenja.

S druge strane, komunikacija roditelja i nastavnika je uspješnija kada su učenici u fokusu razgovora. Roditelji

pozitivno ocjenjuju nastavničko informiranje roditelja o napretku i ponašanju djeteta. Roditelji koji su sudjelovali u istraživanju provedenom u sklopu ovog rada istaknuli su postojanje e-Dnevnika kao značajne karike u informiranju roditelja od strane nastavnika. e-Dnevnik pomaže nastavnicima da pravovremeno obavijeste roditelje o promjenama koje su zamijetili kod učenika. Međutim, e-Dnevnik pruža uvid u šture informacije o djetetu. Za detaljne informacije, dodatne savjete i upute od strane nastavnika ili stručnog osoblja škole roditelji trebaju biti uključeni u ostale oblike suradnje kao što su individualna informiranja ili roditeljski sastanci. Ispitanici su jednoglasni u mišljenju da je suradnja izrazito važna za uspjeh djece u školi. Djeca često nisu sposobna sama riješiti probleme s kojima se suočavaju u pubertetskim godinama. Roditelji i nastavnici trebaju zajedno pružiti pomoć i adekvatnu potporu učenicima kako bi lakše nadišli poteškoće s kojima se susreću.

Kako bi odnosi nastavnika i roditelja bili kvalitetniji, a suradnja uspješnija, važno je da se roditelji osjećaju uključeno i dobrodošlo. Škola se sve više otvara prema roditeljima i nudi im različite aktivnosti kao dodatne mogućnosti za sudjelovanje u radu i životu škole. Informacije o aktivnostima koje se odvijaju u školi do roditelja mogu doći preko roditeljskih sastanaka, individualnih informiranja, internetskih stranica škole, ljetopisa, školskih novina i ostalih medija. Bez obzira na navedeno, roditelji u većini slučajeva nisu upoznati s načinima na koje bi se mogli uključiti u pojedine aktivnosti. Većinom sudjeluju u aktivnostima neposredno, u humanitarnim donacijama, dolascima na dane otvorenih vrata, prisustvovanjem predavanjima u sklopu određenih projekata ili posredno ispunjavanjem anketnih upitnika i slično. Roditelji zaključuju da ne postoji dovoljan interes, da su premalo uključeni u aktivnosti i da po pitanju suradnje s nastavnicima ne rade koliko bi mogli i trebali.

Prilikom intervjuiranja roditelja moglo se primijetiti da roditelji dužim razmišljanjem o pojedinim pitanjima mijenjaju svoja mišljenja. Kroz intervju su ispitanici bili u mogućnosti analizirati svako pitanje, zatražiti dodatno pojašnjenje i razgovarati s ispitivačem. Izricanjem vlastitih misli i odgovaranjem na potpitanja roditelji su donosili nove zaključke. Zbog izravne komunikacije ispitivača i ispitanika ispitanici su više pažnje pridavali pitanjima, što je rezultiralo konkretnim i iskoristivim odgovorima. Navedeno je pokazalo kako u mnogim slučajevima dodatna edukacija roditelja može rezultirati novim pogledima na ovu problematiku, a samim time i boljim stavom te uključivanjem roditelja u obrazovanje i probleme vlastite djece.

Iako roditelji i nastavnici surađuju primarno putem roditeljskih i individualnih sastanaka, utvrđeno je da isto tako koriste i moderne informacijsko-komunikacijske tehnologije poput e-Dnevnika, Facebooka, Skypea, elektroničke pošte itd. Korištene tehnologije ovog tipa omogućuju kako roditeljima tako i nastavnicima lakše i jednostavnije komuniciranje, pogotovo u slučajevima kada izravna komunikacija nije moguća. e-Dnevnik je naročito koristan oblik informacijsko-komunikacijske tehnologije jer omogućava roditeljima uvid u napredak učenika, kao i razmjenu informacija o učeniku između nastavnika i roditelja. Većina roditelja i nastavnika smatra da korištenje informacijsko-komunikacijske tehnologije u još intenzivnijem obliku može doprinijeti još boljoj međusobnoj suradnji.

V. ZAKLJUČAK

Posljednjih godina zamjetno raste uključenost roditelja u proces obrazovanja djeteta. Suradnja roditelja i nastavnika je potrebna kako bi zajednički mogli „kontrolirati i usmjeravati rast i razvoj djeteta odnosno učenika" [9]. Naravno, njihova suradnja nije garancija za sretno i uspješno dijete, ali se pretpostavlja da se postignutom suradnjom uspješno obavljaju odgojni zadaci [6].

Da bi suradnja bila postignuta, nastavnik i roditelj moraju raditi na međusobnom odnosu bez uspostavljanja hijerarhijske strukture. Roditelj treba nastavnika gledati kao stručnu osobu koja prijateljski pristupa djeci i samom roditelju, a nastavnik bi roditelja trebao prepoznati kao nositelja ideja koje bi mu mogle pomoći u odgojno obrazovnom procesu i radu s učenikom [21].

Djetetu su uzor i njegovi roditelji i nastavnik jer s njima provodi najviše vremena. Iz navedenog se može zaključiti da je odnos roditelja i nastavnika važan jer će dijete promatrati i njihov međusoban odnos. U poticajnom i ugodnom ozračju koje može biti rezultat kvalitetnog odnosa nastavnika i roditelja, učenici mogu lakše ostvariti svoj maksimum. Kada se osjećaju ugodno i podržano „budi im se inspiracija, potiču se aktivnost i komunikacija, pobuđuju im se sjećanja, razigrava asocijacija, osjećaju sigurnost u svoje mogućnosti, motivirani su za dodatni napor u svladavanju poteškoća" [19].

O važnosti suradnje roditelja i nastavnika govore brojna istraživanja, a neka od njih su analizirana za potrebe ovog rada. Ispitanici odabranih istraživanja se slažu da su za djetetov uspjeh u školi, za njegovu sreću, motiviranje za rad i razvoj odgovorni i nastavnik i roditelj.

Zaintrigirani rezultatima autorice Žužić [25] proveli smo kvalitativno istraživanje. Njezine tvrdnje bile su temelj za izradu upitnika za naš intervju. Kroz intervju smo željeli saznati mišljenja roditelja i nastavnika o međusobnoj suradnji. Nakon provedenog intervjua provedena je usporedba rezultata s istraživanjem koje je provela Žužić [25]. Uočeno je da se rezultati većinom podudaraju.

Roditelji i nastavnici zaključili su da je njihova suradnja iznimno važna za uspjeh učenika te da kroz međusobnu suradnju nastavnik i roditelj zajednički mogu pomoći učeniku. Većina ispitanika smatra da postoji međusobno razumijevanje, dok se mali broj ispitanika s time ne slaže.

Roditelji su donekle zadovoljni s informacijama i savjetima koje dobivaju od nastavnika. Roditelji u mnogim slučajevima nisu imali prilike sudjelovati u radionicama, ali ih spominju kao željene oblike suradnje s obzirom na to da bi tijekom radionica mogli pobliže raspraviti o dobivenim informacijama i savjetima.

Nismo dobili informacije o poželjnim i korisnim temama radionica, ali svakako bi ih bilo potrebno dodatno istražiti.

Osim radionica, neki roditelji smatraju da im se ne daje mogućnost za sudjelovanjem u aktivnostima škole te da nisu upoznati s načinima na koje bi se mogli uključiti u iste. S druge strane, nekolicina njih ne pokazuje interes za uključenjem u aktivnosti škole. Svoj odgovor argumentiraju nedostatkom vremena, a neki kao razlog navode prethodne neuspješne suradnje i nekompetentnost osoba koje rade u školama.

Roditelji smatraju da bi trebali sudjelovati u odlukama škole kako bi suradnja bila ostvarena u svim aspektima, ali nisu imali ideje o tome koje bi to odluke bile i što bi željeli izmijeniti u odgojno-obrazovnoj ustanovi ili odgojno-obrazovnom procesu.

Nakon provedenog intervjua i analize rezultata zaključili smo da odnos roditelja i nastavnika ide u dobrom smjeru, pri čemu uvijek postoji prostor za dodatno poboljšanje. Rezultati ukazuju da su roditelji i nastavnici sve više spremni na suradnju i kompromis u korist uspješnog i sretnog djeteta.

Dodatni oblici informacijsko-komunikacijske tehnologije, koji bi se mogli koristiti ne samo u procesu obrazovanja djeteta već i kao sredstvo informiranja roditelja i sredstvo komunikacije nastavnika i roditelja, mogli bi dodatno poboljšati kvalitetu odluka i dodatno povećati ne samo razinu informiranosti roditelja o raznim aspektima obrazovanja njihovog djeteta već i razinu i uključenost roditelja u obrazovni proces. Istraživanje mogućnosti korištenja i učinaka dodatnih oblika informacijsko-komunikacijske tehnologije u obrazovnom procesu i suradnji roditelja i nastavnika, kao i detaljnije istraživanje potencijalnog doprinosa roditelja u raznim aspektima obrazovanja djeteta, bit će sastavni dio budućih istraživačkih aktivnosti.

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DRVOKOD

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Sažetak **- „Drvokod“ je projekt - stručni rad - koji je nastao kao rezultat interakcije predmeta biologije i informatike. Ciljevi projekta su učiniti nastavu zanimljivijom (kao korisnici projekta), te istraživački pristupiti izradi projekta korištenjem naprednih tehnologija.**

Cilj popularizacije bioloških sadržaja ostvariti ćemo istraživanjem vrsta drveća i grmlja u školskom dvorištu. Sve vrste ćemo označiti QR-kodovima.

Želja nam je da učenici upotrijebe i primjene stečena znanja ne samo na nastavi nego i u društvenom kontekstu. Korisno je da ne samo učenici nego i ostali sugrađani obrate pažnju na ono što se nalazi u njihovom okolišu, jer „učenjem i opažanjem, okoliš ćemo i bolje čuvati“.

Sustav upotrebe pločica sa QR-kodovima radi na principu skeniranja QR-koda mobitelom te automatskim učitavanjem sadržaja određene web stranice, na kojoj se nalaze podatci o biljkama.

Ovaj projekt je osmišljen za prezentiranje i drugim školama koje će pokazati interes za suradnju. Krajnji rezultat je proširiti bazu podataka na druge škole i izraditi jednu interaktivnu enciklopediju biljnih vrsta u školskim dvorištima diljem naše zemlje.

Autori projekta su prof. biologije i kemije Bernarda Musović i učitelj mentor matematike-fizike i informatike Branko Raičković. U projekt su uključeni osim voditelja učenici IV. osnovne škole Bjelovar .

Ključne riječi – QR cod; biljne vrste; biologija; interaktivna nastava

I. UVOD

Drvokod je baza podataka o biljnim vrstama u okolišu škole koje su obilježene QR kodom. Skeniranjem QR-a saznajemo konkretne podatke o toj biljci (naziv, vrsta, plodovi...), fotografije te geo-lokaciju. Podatci o biljkama se nalaze na javnoj web stranici koju uređuju učenici izvannastavne aktivnosti eko-informatika. Sva zapažanja su originalna i u pravilu su učenički radovi isto kao i fotografije koje su postavljene na stranicama. Podatci o biljnim vrstama se nalaze na posebnom serveru, te javno dostupni tako da će se moći se koristiti i u drugim školama. U sklopu portala „drvokod.hr“, svim školama koje pokažu interes za aktivno uključenje u ovaj program, biti će omogućeno stvaranje posebne web stranice. Interes za provođenje projekta je jako velik, tako da se projekt trenutno provodi u petnaestak osnovnih škola na području Bjelovarsko-bilogorske županije. Sve škole su objedinjene na zajedničkim portalu gdje se prati provedba projekta te njegovo implementiranje kako u nastavi prirode, biologije tako i u nastavi informatike.



Slika 1. Determinacija biljnih vrsta

II. DRVOKOD

A. Istraživačko – edukacijski dio

Cijeli projekt je realiziran kroz projektnu nastavu što znači da smo imali nekoliko zadataka. Odabrali smo područje istraživanja, postavili cilj, odnosno istraživačko pitanje, odredili vrijeme trajanja, metode i oblike rada, proučavanje problema te provedbu plana s ciljem dobivanja određenih rezultata.

Koristila se metoda demonstracije (izvorna stvarnost-promatranje i fotografiranje drveća, grmlja, sakupljanje listova, plodova, cvjetova tijekom godišnjih doba), metoda rada na tekstu (pronalaženje informacija o vrstama u literaturi i na internetskim stranicama), metoda praktičnih radova (determiniranje vrsta putem ključeva i putem web aplikacije Pl@ntNet [2]) i metoda usmenog izlaganja (slika 1). Ovakav timski način rada pospješuje razvoj istraživačkih, organizacijskih i komunikacijskih sposobnosti učenika, potiče na razvijanja osobne odgovornosti za realizaciju projekta, kritičkog načina razmišljanja te učenja i usvajanja metodologije znanstveno-istraživačkog rada.

Učenici su radili u dva tima. Jedan tim su činili učenici koji su se bavili istraživačkim dijelom projekta, a drugi tim se sastojao od učenika koji su se bavili tehničkim i informatičkim dijelom projekta.



Slika 2. Prikaz odabrane web stranice

B. Praktični dio

Da bi se ovaj projekt mogao realizirati potrebni su i neki tehnički preduvjeti.

Na prvom mjestu je web server. Kako svaka škola u našem obrazovnom sustavu ima svoje web stranice cijeli bi se projekt mogao izvoditi i na tim stranicama. No to je vrlo nepraktično jer promjenom putanje web stranice mijenja se i pripadajući link koji je direktno vezan sa sadržajem QR koda. Iz tog razloga preporučljivo je koristiti posebni hosting kao i u našem slučaju. Domenu (ime osnovne web stranice) je također bilo potrebno pribaviti.

Na serveru za udomljavanje web stranica je nadalje potrebno instalirati WordPress alat za CMS uređivanje web stranica. Ovaj alat nam omogućuje osim uređivanje i podjelu korisnika na vrste (administrator, urednik, moderator…). Zbog ovog razloga možemo slobodno dati učenicima na koriste WordPress, bez bojazni da će nešto pogriješiti. Naravno da ovaj dio projekta nadzire osoba zadužena za informatički dio.

Na WordPress-u je potrebno izabrati „temu“ stranice, po posebnom pravilu otvoriti izbornike te imenovati administratore istih. Nakon toga administratori (učitelji i učenici) mogu početi s praktičnim uređivanjem (slika 2.).

Što se tiče uređivanja teksta, najlakše je koristiti tekst koji je pisan u programu „Blok za pisanje“ jer je to tekst koji je većinom preuziman sa e-pošte učenika. Nakon kopiranja u WP editor, tekst je potrebno oblikovati.

Nadalje, pri web dizajnu je potrebno i obraditi već spomenute slike. Tu se misli na isticanje detalja i promjenu rezolucije. Fotografije mogu biti prethodno uređene i od učenika koji ih je snimao.

Sljedeći korak je kopiranje web adrese, koju ćemo pretvoriti u QR kod. Kako bi dobili traženi kod, zadanu adresu trebamo kopirati direktno iz web preglednika i zalijepiti u



Slika 3. Postavljanje oznaka sa QR kodovima

„On-line Free QR-code generator“. Nakon toga preuzmemo sliku koda s interneta i pospremimo u naše računalo.

Sliku zatim ispišemo laserskim pisačem na samoljepljivu naljepnicu. Nakon toga sliku plastificiramo i nalijepimo na pripremljenu plastičnu pločicu. Spajanjem pločice sa metalnim stupićem imamo pripremljeni izradak spreman za postavljanje (slika 3.).

C. Edukacija i implementacija u nastavi

Projektom će se implementirati dobiveni rezultati u nastavi prirode i biologije. Krajnji cilj projekta je odrediti vrste drveća i grmlja i postaviti pločice sa QR-kodovima. Na taj način su stvoreni preduvjeti za organizaciju nastavnog sata u školskom dvorištu.

Učenici će korištenjem tableta ili mobitela skenirati kod, učitati sadržaje naše stranice na kojima će im se otvoriti stranica tražene biljne vrste (slika 4.). Ovakvim načinom rada učenicima će se učenje temeljiti na izvornoj stvarnosti; na primjeru će moći objasniti primjerice oblike listova, vrste cvatova, plodova (5. razred), moći će razlikovati vrste (6. razred), svrstati vrste drveća u određene skupine (7. razred) i upoznati se sa njihovim karakteristikama. Sve ono što se dosada nalazilo u udžbenicima i na internetskim stranicama učenici će moći pronaći na jednome mjestu, poput interaktivne enciklopedije.



Slika 4. Učenici na terenskoj nastavi

III. ZAKLJUČAK

Kao što vidimo iz gore navedenoj projekt DRVOKOD je prilično zanimljiv i sveobuhvatan, baziran na velikoj suradnji kako učenika u timu, tako i njihovih učitelja. Za realizaciju su potrebna minimalna materijalna sredstva u odnosu na kvalitetu i kvantitetu projekta. Sam projekt ima s jedne strane već navedene ciljeve u samoj izradi, a s druge strane u korištenju istog. Krajnji rezultat nije samo usvajanje teoretskog znanja već kako to znanje upotrijebiti u društvenom kontekstu.

Isto tako projekt DRVOKOD je jedan je od rijetkih projekata koji nadilaze okvire škole. Svaki građanin će imati priliku isprobati aplikaciju na svom mobitelu što nam je važno jer krajnji cilj i je da ne samo učenici nego i svi sugrađani obrate pažnju na ono što se nalazi u njihovom okolišu jer učenjem i opažanjem, okoliš ćemo i bolje čuvati.

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Programski paket GNU Octave u nastavi

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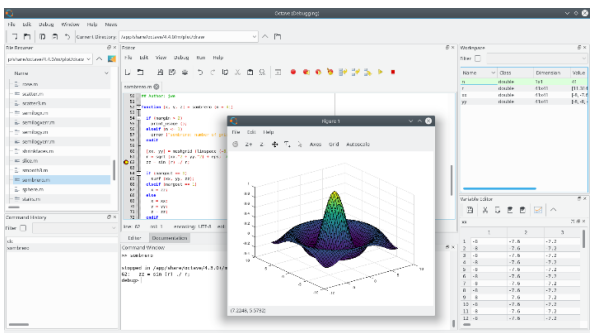
***Sažetak* - Programski paket GNU Octave je besplatni znanstveni programski jezik vrlo sličan Matlab-u. Sadrži matematički orijentiranu sintaksu i ima ugrađene vizualizacijske alate, a dostupan je za Linux, Windows, BSD i macOS sustave. U ovom radu demonstrirat ćemo neke primjene GNU Octave-a koji su primjenjivi u izvođenju nastave: rješavanje sustava linearnih jednadžbi, matrične dekompozicije, numeričko rješavanje diferencijalnih jednadžbi, a navesti ćemo i druga područja primjene. Za odabrane primjene bit će opisan problem te dano rješenje s koracima u GNU Octave-u.**

Ključne riječi* – GNU Octave*; programski jezik, sustavi linearnih jednadžbi; dekompozicija matrice; numeričko rješavanje diferencijalnih jednadžbi, Laplaceova i Fourierova transformacija, FFT.

I. UVOD

Programski paket GNU Octave je besplatni znanstveni programski jezik vrlo sličan Matlab-u. Sadrži matematički orijentiranu sintaksu i ima ugrađene vizualizacijske alate, a dostupan je za Linux, Windows, BSD i macOS sustave na internet stranicama [1] pod sekcijom **Download**. Također, možete raditi i u pregledniku na stranici https://octave-online.net/. Namijenjen je numeričkom računanju, a pogodan je za rješavanje linearnih i nelinearnih problema. Originalno je koncipiran 1988. godine, a ozbiljni razvoj doživljava u 1992. godini. Od tada se neprestano nadograđuje i danas ga koriste tisuće u nastavi, istraživanju i izradi komercijalnih aplikacija. Osim ugrađenih funkcija, svaki korisnik može kreirati svoje skripte za rješavanje problema, a postoje i brojni dodatni paketi koji se mogu instalirati i koristiti kao što su paketi za obradu slika, dodatni statistički alati, obrada signala, itd. Postoji i 64-bitna verzija GNU Octave-a koja omogućava rad sa velikom količinom podataka, što je važno za znanstveni pristup mnogim problemima.

Sintaksa GNU Octave-a je vrlo slična Matlab-ovoj, ako se pažljivo napiše skripta, ona će raditi u oba programska paketa bez dodatnih promjena. GNU Octave je jezik visoke razine i bitno olakšava programiranje inženjerima i matematičarima. Ideja je bila da se korisnik fokusira na rješavanje problema struke, a manje na problem programiranja. Npr. za množenje matrica u programskom jeziku C/C++ potrebno je koristiti trostruku petlju, dok u GNU Octave-u matrice se pomnože kao i brojevi pomoću operacije * (A*B) nakon što se deklariraju. Svojstvene vrijednosti matrice A dobit ćemo pomoću funkcije *eig*(*A*) i ona će vratiti svojstvene vrijednosti i svojstvene vektore matrice *A*. Naravno, moguće je implementirati i svoje skripte za dani problem.



Slika 1. GNU Octave GUI.

GNU Octave sadrži *help* unutar programa kao i cijelu dokumentaciju. Pomoću *help ime funkcije* dobivaju se osnovne informacije o traženoj funkciji – ulazne i izlazne varijable, način pozivanja, primjere pozivanja i popis sličnih funkcija, a to je vrlo korisno u radu. Na internet stranici [2] dostupni su neki materijali za GNU Octave koji se koriste za izvođenje nastave – sintaksa važnih funkcija i deklaracija objekata, napisane skripte za GNU Octave te kratke video lekcije o osnovama vezanim za GNU Octave. Pretraživanjem interneta dostupne su brojne skripte koje rješavaju razne probleme, omogućavaju bolje razumijevanje problematike i ubrzavaju proces rješavanja problema koji je pred nama.

II. PRIMJENA GNU OCTAVE-A U NASTAVI

A. *Rješavanje sustava linearnih jednadžbi*

Sustavi linearnih jednadžbi se prirodno pojavljuju pri rješavanju raznih problemskih situacija. Stoga je potrebno razviti strategiju rješavanja sustava linearnih jednadžbi. Rješavanje linearnih sustava jednadžbi jedan je od osnovnih problema numeričke matematike. Detaljnije o problemu rješavanja linearnih jednadžbi može se pronaći u [3] i [4]. Sustav n jednadžbi s n nepoznanica zadan je na sljedeći način:

$$\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \cdots + a_{1j}x_j + \cdots + a_{1n}x_n &= b_1 \\
a_{21}x_1 + a_{22}x_2 + \cdots + a_{2j}x_j + \cdots + a_{2n}x_n &= b_2 \\
&\vdots \\
a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{ij}x_j + \cdots + a_{in}x_n &= b_i \\
&\vdots \\
a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nj}x_j + \cdots + a_{nn}x_n &= b_n
\end{aligned}$$

Postoje različiti načini rješavanja sustava linearnih jednadžbi, ali je malo njih univerzalnih, odnosno onih koji su primjenjivi u gotovo svim situacijama.

Sustav jednadžbi možemo zapisati u obliku matrične jednadžbe $A \cdot x = b$, gdje je *A* matrica sustava, *b* mat-

rica slobodnih koeficijenata i x matrica nepoznanica, odnosno rješenje sustava koje želimo odrediti.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{in} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_j \\ \vdots \\ x_n \end{bmatrix}, \quad b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_j \\ \vdots \\ b_n \end{bmatrix}.$$

Primjer 1. Riješite sustav linearnih jednadžbi u Octave-u:

$$\begin{cases} 2x_1 + x_2 + x_3 - 2x_4 = -1 \\ \quad x_2 - 2x_3 + 3x_4 = 8 \\ 2x_1 + x_2 - 3x_3 \quad = -5 \\ \quad x_1 + 3x_2 \quad - 2x_4 = -1 \end{cases}.$$

Rješenje: Potrebno je prvo definirati matricu sustava A, vektor desne strane b, a zatim se sustav može riješiti operatorom \.

```
A = [2 1 1 -2; 0 1 -2 3; 2 1 -3 0;  1 3 0 -2]
B = [-1 8 -5 -1]'
x = A\b
```

Izvršavanjem navedenog koda, dobiva se rješenje sustava $x = [1\ 2\ 3\ 4]$. Uvrštavanjem rješenja u jednadžbe možemo se uvjeriti da je rješenje točno.

Dani sustav možemo riješiti pomoću LU faktorizacije. LU faktorizacija matrice A je dana s $A = LU$,

pri čemu je L donjetrokutasta matrica s jedinicama na dijagonali, a U gornjetrokutasta matrica

$$L = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ L_{21} & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ L_{n1} & L_{n2} & \cdots & 1 \end{bmatrix}, \quad U = \begin{bmatrix} U_{11} & U_{12} & \cdots & U_{1n} \\ 0 & U_{22} & \cdots & U_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & U_{nn} \end{bmatrix}.$$

Sada se linearni sustav može zapisati i ovako:

$$Ax = LUx = b.$$

Linearni sustav rješava se kao dva jednostavna linearna sustava. Uz oznaku $Ux = b$, sustavi su

$$Ly = b, \qquad Ux = y.$$

prvi je donjetrokutasti, a drugi gornjetrokutasti. U GNU Octave-u postoji funkcija *lu*() koja za danu matricu vraća matrice iz LU faktorizacije. Zbog bolje numeričke stabilnosti, GNU Octave koristi pivotiranje, tj. $Ax = PLUx = b$, gdje je P matrica permutacija. Matrica sustava *A* i vektor desne strane *b* su kao i prije. Trokutaste sustave *PLy=b i Ux=y* možemo riješiti sa operatorom \ ili možemo kreirati skriptu koja će provoditi supstitucije unaprijed ili unazad po potrebi.

```
>> [L, U, P] = lu(A)
L =

   1.00000   0.00000   0.00000   0.00000
   0.50000   1.00000   0.00000   0.00000
   1.00000   0.00000   1.00000   0.00000
   0.00000   0.40000   0.45000   1.00000

U =

   2.00000   1.00000   1.00000  -2.00000
   0.00000   2.50000  -0.50000  -1.00000
   0.00000   0.00000  -4.00000   2.00000
   0.00000   0.00000   0.00000   2.50000

P =

Permutation Matrix

   1   0   0   0
   0   0   0   1
   0   0   1   0
   0   1   0   0

>>
```

Slika 2. Octave funkcija lu() vraća matrice *L, U* i *P*.

Primjer 2. Riješite sustav linearnih jednadžbi u Octave-u:

$$\begin{cases} 2x_1 - 4x_2 + 2x_3 = 2 \\ 2x_1 + x_2 - x_3 = 4 \\ x_1 + 3x_2 - 2x_3 = 3 \end{cases}.$$

Rješenje: Potrebno je prvo definirati matricu sustava A, vektor desne strane b, a zatim se sustav može riješiti operatorom \.

```
A = [2 -4 2; 2 1 -1; 1 3 -2]
b=[2 4 3]'
x=A\b
```

Izvršavanjem danog koda dobivamo upozorenje (*warning: matrix singular to machine precision*) da je matrica sustava singularna. To znači da je rješenje sustava parametarsko, tj. ima ih beskonačno mnogo ili sustav nema rješenja. Octave nam daje jedno moguće rješenje x = [1.71429 0.14286 -0.42857]. Parametarsko rješenje sustava je $\left(\frac{t+9}{5}, \frac{3t+2}{5}, t\right), t \in \mathbb{R}$ pa se uvrštavanjem $t = -0.42857$ dobiva jedno točno rješenje.

Octave će operatorom \ ponuditi rješenje, tj. aproksimaciju i za sustav koji nema rješenja Zato je potrebno biti oprezan u slučaju da matrica sustava nije regularna. Ako matrica sustava nije velika može se prvo provjeriti je li determinanta matrice sustava različita od nula naredbom *det*(*A*).

Za teorijsku matematiku rješavanje sustava $Ax = b$ gotovo je trivijalan problem, posebno u slučaju kada je matrica sustava kvadratna i regularna. Ono po čemu su računala poznata je brzina, no osnovna značajka moderne numeričke matematike je da joj u primjenama dolaze problemi sve većih dimenzija. Na primjer, broj operacija Gaussovih eliminacija je $\mathcal{O}(n^3)$, a to znači da je npr. za $n = 10^5$ broj operacija reda veličine 10^{15} pa brzinom od 10^9 operacija u sekundi dobivamo vrijeme izvršavanja oko 10^6 sekundi, što je više od deset dana. Problemi koji dolaze iz primjena, pogotovo fizike i kemije, nerijetko imaju sustave dimenzije reda milijun (10^6). Takvi sustavi rješavaju se posebnim sofisticiranim metodama (npr. iterativne metode u Krilovljevim potprostorima). Puno više detalja može se naći u [3].

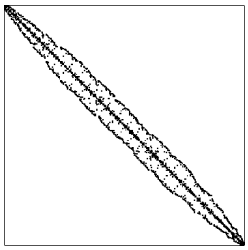
Primjer 3. Mnoštvo korisnih matrica iz teorije i prakse nalaze se na internet stranici Matrix Market [5]. Pretraživati i birati matrice moguće je na razne načine. Cilj će ovoga puta biti pronaći neku „veću“ pozitivno definitnu matricu (reda iznad 1000) i provesti faktorizaciju Choleskog na njoj te riješiti sustav. Simetričnost i pozitivna definitnost nisu sam matematička svojstva, već imaju i dublji fizikalni smisao. Takve se matrice prirodno javljaju u numeričkom rješavanju raznih problema kao što je diskretizacija diferencijalnih jednadžbi, aproksimacijama i sl. Na navedenoj stranici odabrano je pretraživanje po svojstvima matrice (*Search by matrix properties*).



Slika 3. Internet stranica Matrix Market.

Odabrano je za *Linear Algebra problem* Linear System, a za *Numerical Symmetry Properties* Symmetric positive definite. Ostala polja mogu ostati *Any* ili prazna, jer je cilj rješavanje linearnog sustava pri čemu je matrica sustava simetrična pozitivno definitna. Nakon klika mišem na Submit Query prikazane su matrice iz njihove baze koje zadovoljavaju tražena svojstva. Na odabir se dobiva više od 20 različitih matrica iz različitih područja inženjeringa i teorije. Za svaku matricu imamo njen opis što predstavlja, a klikom miša na neku od ponuđenih matrica dobiva se mnoštvo korisnih i važnih informacija o toj matrici (izgled strukture matrice, broj redaka i stupaca, broj ne-nul elemenata u matrici, uvjetovanost, norme, …). Odabrano je za demonstraciju matricu BCSSTK14: *Roof of the Omni Coliseum, Atlanta*, koja predstavlja sustav jednadžbi koje opisuju krov navedene građevine u Atlanti. Odabrana matrica je rijetko popunjena (tzv. *sparse matrix*), jer je većina elemenata jednaka nuli (bijela boja). Da je to uistinu tako dokazuje činjenica da je red matrice 1806, tj. ima $1806^2 = 3\,261\,636$ elemenata, a od toga samo je 63454 elemenata različito od nule (podatak pod naslovom *Nonzeros*). Dakle, u matrici je samo 1,95% elemenata različito od nule. Rijetko popunjene matrice česte su u praksi i za njih postoje dodatno optimizirani algoritmi za rješavanje.

Pri dnu imamo podatke o normi. Važno je pogledati kondicijski broj koji govori koliko će sustav biti osjetljiv na male promjene u vektoru *b*. Za odabranu matricu, kondicijski broj iznosi otprilike $1.3 \cdot 10^{10}$. To je velik broj, jer bi kondicijski broj trebao biti što bliže broju 1 za stabilnost. S druge strane, faktorizacija Choleskog je stabilna metoda i moguće je da nam ova velika uvjetovanost neće onemogućiti dobivanje faktorizacije Choleskog. Pri vrhu je opcija *Download as* i odabrana je prva datoteka *bcsstk14.mtx.gz*. Potrebno je spremiti navedenu datoteku u našu radnu mapu za Octave. Matrica je spremljena u *Matrix Market* formatu i većina programskih paketa ne zna pročitati taj zapis direktno. Za čitanje ovog zapisa matrice potrebna je skripta mmread.m koja radi sa Matlabom i GNU Octave-om. Ta skripta se nalazi na stranici http://math.nist.gov/MatrixMarket/mmio/matlab/mmiomatlab.html ili pretraživanjem u tražilici Google tako da se upiše: Matrix market mmread.m. Potrebno je odabrati stranicu koja spominje Matlab i na toj stranici odabrati mmread.m. Ako je skripta otvorena u pregledniku, treba kod kopirati u Octave skriptu i spremiti ga u mapu gdje je matrica za testiranje. Vrlo je važno da ime spremljene skripte bude baš mmread.m, jer u protivnom Octave neće moći pozvati ovu funkciju i vratit će pogrešku.



Slika 4. Struktura matrice BCSSTK14.

Priprema za testiranje u GNU Octave-u je izvršena. U hodu će se objašnjavati što se radi i zašto. Za početak, Octave radna mapa treba biti mapa u kojoj su matrica krova koliseuma u Atlanti i skripta mmread.m. Funkcije koje će se koristiti postoje u GNU Octave-u osim ako drugačije nije naglašeno.

Matricu se učitava naredbom:

A = mmread('bcsstk14.mtx');.

Učitana matrica bit će spremljena pod imenom *A*, a kao argument funkcije *mmread* šaljemo ime datoteke napisano unutar jednostrukih apostrofa ' '. Na kraju naredbe potrebno je staviti ; jer će se u protivnom ispisati cijela matrica *A*, a to je više od 3 milijuna brojeva. Strukturu učitane matrice moguće je provjeriti naredbom **spy(A).** Funkcija *spy()* prikazuje ne-nul elemente matrice koja je argument. Sve što je bijelo u matrici su nule. Nakon provjere strukture matrice, korisno je znati dimenzije matrice. Poznato je da je ova matrica kvadratna reda 1806, ali često to nije slučaj. Također, ponekad je potrebno spremiti dimenzije matrice kao varijable kako bismo ih mijenjali ili slali kao argument funkcije. Naredba: **[m, n] = size(A)**. Funkcija *size*() vraća broj redaka matrice *A* kao broj *m*, a broj stupaca kao broj *n*. Ovo je općenito korisna informacija i radi se o dva izlazna podatka pa ih se odmah može ispisati (ne stavljamo ; na kraj naredbe). Budući da se radi o dva izlazna podatka, potrebno ih je staviti u zagrade za vektor [].

Faktor *R* faktorizacije Choleskog moguće je izračunati pomoću funkcije *chol*(). Naredba: **R = chol(A);**

Ako program ne javi grešku, faktorizacija Choleskog uspješno je provedena i *R* je traženi faktor. Često se koristi ovakav način provjere je li neka matrica simetrična pozitivno definitna. Pomoću funkcije *spy*(R) možemo provjeriti strukturu matrice *R*. Kako bi se uvjerili da je faktorizacija uistinu uspjela, provjeri se vrijedi li $R^T R = A$. Jedan način je da se odredi relativnu pogreška po normi, tj. izračuna $\frac{\|A - R^T R\|}{\|A\|}$.

Naredba: **norma_2=norm(A – R' * R, 2) / norm(A, 2)**.

Funkcija *norm*() vraća vrijednost tražene norme, a prima prvi argument vektor ili matricu, a drugi argument vrsta norme: 1 za $\| \ \|_1$, 2 za $\| \ \|_2$, inf za max normu, tj. $\| \ \|_\infty$. Rješenje je reda veličine 10^{-16} što je red veličine

jedinične pogreške u formatu dvostruke preciznosti. To znači da je dobiveni faktor *R* izračunat sa velikom točnošću, usprkos velikom kondicijskom broju.

Za rješavanje sustava potreban nam je vektor desne strane *b*. Vektor *b* može se konstruirati od slučajnih realnih brojeva između 0 i 1. Naredba: **b = rand(m, 1);.** Funkcija *rand*() kreira matricu slučajnih brojeva između 0 i 1 kojoj su argumenti željeni broj redaka i broj stupaca. Potreban je vektor pa je broj stupaca jedan, a broj redaka mora biti isti kao i broj redaka matrice sustava. Sustav se sada može riješiti bilo operatorom \, pomoću faktorizacije Choleskog, LU faktorizacije, … Za rješavanje trokutastih sustava moguće je kreirati skriptu koja će vršiti supstitucije unaprijed/unazad ili riješiti te sustave pomoću operatora \.

B. Numeričko rješavanje diferencijalnih jednadžbi

Diferencijalne jednadžbe su efikasan aparat za rješavanje konkretnih problema prirodnih i tehničkih znanosti. Diferencijalna jednadžba je jednadžba koja povezuje nepoznatu funkciju, nezavisne varijable i derivacije nepoznatih funkcija. Ovisno o broju varijabli po kojima imamo derivacije funkcije, diferencijalne jednadžbe mogu biti obične (jedna varijabla) i parcijalne (više varijabli). Red diferencijalne jednadžbe je red najviše derivacije u jednadžbi. Prilikom rješavanja vrlo su važni početni i rubni uvjeti. Oni nam omogućavaju dobivanje jedinstvenog rješenja ako je to moguće. Vrlo često u primjenama, diferencijalnu jednadžbu rješavamo numerički. Jednadžba može biti presložena za rješavanje analitički, problem promatramo u sklopu numeričkog projekta, …

Prvo će se promatrati obične diferencijalne jednadžbe. Rješenje inicijalnog problema

$$\begin{cases} \dfrac{dy}{dx} = f(x,y) \\ y(x_0) = y_0 \end{cases}$$

se traži numerički.

Poznata je funkcija $f(x,y)$ dviju varijabli *x* i *y* te početna vrijednost $y(x_0) = y_0$. Problem je, dakle, za neki x_i izračunati $y(x_i) = y_i$. Nakon integracije početni problem se može zapisati u vidu integralne jednadžbe

$$y(x) = y_0 + \int_{x_0}^{x} f(t, y(t))dt.$$

Metode koje se koristi za rješavanje problema numerički dolaze od načina na koji će se aproksimirati integral. Tako se u Eulerovoj metodi integral aproksimira konstantom pa je metoda dana izrazom:

$$y_{n+1} = y_n + hf(x_n, y_n).$$

Integral je aproksimiran na vrlo jednostavan način, što nam olakšava računanje, ali bi pogreška mogla biti velika. Često se koriste Runge-Kutta metode u kojima koristimo dodatne čvorove i dodatne slobodne parametre koje možemo odrediti tako da dobijemo što veći red konzistentnosti, tj. želimo što manju lokalnu pogrešku diskretizacije. Više o numeričkom rješavanju diferencijalnih jednadžbi može se pronaći u [3] i [4].

U Octave-u se najčešće koriste funkcije *ode45*() i *lsode*() koje numerički rješavaju dani problem. Funkcija *ode45*() zasniva se na Runge-Kutta metodi reda 4 i može riješiti široki spektar problema običnih diferencijalnih jednadžbi. Funkcije *ode15i*(), *ode23*() i druge funkcije koje postoje u Matlabu, a rješavaju inicijalni problem običnih diferencijalnih jednadžbi postale su dio osnovnog paketa Octave-a u verzijama nakon 4.2.x.

Eulerovu metoda možemo zapisati kao pseudo kod:

```
[y] = Euler(f; y0; h; n)
za i = 1 do n-1
        y_{i+1} = y_i + h f(t_i, y_i)
end
```

Taj pseudokod možemo implementirati u GNU Octave-u kao skriptu odj_euler() na sljedeći način:

```
function [x,y] = odj_euler(f,a,b,y0,n)

h = (b-a)/n;          % duljina podintervala

x(1) = a;             % donji rub
y(1) = y0;            % početni uvjet
% koraci Eulerove metode:
for i = 1:n-1
   x(i+1) = a + h*i;
   y(i+1) = y(i) + h*f(x(i),y(i));
end
```

Ulazni parametri su funkcija *f* kao prvi, interval na kojemu aproksimiramo rješenje dan je pomoću donjeg ruba *a* i gornjeg ruba *b* kao drugi, početni uvjet *y0* kao treći te broj čvorova (broj intervala je *n*-1) kao četvrti argument. Izlazni parametri su vektor čvorova *x* i aproksimacija rješenja u tim čvorovima *y*. Pomoću *a*, *b* i *n* računa se duljina podintervala *h* i zatim se inicijalizira početni element vektora čvorova kao *a*, a *y0* je vrijednost tražene funkcije u početnom čvoru. Nakon toga se u petlji izvršavaju koraci Eulerove metode: izračunaj sljedeći čvor, a zatim izračunaj aproksimaciju nepoznate funkcije u tom čvoru.

Primjer 4. Riješite inicijalni problem u GNU Octave-u na intervalu [0, 1].

$$\begin{cases} \dfrac{dy}{dx} = x(1+y^2) \\ y(0) = 1 \end{cases}.$$

Rješenje: Dani inicijalni problem bit će riješen u GNU Octave-u pomoću funkcije *ode45*(), zatim pomoću implementirane Eulerove metode te će se dobiveni rezultati grafički usporediti s eksplicitnim rješenjem problema koje glasi

$$y(x) = \tan\left(\frac{x^2}{2} + \frac{\pi}{4}\right).$$

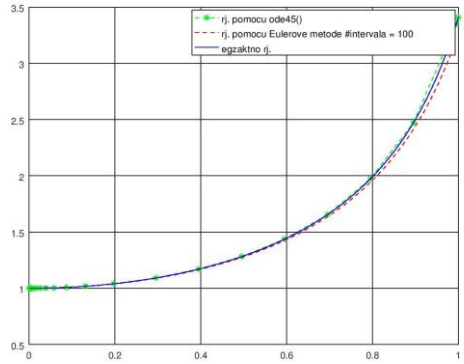
Rješenje nema prekid na intervalu [0, 1], najbliži prekid je u $x = \sqrt{\frac{\pi}{2}}$.

```
% dif. jed. dy/dx = f(x, y) i početni uvjet
f= @(x, y) x*(1+y^2)
a = 0;              % donja granica intervala
b = 1;              % gornja granica intervala
y_0 = 1;            % početni uvjet

% rješenje pomoću funkcije ode45() - red 4
[x45, y45] = ode45(f, [a, b], y_0, 'RelTol', 1e-6);

%rješenje pomoću implementirane Eulerove metode
n = 101;      %broj čvorova
[x_E,y_E] = odj_euler(f, a, b, y_0, n);

% eksplicitno rješenje problema:
rj =@(x) tan(x.^2/2 + pi/4)

% sva dobivena rješenja na istom grafu
figure(1),plot(x45, y45, 'g*--')
hold on
plot(x_E,y_E, 'r--')
hold on
fplot(rj, [0, 1], 'b-'),
legend('rj. pomocu ode45()', 'rj. pomocu Eulerove
metode #intervala = 100', 'egzaktno rj.')
```

GNU Octave funkcija *ode45*() prima funkciju *f*, interval na kojemu aproksimiramo rješenje u obliku vektora s dva elementa [*a b*], gdje je *a* donja granica, a *b* gornja granica intervala, početni uvjet *y0* te dodatne opcije. Puno se informacija može dobiti ako u komandnom prozoru upotrijebimo naredbu *help ode45*. Upotrijebljena je opcija da relativna pogreška rješenja bude manja od 10^{-6}. Izlazni podaci su vektor *x45* koji sadrži čvorove te vektor *y45* koji sadrži aproksimacije rješenja u čvorovima vektora *x45*. Nakon toga je rješenje problema izračunato pomoću prethodno implementirane Eulerove metode, pri čemu je broj podintervala 100, a izlazi su vektor čvorova x_E i vektor aproksimacija y_E. Skripta *odj_euler*() treba biti u istoj mapi kao i test primjer.

Analitičko rješenje kao funkciju možemo definirati pomoću rj =@(x) tan(x.^2/2 + pi/4). Operator @() definira funkciju s varijablama koje navodimo u zagradi. Kvadriranje se vrši pomoću operatora ^, a konstanta π može se koristiti u GNU Octave-u pomoću ključne riječi *pi*.

Dobivena rješenja moguće je crtati na istom grafu radi zorne usporedbe. Za crtanje aproksimacija može se koristiti funkciju *plot*(), pri čemu je prvi argument vektor čvorova, drugi argument vektor aproksimacija, a treći boja i tip linija grafa. Tako je za aproksimaciju pomoću funkcije *ode45*() odabrana zelena boja gdje su točke aproksimacije označene s * i spojene linijama, a za aproksimaciju Eulerovom metodom koristi se crvena linija koja spaja točke aproksimacije. Analitičko rješenje se može crtati pomoću funkcije *fplot*(), kojoj je prvi argument funkcija koju crtamo, drugi argument je interval, a treći tip linija – ovdje je odabrana plava boja linija. Naredba *hold on* služi zadržavanju dosada nacrtanih grafova u istoj figuri, dok



Slika 5. Usporedba aproksimacija dobivenih GNU Octave funkcijom *ode45*(), implementiranom Eulerovom metodom za inicijalni problem ODJ sa analitičkim rješenjem problema.

naredba *legend*() kreira kazalo. Postoje i brojne druge opcije s kojima se može urediti grafički prikaz, npr. imenovati osi, odrediti interval koji će biti vidljiv itd.

Na grafu (Slika 5.) je vidljivo da je aproksimacija pomoću *ode45*() bliže analitičkom rješenju iako koristi 27 čvorova, a aproksimacija Eulerovom metodom 101 čvor. Razlog bi trebao biti veći red konzistentnosti Runge-Kutta metoda koje su osnova funkcije *ode45*(). Povećanjem broja čvorova u Eulerovoj metodi aproksimacija bi trebala biti sve „bolja“.

Za rješavanje parcijalnih diferencijalnih jednadžbi stvari su složenije. Za dani problem potrebno je jednadžbu na primjer diskretizirati, zapisati u obliku sustava jednadžbi i tada se problem može rješavati kao sustav jednadžbi. Ovdje se često koriste metode kao što je Gauss-Seidelova, Jacobijeva metoda, SOR, i dr.

C. Nekoliko drugih primjena

Dodatni paketi mogu biti vrlo korisni. Npr. *symbolic* paket omogućava simboličke varijable. Neke od primjena mogu biti računanje Laplaceove ili Fourierove transformacije analitički. Za *symbolic* paket potrebno je prethodno instalirati Python, uključiti opciju da je vidljiv kao varijabla u sustavu i instalirati SymPy dodatak za Python. Na internet stranici [6] vidljivi su dostupni paketi i informacije o njima. Paketi se mogu instalirati direktno unutar GNU Octave-a naredbom

>> pkg install -forge *ime_paketa.*

Za symbolic paket naredba je pkg install -forge symbolic.

Kod svakog novog pokretanja GNU Octave-a prije korištenja dodatnih paketa potrebno je izvršiti naredbu

>> pkg load *ime_paketa*.

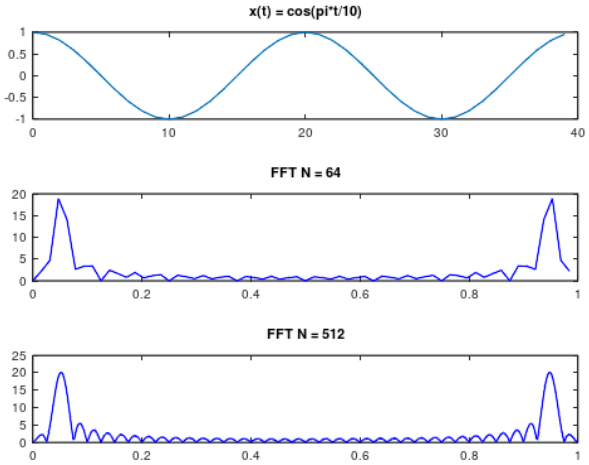
```
syms t
f = exp(-abs(t));
L_f = laplace(f)
fourier(f)
```

Ako je *symbolic* paket uspješno instaliran i učitan tada će gornji kod dati Laplaceove-u transformaciju funkcije $f=e^{-|t|}$: *L_f* = 1/(*s*+1) i Fourierovu transformaciju funkcije *f*: F_f = 2 / (*w*^2+1). Symbolic paket nam omogućava i račun s točnosti u željenom broju znamenaka, npr. 20 ili 50.

U području analize signala iznimno je važna brza Fourierova transformacija (FFT) podataka. O njenom korištenju u Matlab-u i Octave-u može se naći nekoliko demonstracija u [7]. Brzu Fourierovu transformaciju možemo dobiti Octave funkcijom *fft*(), a inverz pomoću funkcije *ifft*(). Funkcija *fft*() prima podatke x koje transformiramo, a kao opciju i broj točaka s kojime ćemo raditi FFT. Slijedi primjer:

```
t = [0:39];
N1 = 64;
N2 = 512;

x = cos(pi*t/10);              % f-ja x(t)

y1 = fft(x, N1);
y2 = fft(x, N2);

subplot(3, 1, 1), plot(t, x),
title('x(t)=cos(pi*t/10)')
F64 = [0:N1-1]/N1;             % normalizacija
subplot(3, 1, 2), plot(F64, abs(y1), 'b-'),
title('FFT N = 64')
F512 = [0:N2-1]/N2;            % normalizacija
subplot(3, 1, 3), plot(F512, abs(y2), 'b-'),
title('FFT N = 512')
```

U primjeru je uzet uzorak duljine 40 koji je opisan funkcijom *x(t) = cos*(t*π/10*). Odabrano je za broj točaka FFT-a prvo 64, a zatim 512. Pozvana je funkcija *fft*() za navedene duljine i rješenje je spremljeno u vektore *y1* i *y2*. Pomoću *subplot*(*m, n, p*) prikazana su tri grafa jedan ispod drugog. Broj *m* govori koliko grafova će biti smješteno vertikalno, *n* horizontalno, a *p* koji je po redu trenutni graf. Apscisa FFT rješenja je normalizirana, a zatim je nacrtano rješenje. Na Slici 6. je vidljivo da broj točaka korištenih pri računu FFT-a utječe na glatkoću prikaza, a forma rješenja je ista.



Slika 6. Grafički prikaz funkcije i pripadnih FFT rješenja dobivenih funkcijom *fft*() za broj točaka 64 i 512.

III. ZAKLJUČAK

Programski paket GNU Octave, iako besplatan, vrlo je moćan alat za rješavanje problema u širokom spektru znanosti. Vrlo je koristan u izvođenju nastave, neki od primjera su rješavanje sustava linearnih jednadžbi, problemi iz područja numeričke linearne algebre, numeričkog rješavanja diferencijalnih jednadžbi, statističke analize uzorka, analizi slike, zvuka, signala, … GNU Octave ugrađene funkcije i paketi ubrzavaju proces učenja rješavanja konkretnih primjera, dok mogućnost implementiranja vlastitih skripti omogućava razvoj algoritamskog i logičkog razmišljanja, ali i implementaciju najnovijih rezultata iz teorije odmah po objavi.

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Ispitivanje preferencija prema različitim grupama multimedijskih obrazovnih sadržaja i spola u razrednoj nastavi

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Sažetak **- Brojna istraživanja bave se utjecajem multimedijskih obrazovnih prezentacija na obrazovna postignuća učenika. Dječaci i djevojčice različito komuniciraju s računalima, različito misle o njima, imaju različite motive, pristupe, preferencije pa je osjetljivost na spolne razlike iznimno važna kako bi multimedijski obrazovni materijali bili primjereni za djecu oba spola. Budući da su spolne razlike u preferencijama prema obrazovnim softverima i igrama dokumentirane, svrha ovog rada je ispitivanje eventualnih preferencija prema multimedijskim obrazovnim sadržajima različite grupe kod dječaka i djevojčica. Istraživanje je provedeno tijekom školske godine 2015. / 2016. i trajalo je 4 mjeseca. Uzorak istraživanja činilo je 97 učenika iz pet razrednih odjela 4. razreda dviju osnovnih škola iz Koprivničko-križevačke županije te dviju osnovnih škola iz Međimurske županije. U istraživanju je korišteno šest grupa multimedijskih obrazovnih sadržaja u uvodnom dijelu sata Prirode i društva: asocijacije, videozapis, interaktivne priče, interaktivne karte, vizualni poticaji (fotografije) te kvizovi i križaljke. Rezultati istraživanja pokazali su postojanje preferencija prema multimedijskim obrazovnim sadržajima ovisno o grupi multimedijskog sadržaja i spolu učenika. Djevojčicama su se više nego dječacima svidjele grupe sadržaja videozapis i vizualni poticaj. Interaktivne priče je grupa aktivnosti koja se najviše svidjela ispitanicima oba spola.**

Ključne riječi – multimedijski obrazovni sadržaj; spolne preferencije; razredna nastava

I. UVOD

„Multimedij i nove tehnologije edukatorima donose mnoštvo novih alata, omogućavaju nov i inovativan pristup podučavanju, a učenicima omogućuju brže, funkcionalnije, raznovrsnije i dostupnije učenje“ [11]. Pri tome je alat u službi prikaza znanja, a njegova učinkovitost korištenja u nastavi u velikoj mjeri ovisi i o učiteljevu stilu poučavanja [3]. Svaki učitelj mora imati spoznaje o mogućnostima samog alata (koje se moraju sustavno nadograđivati i obogaćivati) te o mogućnostima njegova doprinosa u scenariju učenja i ostvarivanju obrazovnih ciljeva kod dječaka i djevojčica.

Brojni autori istražuju utjecaj multimedijskih obrazovnih sadržaja na učenje. Neka istraživanja pokazuju da multimedijske prezentacije nisu utjecale na ocjene, učenje ili prisjećanje naučenog, da je njihova svrha samo zabava i pojednostavljivanje sadržaja te da nedovoljno pripremljene prezentacije mogu čak ometati učenje [5, 9, 17]. Oprečna stajališta prethodno spomenutima tvrde da multimedij povećava i poboljšava učenje i pažnju, razvija pozitivne stavove prema tehnologiji pa čak i prema predavaču [4, 1, 14].

Psiholozi prof.dr.sc. Josip Burušić i prof.dr.sc. Gordana Kuterovac – Jagodić ističu postojanje utjecaja spola na obrazovna postignuća djece u školi dok, nasuprot tome, malobrojni hrvatski autori istražuju utjecaj digitalnih materijala na učenje kod djevojčica i dječaka. Djevojčice češće nego dječaci postižu bolje rezultate u matematici, prirodoslovlju i čitalačkoj pismenosti, što pokazuje studija OECD[1]-a objavljena 2015. godine pod nazivom „Abeceda rodne ravnopravnosti u obrazovanju“ [12].

Dječaci i djevojčice različito komuniciraju s računalima, različito misle o njima, imaju različite motive, pristupe, preferencije. Spolne razlike u preferencijama prema obrazovnim softverima i igrama dokumentirane su. Inkpen [8] ističe važnost osjetljivosti na spolne razlike kako bi multimedijski obrazovni materijali bili primjereni za učenike i učenice. Riding i Grimley [16] istražuju povezanost kognitivnog stila učenja i multimedijskog sučelja kod jedanaestogodišnjih dječaka i djevojčica. Zaključuju da postoje temeljne razlike u načinu na koji dječaci i djevojčice obrađuju informacije iz različitih multimedijskih obrazovnih prezentacija te da prikazane spolne razlike moraju imati implikacije u dizajniranju i korištenju multimedijskih prezentacija. Passig i Levin [13] istraživali su interese dječaka i djevojčica predškolske dobi prema multimedijskom obrazovnom sučelju. Njihov je cilj bio utvrditi karakteristike multimedijskih sučelja koje zanimaju dječake i djevojčice. Rezultati istraživanja pokazali su da djevojčice više vole pisanje, boje, crteže te mirne igre dok dječaci, s druge strane, ističu interes za kontrolom nad računalom i kretanjem na zaslonu. Autori ističu da većina današnjih računalnih igara teži zadovoljiti preferencije dječaka (naglasak je na kontroli, izboru i brzoj navigaciji). Luik [10] istražuje karakteristike obrazovnih programa i njihov utjecaj na učenje kod

[1] Organizacija za ekonomsku suradnju i razvoj, engl. Organisation for Economic Co-operation and Development

dječaka i djevojčica. Pokazalo se da su dječaci imali slabije rezultate od djevojčica u programima koji su većinu pitanja imali u tekstualnom obliku, a bolje su rezultate dječaci postigli sa slikovnim i grafičkim oblikom pitanja. Zanimljiva spoznaja je da su dječaci postizali bolje rezultate kada su animacije nakon točnih odgovora bile različite. U suprotnim slučajevima učenje im je bilo dosadno budući da njihova motivacija za učenjem nije toliko visoka kao kod djevojčica.[2]

Neke zemlje imaju programe koji pomažu nastavnicima da postanu svjesniji rodno – spolnih razlika u nastavnom procesu [12]. Odjel za obrazovanje provincije Alberta u Kanadi izradio je smjernice koje nastavnicima pomažu revidirati obrazovne resurse kako bi se poticala rodna raznolikost. Kroz Zakon o jednakosti u obrazovanju žena, Ministarstvo obrazovanja Sjedinjenih Država podržalo je istraživanje i razvoj inovativnih kurikuluma i strategija podučavanja i učenja za promicanje ravnopravnosti spolova. Washington i Aljaska zahtijevaju od lokalnih škola uklanjanje spolnih predrasuda iz njihovih nastavnih materijala. Razvijeni su alati za osposobljavanje i programi koji pomažu nastavnicima u uklanjanju rodnih stereotipa u nastavnoj praksi. Među programima za promicanje ravnopravnosti spolova u školi, Švedska nudi edukaciju nastavnika o rodnoj svijesti koja odražava cilj ravnopravnosti spolova u kurikulumu. Francuska zajednica Belgije financira internetsku stranicu koja pruža alate za pomoć nastavnicima u rješavanju rodnih stereotipa u svom radu.

Povezanost instrukcijskog dizajna i spola do sada nije dovoljno temeljito istraživano u sklopu hrvatskog obrazovnog sustava, stoga smatramo da je upravo to područje u kojem buduća istraživanja mogu dati vrijedan doprinos.

II. METODOLOGIJA

Eksperimentalno istraživanje u prirodnim uvjetima provedeno je u pet razrednih odjela 4. razreda u dvije osnovne škole u Koprivničko – križevačkoj županiji[3] i u dvije osnovne škole u Međimurskoj županiji[4] tijekom šk. god. 2015./2016.. Istraživanje je trajalo 18 nastavnih sati Prirode i društva, odnosno četiri mjeseca. Uzorak istraživanja činilo je 97 učenika i učenica (N=97). Od čega 48 djevojčica (49,5%) i 49 dječaka (50,5%).

Multimedijske prezentacije izrađene za potrebe ovog istraživanja sadrže šest grupa aktivnosti ovisno o nastavnoj jedinici, obrazovnim postignućima i ciljevima sata: *asocijacije, videozapis, interaktivne priče, interaktivne karte, vizualni prikaz te kvizovi i križaljke.* Svaka od šest grupa predstavlja određeni tip motivacijske i multimedijske instruktivne poruke koji sadrži tri istovrsne aktivnosti različitog sadržaja. Multimedijske prezentacije korištene u ovom eksperimentalnom istraživanju izrađene su alatima PowerPoint i Prezi. Uz postojanje brojnih „novijih“ alata odabrana su ova dva alata zbog svojih brojnih kreativnih i multimedijskih mogućnosti, dostupnosti i, najvažnije, velike raširenosti, odnosno „popularnosti“.

Za procjenu preferencija prema multimedijskim prezentacijama korišten je mjerni instrument anketni upitnik napravljen u obliku Likertove skale od 5 stupnjeva, odnosno 5 ocjena. Učenici su svaku multimedijsku aktivnost, koje su bile prezentirane u uvodnom (motivacijskom) dijelu sata, ocjenjivali ocjenama od 1 do 5 kroz tri kategorije: *poučna, zanimljiva, zabavna.*

Cilj istraživanja bio je pokušati eksperimentalno provjeriti postoje li razlike u preferencijama pojedinih multimedijskih sadržaja kod dječaka i djevojčica. Na temelju postavljenog cilja i prethodno provedenih istraživanja formulirana je sljedeća hipoteza: *Djevojčice će preferirati instruktivne poruke u grupi interaktivne priče i vizualni poticaji, a dječaci video zapise i interaktivne karte.*

A. *Prikaz rezultata*

Za obradu, prikaz i tumačenje rezultata korišten je t – test i deskriptivna statistika.

Djevojčice su boljim ocjenama nego dječaci ocijenile poučnost druge prikazane igre asocijacije (Tablica I, $M_{djevojčice}$=4,96, $M_{dječaci}$=4,77), dok u Tablici II vidimo bolje ocjene djevojčica u ocjenjivanju prvog kviza ($M_{djevojčice}$=4,94, $M_{dječaci}$=4,69).

TABLICA I. OCJENE UČENIKA I UČENICA PO KATEGORIJAMA ZA AKTIVNOST ASOCIJACIJA

Grupa i redni broj aktivnosti		Kategorija	Dječaci M SD	Djevojčice M SD	t (p)
Asocijacije	1. asocijacija ($N_{dječaka}$=49, $N_{djevojčica}$=48)	poučna	4,73 0,446	4,88 0,444	1,553 (0,124)
		zanimljiva	4,80 0,456	4,88 0,334	0,976 (0,332)
		zabavna	4,82 0,486	4,79 0,410	0,270 (0,788)
	2. asocijacija ($N_{dječaka}$=47, $N_{djevojčica}$=48)	poučna	4,77 0,520	4,96 0,202	2,369 (0,021)
		zanimljiva	4,77 0,476	4,83 0,377	0,766 (0,446)
		zabavna	4,60 0,712	4,75 0,484	1,233 (0,221)
	3. asocijacija ($N_{dječaka}$=46, $N_{djevojčica}$=45)	poučna	4,59 0,617	4,67 0,739	0,559 (0,578)
		zanimljiva	4,16 0,714	4,73 0,720	0,829 (0,409)
		zabavna	4,72 0,688	4,69 0,793	0,183 (0,855)

[2] Dio teksta uvoda i rezultati istraživanja preuzeti su iz doktorskog rada autorice Bistrović, J. [2].

[3] Osnovna škola „Braća Radić“, Koprivnica i OŠ Sokolovac

[4] III. osnovna škola Čakovec i OŠ Ivanovec

TABLICA II. OCJENE UČENIKA I UČENICA PO KATEGORIJAMA ZA AKTIVNOST KVIZOVI I KRIŽALJKE

Grupa i redni broj aktivnosti		Kategorija	Dječaci M SD	Djevojčice M SD	t (p)
Kvizovi i križaljke	1. kviz ($N_{dječaka}$=45, $N_{djevojčica}$=48)	poučna	4,69 0,733	4,94 0,320	2,096 (0,040)
		zanimljiva	4,62 0,806	4,71 0,683	0,557 (0,579)
		zabavna	4,56 0,785	4,58 0,871	0,161 (0,872)
	2. križaljka ($N_{dječaka}$=47, $N_{djevojčica}$=47)	poučna	4,94 0,247	4,91 0,351	0,340 (0,735)
		zanimljiva	4,87 0,337	4,91 0,351	0,599 (0,550)
		zabavna	4,85 0,465	4,81 0,613	0,379 (0,705)
	3. križaljka ($N_{dječaka}$=45, $N_{djevojčica}$=45	poučna	4,96 0,208	4,98 0,149	0,582 (0,562)
		zanimljiva	4,96 0,208	4,98 0,149	0,582 (0,562)
		zabavna	4,96 0,208	5,00 0,000	1,431 (0,160)

Suprotno pretpostavkama, temeljenim na prethodnim istraživanjima o boljoj čitalačkoj pismenosti djevojčica, da će djevojčice boljim ocjenama ocijeniti većinu kategorija u grupi aktivnosti interaktivne priče, naši rezultati nisu pokazali statističku značajnost u ocjenama ove grupe aktivnosti (Tablica III).

TABLICA III. OCJENE UČENIKA I UČENICA PO KATEGORIJAMA ZA AKTIVNOST INTERAKTIVNE PRIČE

Grupa i redni broj aktivnosti		Kategorija	Dječaci M SD	Djevojčice M SD	t (p)
Interaktivne priče	1. priča $N_{dječaka}$=47, $N_{djevojčica}$=48)	poučna	4,94 0,247	4,92 0,277	0,332 (0,741)
		zanimljiva	4,83 0,524	4,82 0,527	0,125 (0,900)
		zabavna	4,62 0,848	4,76 0,693	0,875 (0,384)
	2. priča ($N_{dječaka}$=46, $N_{djevojčica}$=44)	poučna	4,85 0,420	4,93 0,255	1,153 (0,253)
		zanimljiva	4,83 0,486	4,93 0,255	1,301 (0,198)
		zabavna	4,89 0,379	4,89 0,321	0,067 (0,947)
	3. priča $N_{dječaka}$=45, $N_{djevojčica}$=45)	poučna	4,87 0,405	4,98 0,149	1,729 (0,089)
		zanimljiva	4,82 0,387	4,91 0,288	1,237 (0,220)
		zabavna	4,80 0,505	4,96 0,208	1,912 (0,061)

U grupi aktivnosti vizualni poticaji uočene su značajnije razlike u ocjenama pojedinih kategorija kod djevojčica i dječaka (Tablica IV: poučnost 1. aktivnosti ($M_{djevojčice}$=4,77, $M_{dječaci}$=4,43), zanimljivost 2. aktivnosti ($M_{djevojčice}$=4,89, $M_{dječaci}$=4,48), zabavnost 2. aktivnosti ($M_{djevojčice}$=4,87, $M_{dječaci}$=4,50), zabavnost treće aktivnosti vizualni poticaj ($M_{djevojčice}$=4,93, $M_{dječaci}$=4,63)), što je podudarno s Passnigovim i Levinovim [13] rezultatima koji su pokazali da djevojčice više vole pisanje, boje i crteže nego dječaci.

TABLICA IV. OCJENE UČENIKA I UČENICA PO KATEGORIJAMA ZA AKTIVNOST VIZUALNI POTICAJ

Grupa i redni broj aktivnosti		Kategorija	Dječaci M SD	Djevojčice M SD	t (p)
Vizualni poticaji	1. vizualni poticaj ($N_{dječaka}$=46, $N_{djevojčica}$=48)	poučno	4,43 0,910	4,77 0,660	2,014 (0,044)
		zanimljivo	4,35 0,971	4,54 0,874	1,018 (0,311)
		zabavno	4,35 1,079	4,40 1,125	0,211 (0,833)
	2. vizualni poticaj ($N_{dječaka}$=46, $N_{djevojčica}$=47)	poučno	4,50 0,983	4,81 0,711	1,731 (0,087)
		zanimljivo	4,48 1,150	4,89 0,375	2,332 (0,023)
		zabavno	4,50 1,049	4,87 0,499	2,158 (0,035)
	3. vizualni poticaj ($N_{dječaka}$=46, $N_{djevojčica}$=43)	poučno	4,76 0,673	4,93 0,258	1,587 (0,118)
		zanimljivo	4,72 0,688	4,93 0,258	1,955 (0,055)
		zabavno	4,63 0,853	4,93 0,258	2,276 (0,027)

Zbog dokazane bolje prostorne orijentacije i snalaženja u prostoru muškaraca od žena očekivali smo značajnije bolje ocjene dječaka u aktivnosti interaktivne karte no rezultati su pokazali suprotno (Tablica V). U aktivnosti interaktivne karte nisu uočene statistički značajne razlike u ocjenama dječaka i djevojčica.

TABLICA V. OCJENE UČENIKA I UČENICA PO KATEGORIJAMA ZA AKTIVNOST INTERAKTIVNE KARTE

Grupa i redni broj aktivnosti		Kategorija	Dječaci M SD	Djevojčice M SD	t (p)
Interaktivne karte	1. karta ($N_{dječaka}$=47, $N_{djevojčica}$=48)	poučna	4,70 0,689	4,77 0,692	0,485 (0,629)
		zanimljiva	4,53 0,856	4,69 0,776	0,928 (0,356)
		zabavna	4,30 1,061	4,65 0,887	1,732 (0,087)
	2. karta ($N_{dječaka}$=46, $N_{djevojčica}$=48)	poučna	4,65 0,706	4,88 0,393	1,880 (0,064)
		zanimljiva	4,70 0,591	4,77 0,555	0,636 (0,527)
		zabavna	4,65 0,640	4,75 0,601	0,764 (0,447)
	3. karta ($N_{dječaka}$=45, $N_{djevojčica}$=45)	poučna	4,76 0,679	4,93 0,330	1,579 (0,119)
		zanimljiva	4,78 0,560	4,93 0,252	1,700 (0,094)
		zabavna	4,76 0,529	4,89 0,318	1,449 (0,152)

U analizi ocjena za grupu aktivnosti videozapis dolazimo do iznenađujućih rezultata. Djevojčice su boljim ocjenama nego dječaci ocijenile zabavnost prvog ($M_{djevojčice}$=4,96, $M_{dječaci}$=4,77) i trećeg ($M_{djevojčice}$=4,96, $M_{dječaci}$=4,77) videa (Tablica VI). Zbog prethodno prikazanih istraživanja koja govore da dječaci preferiraju brzinu i pokret na ekranu očekivali smo bolje ocjene dječaka u aktivnosti videozapis.

TABLICA VI. OCJENE UČENIKA I UČENICA PO KATEGORIJAMA ZA AKTIVNOST INTERAKTIVNE KARTE

Grupa i redni broj aktivnosti		Kategorija	Dječaci M SD	Djevojčice M SD	t (p)
Videozapisi	1. video ($N_{dječaka}$=47, $N_{djevojčica}$=48)	poučan	4,83 0,481	4,96 0,202	1,692 (0,096)
		zanimljiv	4,81 0,449	4,94 0,245	1,733 (0,087)
		zabavan	4,64 0,792	4,90 0,309	2,080 (0,042)
	2. video ($N_{dječaka}$=47, $N_{djevojčica}$=47)	poučan	4,70 0,778	4,85 0,360	1,191 (0,238)
		zanimljiv	4,81 0,647	4,87 0,448	0,556 (0,580)
		zabavan	4,77 0,698	4,77 0,633	0,000 (1,000)
	3. video ($N_{dječaka}$=43, $N_{djevojčica}$=47)	poučan	4,88 0,391	4,91 0,282	0,437 (0,664)
		zanimljiv	4,84 0,374	4,96 0,204	1,871 (0,066)
		zabavan	4,77 0,571	4,96 0,204	2,066 (0,044)

Za svaku od šest grupa aktivnosti izračunata je i aritmetička sredina (ukupna aritmetička sredina svih ocjena istovrsnih aktivnosti i svih kategorija (poučnost, zanimljivost i zabavnost) za pojedinu grupu aktivnosti) koja se tada uspoređivala po spolu (Tablica VII i Tablica VIII).

TABLICA VII. ARITMETIČKE SREDINE OCJENA GRUPA AKTIVNOSTI: ASOCIJACIJE, KVIZOVI I KRIŽALJKE TE VIDEO

Spol učenika		Asocijacije	Kvizovi i križaljke	Video
Muški (N=49)	M	4,70	4,82	4,79
	SD	0,305	0,262	0,305
Ženski (N=48)	M	4,78	4,87	4,90
	SD	0,363	0,237	0,180
	t-test (p)	1,140 (0,257)	0,844 (0,401)	**2,226 (0,029)**

TABLICA VIII. ARITMETIČKE SREDINE OCJENA GRUPA AKTIVNOSTI: INTERAKTIVNE PRIČE, INTERAKTIVNE KARTE I VIZUALNI POTICAJ

Spol učenika		Interaktivne priče	Interaktivne karte	Vizualni poticaj
Muški (N=49)	M	4,84	4,64	4,53
	SD	0,241	0,467	0,656
Ženski (N=48)	M	4,90	4,80	4,77
	SD	0,194	0,420	0,332
	t-test (p)	1,461 (0,147)	1,667 (0,099)	**2,251 (0,028)**

Aritmetičke sredine ocjena grupa aktivnosti pokazuju da su se djevojčicama najviše svidjeli videozapisi i interaktivne priče, a dječacima interaktivne priče te kvizovi i križaljke. Interaktivne priče je grupa aktivnosti koja se najviše svidjela ispitanicima oba spola. Djevojčicama i dječacima najmanje se svidjela aktivnost vizualni poticaji – opisivanje i otkrivanje slika te pamćenje vizualnih i tekstualnih pojmova. U dvije od šest grupa aktivnosti uočene su statistički značajnije razlike u ocjenama učenika i učenica - učenice su boljim ocjenama ocijenile aktivnosti videozapis i vizualni poticaj od učenika (Tablica VII i Tablica VIII) što je podudarno s istraživanjem autorice Hui-Mei Hsu [7] koja govori da žene preferiraju igre s edukativnim značenjem i smislom, ali iznenađujuće zbog postojećih istraživanja koja pokazuju da dječaci preferiraju dinamičnost i pokretne slike [8, 10] više od djevojčica. Dakle, statistički značajna razlika u spolu i preferencijama prema tipu aktivnosti uočena je kod videozapisa i vizualnih poticaja. Analizom dobivenih rezultata odbacujemo postavljenu hipotezu – djevojčice će preferirati instruktivne poruke u grupi interaktivne priče i vizualni poticaji, a dječaci videozapis i interaktivne karte. Postojeća istraživanja govore kako dječaci više od djevojčica računala koriste za igru i zabavu, a manje za učenje i izvršavanje školskih obveza [8, 7, 18, 6] što može biti objašnjenje za lošije ocjene koje su multimedijskim sadržajima dodijelili učenici.

III. ZAKLJUČAK

Učitelji i nastavnici mogu odigrati značajnu ulogu u oblikovanju stavova učenika prema školi i učenju potičući ih da rade najbolje što mogu te kroz korištene nastavne strategije i obrazovne materijale. Očigledno je da postoji niz razlika u načinu na koji dječaci i djevojčice pristupaju, koriste i komuniciraju s računalnim tehnologijama. Ono što se do sada nije dovoljno temeljito istražilo jest način na koji multimedijski sadržaji za učenje utječu na učenje učenika različitog spola. To je područje u kojem buduća istraživanja mogu biti vrijedan znanstveni i praktični doprinos.

Ovim se radom željelo provjeriti postojanje preferencija učenika i učenica razredne nastave prema multimedijskim aktivnostima u predmetu Priroda i društvo. Učenici su Likertovom skalom od 5 stupnjeva ocjenjivali aktivnosti u kategorijama poučnost, zanimljivost i zabavnost. U istraživanju je sudjelovalo 97 učenika iz pet razrednih odjela četvrtih razreda dviju osnovnih škola iz Koprivničko-križevačke županije i dviju iz Međimurske županije.

U dvije od šest grupa aktivnosti uočene su statistički značajnije razlike u ukupnim ocjenama učenika i učenica. Učenice su boljim ocjenama ocijenile aktivnosti videozapis i vizualni poticaj od učenika. Dobiveni rezultati podudarni su s prethodnim istraživanjima koja govore da žene preferiraju igre s edukativnim značenjem i smislom, ali začuđujući zbog istraživanja koja pokazuju da dječaci preferiraju pokretne slike više od djevojčica. Dobivene rezultate možemo poistovjetiti s postojećim spoznajama o tome kako dječaci računala u većoj mjeri koriste za igranje i zabavu, a djevojčice za učenje, izvršavanje školskih zadataka, komunikaciju i socijalnu interakciju.

Ovo eksperimentalno istraživanje ispitivalo je dosad manje istraživano područje preferencija u multimedijskim materijalima kod dječaka i djevojčica. Pedagoška perspektiva svakako prihvaća multimedijsku tehnologiju kao potencijal za preoblikovanje i dodavanje nove dimenzije učenju. Prilikom izrade multimedijskog materijala za učenje valja znati kako dobar multimedijski materijal treba izgledati te koje uvjete mora uvažiti i zadovoljiti. Nastavnik mora znati koje ciljeve učenja želi ostvariti, u kojem okruženju će se materijal koristiti te koje su karakteristike njegovih učenika.

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Položaj učenika i nastavnika pri odvijanju nastave na daljinu

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***Sažetak* - Pri odvijanju nastave na daljinu informacijsko-komunikacijskom tehnologijom učeniku i nastavniku može se olakšati rad te ujedno omogućiti više vremena potrebnog za poučavanje i razgovor o određenim specifičnim problemima unutar nastavnog procesa. Naime, u današnje vrijeme nastavnici zbog sve većeg obujma gradiva za koje je predviđen samo određeni broj sati nemaju dovoljno vremena za ponavljanje gradiva kao ni za raspravu s učenicima o mogućim nejasnoćama. Ova ograničenja imaju za posljedicu lošije rezultate učenika na pisanim provjerama usvojenosti nastavnih sadržaja. Ocjenjivanje i vrednovanje znanja najveći je izazov ovakvog načina poučavanja, a češće provjere usvojenosti nastavnih sadržaja također su logična posljedica i prednost ovoga načina rada. Ograničavajući faktor rada za nastavnika može biti i broj učenika u razredu pa se često događa da se precijene mogućnosti informacijsko-komunikacijske tehnologije te se pojedinom nastavniku dodijeli previše učenika u grupi koju poučava. Naime, nastavnik mora proces poučavanja voditi tako da pravovremeno i relativno učestalo svakom pojedinom učeniku daje određene ovlasti i zadatke u sustavu kako bi se smanjio osjećaj izolacije samoga učenika i kontrolirao način njegova rada. Cilj je ovoga rada ponuditi načine organizacije, metodička rješenja i načine vrednovanja znanja koji mogu pomoći nastavnicima da lakše organiziraju kvalitetnu nastavu u kojoj bi se ostvarilo više vremena za individualne potrebe svakog pojedinog učenika obrazovanjem na daljinu.**

Ključne riječi - učenik; nastavnik; nastava na daljinu; informacijsko-komunikacijska tehnologija; vrednovanje i ocjenjivanje; metode poučavanja; strategije učenja

I. UVOD

U ovom se radu razrađuje problematika organizacije nastave, metodološko-metodičkog pristupa i vrednovanja znanja kod obrazovanja na daljinu te ističu prednosti i nedostatci ovakvog načina poučavanja sa svim implikacijama. Ovakva funkcija učenja i prijenosa znanja pretpostavlja drugačije metode rada i drugačije oblike vrednovanja znanja. Naime, ostvaruju se bitno drugačije pozicije učenika i nastavnika.

Osobna računala i multimedijski software značajno obogaćuju i ubrzavaju odgojno-obrazovnu komunikaciju i zbog toga uvjetuju značajnije promjene uloga i zadataka nastavnika i učenika u suvremenoj školi. Ovakva nastava omogućuje objektiviziranje obrazovnog procesa, tj. nastavnik dio svojih funkcija prenosi na računalo pa se sam može posvetiti kreativnijim poslovima kakvih u nastavnom procesu ima mnogo. Međutim, pedagozi upozoravaju da se na nastavi ne uči samo glavom, već i srcem i rukama. Dakle, njoj nije zadaća samo puko učenje informacija već treba utjecati na cjelovit i mnogostran razvoj učenikove ličnosti, u kojem afektivni i motorički razvoj zauzimaju ravnopravno mjesto uz sam kognitivni razvoj. Ova potonja činjenica može predstavljati izazove kod nastave na daljinu.

Tehnološki aspekt upotrebe informacijsko-komunikacijske tehnologije unutar procesa nastave na daljinu može se odvijati na raznim poznatim i za te potrebe odabranim platformama (npr. MOODLE, LOOMEN…). Pri obavljanu posla nastavnika u srednjoj strukovnoj školi na konkretnim primjerima lako se uočavaju specifičnosti položaja učenika i nastavnika u ovome procesu. Zbog toga se nameće i razmatranje ove problematike manje s tehnološkog aspekta nastave na daljinu, a više s aspekta samog položaja učenika i nastavnika u ovome procesu. Naime, za učinkovito provođenje procesa poučavanja uz osiguranje primjerene tehnološke platforme potreban je i posebni metodološko-metodički model. Također je kod ovoga oblika obrazovanja potrebno posebnu pažnju posvetiti problemu vrednovanja znanja.

Kao značajna tema nameće se sam položaj i vođenje učenika kroz obrazovni proces, tj. koliko uspješno nastavnik može usmjeriti njegovo učenje. Kao drugo važno pitanje postavlja se način provođenja pisanih i usmenih provjera znanja kao i oblici ispita te načini vrednovanja tako stečenoga znanja. Odgovori na ova i još neka zanimljiva pitanja nalaze se u tekstu koji slijedi.

II. TEORIJSKA ANALIZA

A. Organizacija nastave na daljinu

Suvremeno obrazovanje sve se više orijentira na dostignuća informacijsko-komunikacijskih tehnologija. Razvoj suvremene tehnologije uvjetuje uvođenje novih pristupa u cjelokupnom sustavu današnjeg obrazovanja, koje u informacijskom društvu ima poseban značaj i posve novu dimenziju. Znatno je smanjen vremenski ciklus od otkrića do primjene tehnološkog rješenja pa se ova brzina promjene znatno odražava i na obrazovni proces. Znanstveno–tehnološki napredak prouzročio je korjenite promjene u svim sferama društva. Gospodarski razvoj današnjeg društva direktno ovisi o stupnju razvoja i primjene znanosti, a posljedično i o samoj kvaliteti

obrazovanja. Međutim, možemo primijetiti da obrazovanje zaostaje u primjeni informacijske tehnologije u svim svojim dijelovima i procesima. Jedan od najpoznatijih znanstvenika na području ljudskih komunikacija sa stajališta medija, Marshall McLuhan, rekao je „mediji su produžena ruka čovjekovih osjetila, oni su posrednik u odnosu čovjeka i svijeta oko njega". Učenici vole raditi s računalima zato što su računala beskonačno strpljiva, ne umaraju se i ne ljute, dozvoljavaju im privatnost pri radu, ne zaboravljaju pohvaliti ni ispraviti, poučavaju na individualiziran način, omogućuju isprobavanje različitih opcija, mnogo su objektivnija od učitelja i poučavaju u malim koracima. [Cotton, 1991]

U ovakvom obliku nastave na daljinu učenik nije potpuno vođen od strane nastavnika niti su mu ponuđena znanja u gotovom obliku. Naprotiv, u ovom konceptu nastave učenik je vođen od strane nastavnika samo onoliko koliko je to neophodno da bi mogao nastaviti samostalno raditi. Umjesto znanja u gotovom obliku, koja nastavnik u tradicionalnom školskom konceptu pokušava prenijeti učeniku, u ovom se novom konceptu škole učeniku nude samo neophodne smjernice koje će mu omogućiti dolazak do preostalih znanja i nastavnih materijala učeći samostalno. To je strategija koja iz temelja mijenja pozicije sudionika u nastavnome procesu. Dominantna se uloga nastavnika gubi ustupajući mjesto procesu učenja u kome aktivnost i zainteresiranost učenika dobivaju na važnosti. Učenik se ovakvim procesom osposobljava da kritički prosuđuje, zaključuje, uspoređuje, otkriva nepoznato, analizira i istražuje. Zbog toga je od krucijalne važnosti postizanje intrinzične motivacije kod učenika i prilagođavanje nastavnog sadržaja što je više moguće učenikovim interesima. Također je potrebno kod učenika kontinuirano poticati osjećaj društvene korisnosti te ga direktno povezati s osobnim uspjehom učenika.

U obrazovanju na daljinu javljaju se neki izazovi kakve u klasičnoj izravnoj nastavi ne susrećemo. Jedan od njih je i učenička izolacija zbog pretežitog prakticiranja samostalnog učenja. Naime, brojni anketirani polaznici u istraživanjima obrazovanja na daljinu istaknuli su osjećaj izolacije tijekom nastavnih aktivnosti kao negativan aspekt ovoga oblika učenja.

Na konkretnom primjeru obrazovanja na daljinu u praksi se kao ograničavajući faktor rada za nastavnika pokazao i broj učenika koje podučava u jednoj grupi, tj. razredu. U ovome se slučaju dogodilo da su se precijenile mogućnosti tehnologije pa je nastavniku dodijeljeno previše učenika u pojedinoj grupi koju je trebao podučavati, umjesto da taj broj bude manji ili jednak standardnom broju učenika u jednom razredu. Zbog specifičnosti ovoga načina poučavanja i potrebe za velikom intrinzičnom motivacijom te smanjenim mogućnostima kontrole samoga učenika pokazalo se da je broj učenika u grupi bio od velike važnosti i u bitnoj korelaciji s postignutim ishodima učenja. O samome broju učenika koji su bili prisutni prilikom obrade pojedine nastavne jedinice ovisio je i način kontrole njihova rada pomoću odabrane tehnološke platforme. Naime, nastavnik je morao proces poučavanja voditi tako da pravovremeno i relativno učestalo svakom pojedinom učeniku daje zadatke i izvjesne ovlasti u sustavu kako bi se smanjio osjećaj izolacije samoga učenika. Ovakvim je postupkom pokušao povećati i kontrolu rada učenika kojem tehnologija omogućava da se paralelno s nastavom bavi i drugim aktivnostima te da zapravo bude odsutan s nastave iako se nastavniku tako ne čini jer je prijavljen u sustavu. Zbog velikog broja učenika u grupi u ovome slučaju ovakav način kontrole nije bio dovoljno učinkovit.

B. Metodičko- metodološki pristup

Shodno tome strategije za poticanje učeničke kreativnosti i samostalnosti pri odvijanju nastave na daljinu moraju uključivati kognitivne (strategija ponavljanja i organiziranja), metakognitivne (strategija planiranja i nadgledanja), društvene i afektivne komponente. Potrebno je poticati problemsko-stvaralački tip učenja i nastave gdje nastavnik ima isključivo ulogu organizatora koji usmjerenim pitanjima (heurističkim razgovorom) učenike poučava da samostalno ovladavaju tehnikama učenja. Ovakvim se aktivnostima potiče kreativno razmišljanje, primjena teorijskog znanja u praksi, unapređenje raznih organizacijskih sposobnosti učenika itd. Cilj ovakvih aktivnosti možemo lakše postići ako je naglasak prilikom obrade nastavnog sadržaja stavljen na sam rad učenika, na njihovo interaktivno sudjelovanje i donošenje samostalnih zaključaka, a ne kao u klasičnoj nastavi na izlaganje i tumačenje (frontalni rad). Učenici su ovakvim tipom aktivnosti stavljeni pred konkretne probleme koje moraju samostalno riješiti da bi razumjeli nastavni sadržaj, čime se ujedno postiže njihova stvaralačka kreativnost. S aspekta društvene komponente potrebno je poticati rad u grupama kako bi učenici što više komunicirali međusobno, makar i u virtualnom okruženju.

Obilježja nastave na daljinu trebaju se temeljiti na diferenciranom i individualiziranom principu učenja i modeliranja nastave. Ovakav pristup bazira se na rezultatima diferencirane psihologije, koja je konstatirala postojanje značajnih individualnih razlika među učenicima. Na svijetu ne postoje dvije jednake osobe te znamo da je svaka osoba neponovljiva i jedinstvena. Mnogi su pedagozi u praksi klasičnog okruženja pokušali poštivati te činjenice i s manjim ili većim uspjehom prilagoditi nastavu individualnim mogućnostima pojedinog učenika. Dakle, koncept nastave na daljinu treba biti postavljen prema „modelu učenika". Nastava na daljinu proces je koji se u bitnome oslanja na učenikovu individualnost, na njegovu intrinzičnu motivaciju i njegove socijalne potrebe za učenjem. Pitanje je kako će ove učenikove potrebe biti zadovoljene i je li nastavnikova glavna briga podučavati učenike ili ih motivirati da uče. Nadalje, hoće li nastavnik uspjeti usmjeriti dovoljno pažnje na socijalne aspekte učenja. Procesi učenja na daljinu trebaju uračunati i individualne ciljeve u učenju, individualnu biografiju i socijalnu situaciju svakog pojedinog učenika. Sam učenik dijeli odgovornost za svoj vlastiti proces učenja u puno većoj mjeri nego kod klasičnog procesa poučavanja. Aktivno učestvovanje učenika u ovakvom nastavnom procesu podrazumijeva postojanje visokog stupnja suradnje s nastavnikom. Za djelotvornu nastavu na daljinu nije dovoljno postaviti obrazovne sadržaje i pisane provjere znanja na multimedijsku platformu te o tome informirati učenike već je potrebno koristiti sve dostupne i gore opisane pedagoške metode kojima se prilagođava način

prezentiranja sadržaja i poučavanja specifičnostima pojedinog nastavnog predmeta. Zbog toga je zadatak novih metodičkih pristupa definirati precizne procedure i tehnike kojima se može poučavati pojedini predmet. U konačnici ovakve metode poučavanja trebaju učiniti učenika znatiželjnijim i motivirati ga dok mu nastavnik osigurava individualnu podršku za učenje. Treba posebno uzeti u obzir da su biografija, motivacija i način učenja svakog pojedinog učenika mnogo važniji za njegov uspjeh i ishode učenja nego tehnološke mogućnosti ovoga procesa.

Procjenjuje se da najbolje rezultate obrazovanje na daljinu može postići ako je koncipirano po metodi interaktivnog učenja**.** Najvažnije metodičko obilježje obrazovanja na daljinu jest činjenica da bi učenik trebao biti aktivni subjekt, a ne objekt procesa poučavanja. Učenikovo aktivno sudjelovanje i metode njegova motiviranja već su poznati procesi koje je potrebno prilagoditi novome tehnološkom okruženju. Nadalje, takav sustav obrazovanja treba biti fleksibilan i pružiti velike metodičke različitosti kako bi se učeniku omogućile primjerene i pravovremene reakcije tijekom procesa poučavanja te razvoj osobnih strategija učenja.

U primjeru nastave na daljinu upotrijebljen je problemsko-stvaralački tip nastave gdje je nastavnik imao ulogu organizatora koji je usmjerenim pitanjima (heurističkim razgovorom) učenika poučavao da samostalno, induktivnim putem na vlastitoj igrački upozna tehnike spajanja u elektrotehnici. Svaki je učenik demonstrirao vlastitu igračku (npr. auto na daljinsko upravljanje s elektroničkim sklopovima) i tako povezao ono što uči s osobnim životom. Učenici su demontažom i ponovnom montažom vlastite igračke upoznali vrste kućišta i konstrukcije, tehnike spajanja, lemljenje, lijepljenje i ljepila te sastavljanje i pakiranje integriranih krugova. U obradi nastavnoga sadržaja krenulo se od kognitivno-emocionalnog (intelektualno-doživljajnog), tj. iskustvenog svijeta samog učenika te se nastavni sadržaj prilagodio učeničkim interesima. Na ovaj se način postigla motivacija za samostalan popravak elektroničkih uređaja, potakla se radoznalost učenika i osjećaj društvene korisnosti povezan s osobnim uspjehom. Ovom je aktivnošću kod učenika potaknuto kreativno razmišljanje, razvijanje njegovih motoričkih i organizacijskih sposobnosti te primjena teorijskog znanja u praksi. Primijenjeni metodički pristup potaknuo je razvijanje sljedećih učeničkih kompetencija, a to su: zapažanje, povezivanje, uspoređivanje, zaključivanje, logičko i apstraktno mišljenje. Zadani cilj ove aktivnosti postignut je tako što naglasak prilikom obrade nastavnog sadržaja nije stavljen samo na izlaganje i tumačenje nego na teoretski i praktični rad učenika, na njihovo (inter)aktivno sudjelovanje i donošenje samostalnih praktičnih odluka i zaključaka. Učenici su ovakvom nastavom na daljinu bili stavljeni pred konkretne probleme koje su morali samostalno riješiti da bi razumjeli nastavni sadržaj. Ovim se načinom rada postigla njihova stvaralačka kreativnost i potaklo ih se da samostalno traže odgovore na postavljena pitanja preko ponuđenih nastavnih sadržaja na odabranoj tehnološkoj platformi.

C. Vrednovanje znanja

Ocjenjivanje i vrednovanje znanja dio je i ovoga nastavnog procesa putem kojega utvrđujemo koliko su učenici usvojili znanje koje proizlazi iz nastavnog plana i programa te takvo vrednovanje ne služi samo za mjerenje znanja već bitno potiče učenika na daljnji rad. Ono se u ovakvom obliku nastave također može izvoditi pismeno putem raznih vrsta testova, zatim usmeno te putem domaćih zadataka i praktičnih radova. Vrednovanje i ocjenjivanje znanja vrlo je važan dio ovakvog odgojno-obrazovnog procesa kojim se procjenjuje i o kojem direktno ovisi razina učeničkih postignuća. Način na koji se ono provodi snažno utječe na motivaciju učenika za rad i posljedično na kvalitetu samog nastavnog procesa. Kad ocjenjujemo znanje učenika, mi zapravo procjenjujemo koliko su ostvareni ciljevi odgojno-obrazovnog rada. Sama svrha provjeravanja znanja za učenika može biti i povratna informacija o njegovu stvarnom znanju i napredovanju. Može mu eventualno korigirati strategije učenja te dati komentar na što bi se trebao dodatno usmjeriti. U motivacijskome smislu povratna informacija može djelovati poticajno ako se provode češće i kraće provjere znanja za razliku od rijetkih i dugih pisanih ispita. To znači da ocjenjivanje znanja ima i formativni karakter i omogućuje praćenje napredovanja učenika, vrednovanje predznanja i planiranje ostatka poučavanja.

Aktivnost učenika značajno se povećava redovitim provjeravanjem njegovih do tada stečenih znanja i njegovim osposobljavanjem da može sam vrednovati i pratiti vlastiti napredak tako da i mogućnosti samotestiranja učenika trebaju pronaći svoje mjesto tijekom procesa učenja.

Ovako postavljen način ispitivanja i provjeravanja znanja treba:

- biti transparentan u procesu određivanja brojčane mjere učenikova postignuća

- dati pravovremenu povratnu informaciju o postignuću kako učeniku, tako i nastavniku

- ocjenjivati što je učenik postigao, a ne koliko je sadržaja riješio

- biti točan (valjan), tj. mjeriti znanje, a ne sposobnost ili čuvstvenu otpornost učenika

- biti objektivan, tj. minimalno ovisiti o nastavniku i njegovim interpretacijama i raspoloženjima

- biti pouzdan, tj. stabilan u vremenu i unaprijed zadan

- biti osjetljiv, tj. mjerenjem uspjeti razlikovati pojedince u količini znanja

- povećavati jasnoću postavljenih zadataka

- davati objektivniju vrijednost procijenjenom znanju.

U ovakvom obliku nastave na daljinu vrednovanje znanja učenika uglavnom će se provoditi u virtualnom okruženju na više načina prema unaprijed objavljenim kriterijima. Treba se organizirati kontinuirano praćenje i ocjenjivanje učenika u virtualnim diskusijama i to u interakciji sa sadržajem, drugim učenicima i sa samim nastavnikom. Nadalje, potrebno je organizirati izradu seminarskih i grupnih radova. Putem videokonferencije

moguće je provesti i usmeno ispitivanje, a pismeno ispitivanje potrebno je provesti jednokratnim rješavanjem pisane provjere znanja zaštićene lozinkom uz ograničeno vrijeme i unaprijed definiranu IP-adresu učenika. U slučaju postavljanja otvorenog tipa pitanja kod pisane provjere znanja treba uzeti u obzir i motoričke sposobnosti svakoga pojedinog učenika kako bi se objektivizirali rezultati ispitivanja usvojenosti nastavnih sadržaja ovisno o tome ocjenjuju li se samo kognitivna ili kognitivna i motorička dostignuća. U slučaju da nastavnik procijeni da provjera znanja putem informacijsko-komunikacijske tehnologije nije dovoljna, sukladno učenikovim mogućnostima, treba provesti ispitivanje na lokaciji na kojoj se nalazi učenik u kontroliranim uvjetima i na tradicionalan način.

III. ZAKLJUČAK

Sustavi za odvijanje nastave na daljinu mogu učeniku i nastavniku olakšati rad te ujedno omogućiti više vremena potrebnog za razgovor o određenim specifičnim problemima. Češće provjere znanja također su logična posljedica ovoga načina rada, a njih bi inače bilo nemoguće provesti u klasičnoj nastavi zbog nedostatka vremena. Naime, u današnje vrijeme nastavnici zbog sve većeg obujma gradiva za koje je predviđen određeni broj sati nemaju dovoljno vremena za ponavljanje gradiva kao ni za raspravu s učenicima o mogućim nejasnoćama. Takva ograničenja imaju za posljedicu lošije rezultate učenika na pisanim provjerama znanja. Upravo zbog takvih problema obrazovanje na daljinu može pomoći nastavnicima da lakše organiziraju kvalitetnu nastavu u kojoj bi se ostvarilo više vremena za individualne potrebe svakog pojedinog učenika. Na kraju se može zaključiti da bi najbolja opcija za učenika bila kombinacija nastave na daljinu i tradicionalne nastave, ali ona zahtijeva značajne napore i od učenika i od nastavnika kako bi se prilagodili ovome načinu rada.

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Izrada virtualnog modela školskoga atrija: Rezultat projektne nastave u III. OŠ Čakovec

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Sažetak - Projektna nastava omogućuje provedbu projekata u nastavi, pri čemu učenici preuzimaju ulogu aktivnih sudionika. U vrijeme informatizacije i digitalizacije odgojno-obrazovnog procesa učitelj djeluje kao mentor, medijator i koordinator.

U III. OŠ Čakovec provedena su istraživanja o mjeri zastupljenosti projektne nastave u školi te o zainteresiranosti učenika za sudjelovanje u projektnoj nastavi. Obuhvaćeni uzorak (za oba istraživanja) odnosio se na sve više razrede. Rezultati su ukazali na slabu opću zastupljenost projektne nastave (pri čemu je ona najzastupljenija u nastavi informatike i građanskog odgoja) te na izrazito veliku motiviranost učenika. Prikupljeni i analizirani podaci statistički su (kvalitativno i kvantitativno) obrađeni.

Proveden je projekt izrade virtualnog školskog atrija s učenicima osmih razreda, u sklopu nastavnih predmeta matematike i informatike.

Cilj projekta bio je analizirati stanje trenutne uređenosti školskog atrija te kreiranje virtualnog modela koji prikazuje njegovo unaprijeđeno stanje. Zadatak učenika bio je napraviti troškovnike trenutnog i zamišljenog novog atrija te digitaliziranje modela novog atrija. Primjenom matematičkih znanja, učenici su izračunavali troškovnike, vršili geometrijska mjerenja prostornog modela te napravili tlocrt u umanjenom mjerilu. Primjenom informatičkih znanja, na Internetu su pretraživali postojeće cijene određenih konstrukcijskih materijala, računali konačne iznose u programu za tablična kalkuliranja te digitalizirali tlocrt i model zamišljenog novog atrija.

I. UVOD

Suvremeno društvo u globalizacijsko i digitalno doba zahtijeva nove izazove i paradigme poučavanja i učenja. Naglasak je na projektnoj nastavi gdje učenik postaje aktivni sudionik odgojno – obrazovnog procesa, a učitelj preuzima ulogu mentora, medijatora i koordinatora.

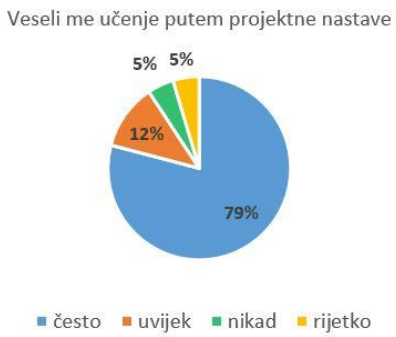
Začeci projektne nastave sežu u 18. stoljeće gdje je temelje postavio J. H. Pestalozzi. U samom odgojno-obrazovnom sustavu, projektna nastava se uvodi u drugoj polovici 20. stoljeća u Njemačkoj. Projekt je definiran kao zajednički pokušaj nastavnika i učenika da život, učenje i rad povežu tako da se društveno značajan i s interesima sudionika povezan problem zajednički obradi i dovede do rezultata (Meyer, 2002), koji za sudionike odgojno – obrazovnog procesa ima pozitivan ishod.

Projektna nastava je model organiziran oko projekta koja se temelji na problemskoj nastavi u kojoj učenici istražuju i uče sadržaj na autentičan način (Thomas, 2000). Istraživanja i radovi u Republici Hrvatskoj vezano za projektnu nastavu u osnovnoj školi te njeni učinci gotovo i ne postoje. Provedeno je istraživanje B. Žugaj (2014): Utjecaj projektne nastave na promjenu stava kod učenika prema nastavnim sadržajima iz biologije. Međutim, vezano za predmete matematike i informatike, ne postoje rezultati znanstvenih istraživanja u realizaciji projektne nastave.

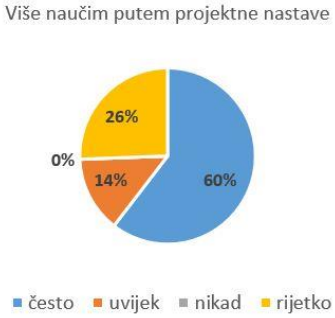
Provedeno je istraživanje u III. OŠ Čakovec. Cilj istraživanja je bio ispitati stavove učenika o projektnoj nastavi, kao i njenu zastupljenost u predmetnoj nastavi. Nakon toga je dogovoren i realiziran rad na projektu: Izrada virtualnog modela školskog atrija s prethodnom analizom postojećeg stanja.

II. GLAVNI DIO

Provedeno je empirijsko istraživanje u siječnju 2019. godine u III. osnovnoj školi Čakovec. Uzorak je obuhvatio sve dostupne učenike od petog do osmog razreda (N=164). Učenici su ispunjavali skalu procjene i anketni upitnik. Provodili smo ispitivanje stavova učenika o projektnoj nastavi kao i njenu zastupljenost, da dobijemo mjerodavne podatke o upoznatosti učenika s takvim oblikom nastave i u kojim predmetima se ona primjenjuje.



Slika 1. Izraz motiviranosti učenika za projektnom nastavom



Slika 2. Izraz procjene učenika o naučenom putem projektne nastave

Slika 1 prikazuje da među učenicima viših razreda postoji motivacija za učenjem putem projektne nastave i da takva nastava učenike veseli. Slika 2 prikazuje kako većina učenika smatra da više nauči putem projektne nastave.

Nadalje, istraživanje je pokazalo da je projektna nastava najviše zastupljena u izbornim predmetima informatike i građanskog odgoja i obrazovanja. U redovnoj nastavi ponekad je zastupljena u slijedećim predmetima: Hrvatski jezik, Povijest, Geografija, Biologija, Priroda i Matematika. U izvannastavnim aktivnostima, ona je najviše zastupljena u izvannastavnoj aktivnosti „eTwinning club“, gdje učenici aktivno odrađuju unaprijed dogovoreni projekt u suradnji sa školama partnerima diljem Europe.

U dogovoru s učenicima definirana je tema projekta kao i plan realizacije.

U projekt su bili uključeni učenici osmog razreda dodatne nastave matematike i informatike. Učenici su u realizaciji projekta primjenjivali stečena znanja i vještine iz nastavnih predmeta matematike, informatike, tehničke kulture, geografije, likovne kulture, fizike i građanskog odgoja i obrazovanja. Cilj projekta bio je analizirati postojeće stanje školskog atrija, izračunati troškove uređenja istog i ponuditi novi virtualni izgled.

A) Izvedba projektnog zadatka

Faze izvedbe:

1. Podjela učenika u timove (2-3 učenika)
2. Podjela zadataka
3. Dodatno objašnjenje zadataka:

- Napraviti snimku postojećeg stanja (foto zapis)
- Uočiti i prepoznati dijelove u školskom atriju (zelena površina, staze, stepenice, sjenica)
- Uočiti i prepoznati materijale na pojedinim dijelovima (travnati dio, dio s ukrasnim kamenčićima, drveni dio)
- Uočiti mnogokute u školskom atriju
- Izmjeriti duljine pojedinih stranica mnogokuta
- Izrada tlocrta školskog atrija na milimetarskom papiru u mjerilu 1:10, izrada digitalnog tlocrta (program Autocad))
- izračunati površine dijelova atrija i pridružit odgovarajuće materijale
- pretražujući Internet pronaći najprihvatljivije cijene pojedinih materijala
- izračun troškovnika za postojeće stanje školskog atrija (Excel)
- Idejni prikaz virtualnog školskog atrija (oluja ideja)
- Definirati novi izgled virtualnog školskog atrija
- Napraviti shematski prikaz zamišljenog školskog atrija (digitalni)

B) Projektna dokumentacija

1. Tlocrt postojećeg školskog atrija (milimetarski papir) u mjerilu 1:10
2. Tlocrt postojećeg školskog atrija u digitalnom obliku (program Autocad)
3. Troškovnik postojećeg školskog atrija (dokument Excela)
4. Digitalnog modela zamišljenog školskog atrija (program 3D Paint)
5. Prezentacije po fazama realizacije projekta (PowerPoint)

B) Rezultati rada na projektu

U realizaciji projekta sudjelovalo je 12 učenika polaznika dodatne nastave matematike i informatike. Učenici su se samostalno podijelili u grupe. Formirali su 4 grupe po 3 učenika. Zadatke su učenicima/grupama zadale učiteljice.

Grupa 1 je napravila snimku postojećeg stanja atrija – skicirala je atrij s određenim dijelovima kao sastavnim elementima istog i to: sveukupnu površinu, površinu bez kamenčića, stepenice, stazu, kućicu i travnati dio. Grupa 1 je nadalje izvršila sva potrebna mjerenja i napravila tlocrt crtan rukom na milimetarskom papiru (mjerilo 1:50).

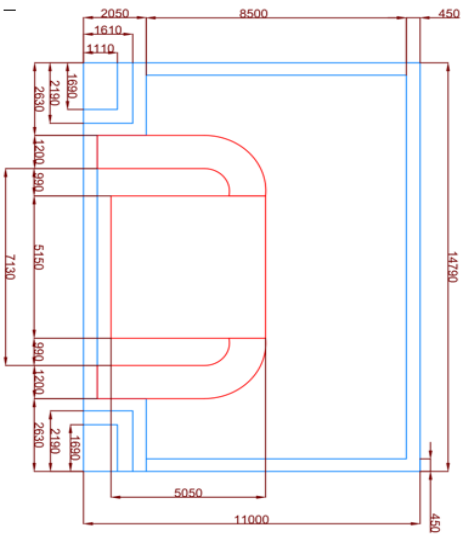


Slika 3. Postojeći školski atrij

Grupa 2 je proučila tlocrt koji je napravila Grupa 1 i u programu Autocad napravila digitalnu verziju, koristeći se studentskom verzijom programa.
Grupa 3 je proučila tlocrt i izračunala sve površine i to na 2 načina. Prvi način je bio način naučen na matematici – ručni izračuni, a drugi način – način naučen na informatici koristeći se programom za tablične izračune. Učenici su koristili program Ms Excel. Grupa 3 je izračunala sveukupnu površinu atrija (162.69 m^2), površinu s kamenčićima (14.30 m^2), površinu stepenica 25.389 m2, površinu staze od dasaka (13.824 m^2), površinu koju zauzima drvena sjenica (26.007 m^2) i površinu s travnatim dijelom (94.73 m^2).
Grupa 4 je imala zadatak napraviti okvirni troškovnik postojećeg atrija za troškove pojedinih dijelova što se tiče materijala, bez usluga radova. U tu svrhu trebali su pronaći materijale i cijene na internetu te na osnovu toga napraviti približan troškovnik. Troškovnik su radili na 2 načina; analogno i digitalno (Ms Excel). Grupa 4 je izračunala da je ukupni trošak uređenja dvorišta 9.340,51 kn. Pojedinačni troškovi:

- Površina s kamenčićima:14.30 m^2 – 1.424,05 kn
- Površina stepenica: 25.39 m^2 - 3.681,42 kn
- Površina staze od dasaka: 13.82 m^2 - 1.956,00 kn
- Površina drvene sjenice: 26.01 m^2 – 2.100,00 kn
- Površina travnatog dijela: 94.73 m^2 – 179,04 kn

Svi učenici su bili upoznati s zadacima svih grupa kao i rezultatima realizacije. Složili su se da im se sviđa trenutni izgled školskog atrija, ali bi dodali još neke elemente: cvijeće na prozore, klupe za sjedenje, ljuljačku i spravu za vježbanje. Postojeće sive kamenčiće bi zamijenili ukrasnim antracit bijelim kamenčićima. Posadili bi bonsai drvo. Model zamišljenog bonsai drva su izradili 3D modeliranjem i nazvali ga Pitagorino stablo.



Slika 4. Slika 4. Digitalni tlocrt školskog atrija

Primijenili su poveznicu sa nastavnim gradivom iz matematike u 8. razredu, a to je Pitagorin poučak. Pitagorin poučak pomaže u konstruiranju Pitagorina stabla. Ono nastaje tako da nad jednom stranicom kvadrata konstruiramo jednakokračni pravokutni trokut. Zatim se na njegove katete pridodaju novi kvadrati, a potom opet trokuti. Postupak se može ponavljati u beskonačnost. Pitagorino stablo može biti simetrično i asimetrično. Učenici su izradili simetrično Pitagorino stablo za virtualni školski atrij.



Slika 5. Pitagorino stablo izrađeno 3D pisačem



Slika 6. Zamišljeni (virtualni) školski atrij

III. ZAKLJUČAK

Ovaj projekt je pokazao da je projektna nastava izrazito primjenjiva i zanimljiva za učenike, iako iziskuje puno vremena za pripremu i samu realizaciju. Učenici su na dodatnoj nastavi matematike i informatike usvojili nove metode učenja gdje je do izražaja došla interdisciplinarnost obrazovnih ishoda. Naše istraživanje je pokazalo da učenici žele promjene, da oni žele biti aktivni sudionici nastavnog procesa. Isto tako, izrazili su želju da više uče putem projektne nastave. Učenici se osjećaju bolje kada se uvažavaju njihove ideje i stavovi. Ostvarene su sve faze projekta. Cilj projekta bio je analizirati stanje trenutne uređenosti školskog atrija i izračunati ukupan troškovnik te ponuditi novi, dopunjeni izgled školskog atrija.

Novi izgled iziskuje i nove, dodatne troškove, ali time će se učenici tek baviti. Učenici su zamislili novi virtualni atrij kao prostor za odmor (ležaljka, ljuljačka) u ugodnom okruženju (ukrasni kamenčići, trava i cvijeće, ukrasna drvca). Isto tako, isplanirali su da taj prostor posluži i za aktivni odmor (sprava za vježbanje na otvorenom) i učenje na otvorenome (klupice i stol). Primjenom znanja iz matematike i informatike, digitalizirali su postojeće i virtualno stanje.

Kroz rad na ovom projektu učenici su primijenili stečena znanja, ponajviše iz područja matematike i informatike. Pokazali su da su vrlo vješti u primjeni informacijsko-komunikacijske tehnologije koju su koristili za realizaciju samog projekta ali i za međusobnu komunikaciju kroz rad na projektu između sebe, ali i prema nama, učiteljicama.

Ovaj primjer projektne nastave je dobar primjer prakse, i potrebno je više istraživanja o projektnoj nastavi u višim razredima osnovne škole kao i definirati projektnu nastavu u kurikulumu.

Glavni razlog zašto su u projektu sudjelovali samo polaznici dodatne nastave je prije svega zahtjevnost ovog projekta, a zatim i nedostatak vremena u redovnoj nastavi s obzirom na složenost projekta. Naime, poznato je da su u dodatnu nastavu uključeni učenici koji u odnosu na većinu učenika u razredu s prosječno razvijenim sposobnostima, imaju natprosječno razvijenu jednu ili više sposobnosti. Takvi učenici hoće i mogu više i njihovi potencijali teško mogu doći do punog izražaja u redovnoj nastavi. Za razvoj njihovih potencijala potrebna je osmišljena, bogata i stimulirajuća okolina. S obzirom na to, kao i na fleksibilnost u kreiranju kurikuluma dodatne nastave, gdje učitelj sam kreira isti, osmišljen je i realiziran ovaj projekt.

IV. POPIS LITERATURE

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Upoznavanje Europske unije kroz nastavu informatike

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Sažetak

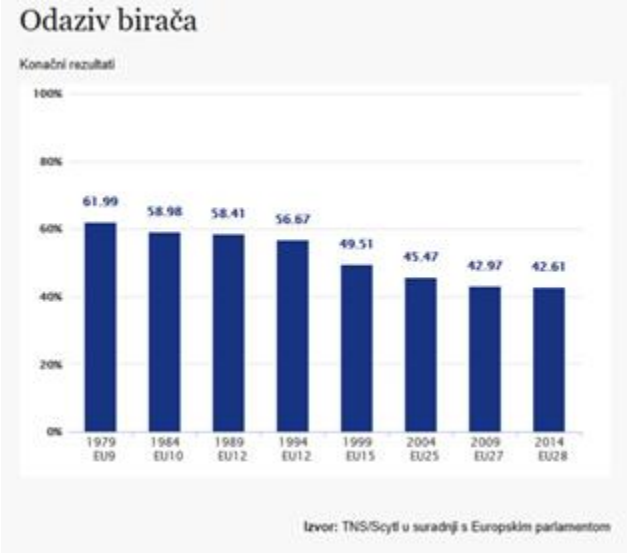
Kako bi ojačali svijest učenika o pripadanju europskom kulturnom krugu, glavni izvor informacija o Europskoj uniji trebaju biti nastavni sadržaji u školi, uz saznanja koja učenici otkrivaju putem medija, obitelji ili razgovora s prijateljima.
Autorica je sudjelovala na seminaru stručnog usavršavanja "Edukacija o Europskoj uniji" u organizaciji Foruma za slobodu odgoja. Ova edukacija informira učitelje o bitnim aspektima Europske unije i predlaže im zanimljive radionice koje mogu provoditi u školi kako bi učenicima približili načine i područja rada Europske unije i kako ona utječe na naše živote.
Europeana kao digitalna platforma Europske komisije za kulturnu baštinu omogućuje građanima pristup europskoj kulturi. Poticaj je učenicima na istraživanje bogate i raznovrsne kulturne baštine Europe kako bi štitili njezinu jedinstvenu vrijednost. MOOC „Europeana in your classroom: building 21st-century competences with digital cultural heritage" u organizaciji European Schoolnet Academy pruža izbor testiranih aktivnosti u nastavi i resursa iz različitih europskih zemalja te osnažuje nastavnike u uvođenju kulturne baštine u nastavu.
U radu su predstavljeni primjeri u nastavi informatike koji kroz projektnu nastavu uz druge nastavne predmete pomažu učenicima kod upoznavanja EU. Kroz međunarodne projekte kao što su Erasmus + i eTwinning projekti, brojne aktivnosti i primjena različitih digitalnih alata podupiru razvoj ključnih kompetencija učenika.

Ključne riječi – Europska unija, informatika, edukacija o EU, Europeana, projekti, kulturna baština, kompetencije učenika

I. UVOD

Republika Hrvatska 2018. godine obilježila je petu godišnjicu članstva u Europskoj uniji. Bliže se novi izbori za Europski parlament 2019. godine. Hrvatska će u prvoj polovici 2020. prvi put predsjedati Vijećem Europske unije, što je važan pokazatelj doprinosa Hrvatske djelovanju i razvoju Europske unije. Grad Rijeka će se 2020. godine predstaviti kao Europska prijestolnica kulture. Koliko o tome znaju učenici? Koliko poznaju Europsku uniju, njezine institucije, djelokrug aktivnosti i prilike koje ona nudi? Većinu informacija otkrivaju putem medija, kroz razgovor s obitelji ili prijateljima.

Prema ispitivanju javnog mnijenja Eurobarometra iz 2014. godine, 44 % građana Europske unije smatra da ima ograničeno razumijevanje načina na koji funkcionira EU [1]. Na posljednjim izborima za Europski parlament glasovalo je samo 42,61 % građana EU-a (slika 1), a samo 27 % pripadnika dobne skupine od 18 do 24 godine, što je najslabiji odaziv glasača od 1979. godine [2].



Slika 1. Odaziv birača na EU izborima [2]

Europski parlament usvojio je u travnju 2016. godine na plenarnoj sjednici u Strasbourgu rezoluciju kojom poziva na poticanje učenja o Europskoj uniji u školama kako bi se smanjio jaz između europskih građana i europskih institucija. Rezolucijom se ističe da bi Europska unija trebala biti vidljivija u nastavnim materijalima i izvannastavnim aktivnostima i u njih bolje integrirana s obzirom na utjecaj koji ima u svakodnevnom životu svojih građana. Sadržaj koji je izričito povezan s EU-om može bitno doprinijeti školskom kurikulumu i osobnom razvoju i rastu učenika. Dimenzija EU-a u obrazovanju treba omogućiti učenicima ne samo da steknu znanje i razviju osjećaj pripadnosti i europskog građanstva, nego i da sudjeluju u kritičkom razmišljanju o EU-u, između ostalog i učenjem o temeljnim vrijednostima EU-a zasnovanima na vladavini prava i ljudskim pravima, o postupcima upravljanja EU-om i donošenja odluka u EU-u te načinu na koji oni utječu na države članice i njihovo vlastito demokratsko sudjelovanje. Poticanje upotrebe igara uloga u okviru Europskog parlamenta mladih učenicima pomaže da shvate europske procese i povećava njihovu svijest o europskim pitanjima [3].

II. EDUKACIJA O EUROPSKOJ UNIJI

Važno je poboljšati znanje i vještine nastavnika i ostalog obrazovnog osoblja o temama povezanim s Europskom unijom. Potrebno je proširiti početne i postojeće profesionalne cjeloživotne mogućnosti razvoja za nastavnike te im osigurati odgovarajuću potporu i sredstva kako bi mogli uključiti europsku dimenziju u svoja predavanja, te realizirali strategije usredotočene na učenike i svoje nastavne metode prilagodili potrebama učenika [3].

Obrazovnim institucijama i nastavnicama potrebna je adekvatna pomoć u skladu s njihovim specifičnim potrebama kroz stalna osposobljavanja o Europskoj uniji. Veći dio nastavnika koji trenutačno rade u hrvatskom obrazovnom sustavu educiran je u razdoblju kada Republika Hrvatska nije bila članica Europske unije. Često nisu adekvatno pripremljeni za pružanje obimne i dubinske edukacije o Europskoj uniji [4]. Stoga je nastavnicima potrebna dodatna edukacija.

Pokušavajući nadoknaditi manjkavosti u poučavanju o Europskoj uniji, Forum za slobodu odgoja već više od deset godina provodi program „Edukacija o Europskoj uniji“ u sklopu kojeg je razvijen seminar stručnog usavršavanja. Tijekom listopada i studenog 2018. godine za djelatnice i djelatnike osnovnih i srednjih škola Vukovarsko-srijemske, Osječko-baranjske, Požeško-slavonske i Brodsko-posavske županije organizirano je sudjelovanje u seminaru stručnog usavršavanja. Ova edukacija informira učitelje o bitnim aspektima Europske unije, oprema ih znanjem i predlaže im zanimljive radionice koje mogu provoditi u školi kako bi učenicima približili načine i područja rada Europske unije i kako ona utječe na naše živote.

Edukacija se snažno naslanja na temeljne pojmove građanskog odgoja i obrazovanja, potiče na istraživanje i analiziranje, zahtijeva kritičko promišljanje i zauzimanje stava o određenim pitanjima. Poseban naglasak edukacije je na obrazovnim politikama Europske unije te načinima kako učitelji i škole mogu sudjelovati i koristiti različite prilike koje se provode unutar tih politika. Projekt „Edukacija o Europskoj uniji“ financiralo je Ministarstvo vanjskih i europskih poslova.

Polaznici su nakon seminara dostavili svoj primjer obrade teme Europske unije u učionici. Pripreme su prilagođene i objedinjene u publikaciju „Kako s učenicima razgovarati o Europskoj uniji“ (slika 2). Ova zbirka nastavnih priprema sadrži 29 primjera aktivnosti kako se s učenicima osnovne i srednje škole može razgovarati o Europskoj uniji.

Zahvaljujući kreativnosti i stručnosti polaznika, pripreme pokazuju da je u planu i programu moguće napraviti poveznicu s temom Europske unije te je predstaviti učenicima na zanimljiv i interaktivan način. Isto tako, polaznice i polaznici pokazali su da nema predmeta ili dobne skupine s kojom se tema Europske unije ne može povezati i raditi. Kao što Europska unija utječe na različita područja naših života, tako se može povezati i s gotovo svim područjima obrazovanja.



Slika 2. Publikacija “Kako s učenicima razgovarati o Europskoj uniji [5]

Vodeći se stručnim smjernicama, potrebno je uključivati u rad s učenicima brojne sadržaje koji pokazuju kako je Europska unija iznimno složena u svojim procedurama i dokumentima, omogućiti im da istražuju i analiziraju, da argumentirano raspravljaju, da imaju stav o određenim pitanjima i da su ga spremni poduprijeti dokazima.

Prijedlozi nastavnih aktivnosti sadržani u ovoj publikaciji napravljeni su u dobroj namjeri te ponuđeni učiteljima i stručnim suradnicima kao poticaj. Učitelji i stručni suradnici svaku predloženu nastavnu aktivnost mogu prilagoditi uzrastu i pojedinom razrednom odjelu poštujući stručne, pedagoške, metodičke i didaktičke standarde [5].

III. EUROPEANA

Europeana je digitalna platforma Europske komisije za kulturnu baštinu koja građanima omogućuje pristup do preko 50 milijuna digitaliziranih objekata – knjiga, notnih zapisa, umjetničkih djela, video i zvučnih zapisa iz cijele Europe. Primjenjuju se napredni alati za pretraživanje i filtriranje koji omogućavaju da pronađete upravo ono što tražite [6].

Specijalizirane tematske zbirke o umjetnosti, modi, glazbi, fotografiji i prvom svjetskom ratu sadržavaju galerije, blogove i izložbe za informiranje i inspiriranje. Iako se obrazovni programi i nacionalni prioriteti razlikuju, u srži obrazovnih sustava je nastojanje i želja kreirati najzanimljiviji i inspirativniji sadržaj koji je dostupan učenicima. Zbirke pružaju višestruke poglede na povijesne, političke, ekonomske i kulturne događaje diljem Europe i šire.

Mogućnosti korištenja otvorene kulturne baštine u novim aplikacijama, proizvodima i uslugama gotovo su neograničene. Europeana pruža niz aplikacija i alata otvorenog softvera koji koriste materijal kulturne baštine čime nastavnici mogu obogatiti svoje obrazovne resurse i potaknuti učenike s upoznavanjem digitalne kulturne baštine.

Među strateškim dokumentima nalaze se scenariji učenja sa sadržajem Europeane. Ove scenarije izradila je odabrana skupina nastavnika, kao dio projekta kojeg je naručilo francusko Ministarstvo obrazovanja tijekom razdoblja Europeana DSI3 s ciljem uvođenja francuske kulture u obrazovanje. Scenariji su testirani sa srednjoškolcima i pokrivaju nekoliko disciplina, od povijesti, vizualnih umjetnosti, engleskog i francuskog jezika, tehnologije te još mnogo toga. Pedagoški materijal spreman za uporabu, pomoći će nastavnicima da integriraju Europeana resurse i sadržaj u aktivnosti učenika na nastavi [7].

Učenici pri korištenju Europeane stječu:

- vještine medijske pismenosti (uključujući korištenje vizualnih i multimedijskih alata za izradu slika, audio, video, foto galerija)
- znanje o autorskim pravima i kako koristiti digitalnu kulturnu baštinu u kreativnom projektu
- vještine suradnje
- vještine poduzetništva
- osjećaj vlasništva, odgovornosti i brige nad svojom digitalnom kulturnom baštinom.

Zajednica obrazovanja Europeane okuplja sve koji vjeruju da europska digitalna kulturna baština ima važnu ulogu u obrazovanju i žele raditi na uključenju Europeane u formalno i neformalno obrazovanje za poticanje inovacija. Zajednica je otvorena svim profesionalcima koji se bave kulturnom baštinom i učenjem u kulturnim i/ili obrazovnim institucijama, školama, nevladinim organizacijama, ministarstvima i lokalnim vlastima te privatnom sektoru.

U svrhu što većeg upoznavanja i primjene platforme Europeana, prvi Europeana MOOC „Europeana in your classroom: Building 21st century competences with digital cultural heritage“, održan je u organizaciji European Schoolnet Academy od 30. travnja do 15. lipnja 2018. godine (slika 3). Tečaj je upoznao sudionike s Europeana platformom kako bi im pomogao izgraditi scenarije učenja koristeći digitalnu kulturu i poticati vještine 21. stoljeća. Sudjelovalo je više od 2.000 polaznika iz 59 zemalja.

Edukacija traje 6.5 tjedana: jedan modul tjedno uz 1.5 dodatni tjedan na kraju MOOC-a. Sveukupno oko 25 sati usavršavanja kroz pet modula:

- Modul 1: Europeana: transformiranje obrazovanja s digitalnom kulturom
- Modul 2: Pretražite i koristite Europeana zbirke za podučavanje vašeg predmeta
- Modul 3: Istražite Europeana obrazovne alate i resurse
- Modul 4: Dizajnirajte scenarije učenja sa sadržajem i resursima Europeane
- Modul 5: Procijenite lekcije kulturne baštine prema vještinama 21. stoljeća [8].



Slika 3. MOOC „Europeana in your classroom: Building 21st century competences with digital cultural heritage“ , izvor: https://pro.europeana.eu

Sadržaji modula popraćeni su s videozapisima u razredu, intervjuima nastavnika ili učenika. Istražujući različite scenarije učenja polaznici će otkriti zanimljive alate i inovativne pristupe koji će pomoći u razvoju vještina 21. stoljeća te učenje učiniti zabavnijim i zanimljivijim za učenike. Osim toga, nastavnici će naučiti kako raditi u međupredmetnom projektu uz uporabu sadržaja Europeane [8].

Na kraju tečaja polaznici moraju, kako bi završili tečaj i dobili certifikat, izraditi i podijeliti s ostalim polaznicima završni i cjeloviti plan scenarija učenja koji sadrži: opis s glavnim idejama aktivnosti, IKT alate i resurse, relevantne trendove u poučavanju (npr. učenje putem društvenih medija, mobilno učenje, učenje temeljeno na igrama), ciljeve učenja, vještine i kompetencije (koje će učenici razviti i demonstrirati tijekom aktivnosti), ulogu učenika, ulogu nastavnika, prostor za učenje (gdje će se odvijati učenje, npr. školska učionica, lokalna knjižnica, muzej, na otvorenom, u online prostoru).

Polaznici također imaju mogućnost istražiti različite oblike procjene scenarija učenja koji koriste kulturnu baštinu, kao što su recenzije ili vršnjačke (peer-to-peer) aktivnosti, rubrike i druge vrste formativnih procjena koje nastavnici mogu integrirati u svoju svakodnevnu praksu. U sklopu online tečaja, kako bi polaznici proslavili Europsku godinu kulturne baštine (2018.), predložena je volonterska aktivnost u kojoj su polaznici predali svoje digitalne slike važnog spomenika u gradu ili širem području. Od svih fotografija kreiran je zanimljiv foto mozaik (slika 4). Ova aktivnost je zgodna za primjenu u školi s učenicima.



Slika 4. Mozaik izrađen u MOOC-u „Europeana in your classroom: Building 21st century competences with digital cultural heritage“ [9]

IV. EU U NASTAVI INFORMATIKE

Četiri su domene kojima se realiziraju ciljevi predmeta informatike prema novom kurikulumu: e-Društvo, Digitalna pismenost i komunikacija, Računalno razmišljanje i programiranje te Informacije i digitalna tehnologija [10]. Brojne su aktivnosti koje učenici mogu izvoditi na nastavi informatike vezano za upoznavanje Europske unije. Svaka aktivnost može se primijeniti u razradi barem jednog odgojno-obrazovnog ishoda pojedinih domena kurikuluma u osnovnoj i srednjoj školi.

Aktivnosti su vezane za očekivanja pojedinih međupredmetnih tema kao što su: Uporaba informacijske i komunikacijske tehnologije, Osobni i socijalni razvoj, Učiti kako učiti, Građanski odgoj i obrazovanje i Poduzetništvo. Ostvaruje se i povezanost s nastavnim predmetima: hrvatski jezik, engleski jezik, povijest, geografija, likovna kultura, sat razrednika.

Sijedi popis mogućih aktivnosti/tema:

1. Pretraživanje na internetu o zemljama članicama EU
2. Povijest Europske unije (Učenici će izraditi vremensku traku razvoja EU. Istražiti će povijesne događaje koji su vodili do stvaranja Europske unije, kao i priključenju pojedinih zemalja EU koristeći enciklopedije, internet i druge dostupne resurse. Identificirati će važne događaje i organizirati te događaje u kronološkom redoslijedu kako bi kreirali će vremensku traku. Kod izrade vremenske trake učenici moraju odrediti vrijeme za koje će izraditi vremensku traku, datume početka i završetka, unijeti najznačajnije datume i zatim priložiti podatke - tekstove, slike, videozapise, itd., koji su se odvijali na ovim specifičnim datumima).
3. Himna EU (Učenici će potražiti himnu EU, prepoznati himnu EU, na mrežnom servisu YouTube mogu naći i izvedbe u drugim, suvremenijim stilovima. Učenici će otpjevati/odsvirati himnu, snimiti pjevanje ili sviranje himne EU).
4. Zastava EU i zastave zemalja članica EU (Učenici će pomoću interneta pronaći slike zastave EU. Otkriti će popis zemlja članica Europske unije te njihove zastave. Izraditi će digitalni plakat.)
5. Izrada infografikona (Učenici odabiru nekoliko zemalja EU. Istražuju o odabranim zemljama EU, npr. Poljska, Portugal, Austrija, Estonija, Finska. Pretražuju podatke o većim gradovima ovih zemalja)
6. Znamenitosti u EU i Europske prijestolnice kulture
7. Istražiti nacionalnu hranu/jela pojedinih zemalja EU
8. Istražiti više o različitim igrama koje igraju djeca diljem Europe (Učenici mogu odigrati neke tradicionalne igre iz cijele Europe, važno je upoznati pravila prije nego počnu igrati. Izrađuju zajedničku prezentaciju ili plakat o igrama) [11]
9. Veliki sportski stadioni Europe (Učenici izrađuju prezentaciju o sportskim stadionima u različitim zemalja Europe. Podaci: zemlja, grad, naziv stadiona, kapacitet, sport, zanimljivi podaci, fotografije. Izrada plakata/prezentacija.)
10. Izrada grafikona (Učenici prikupljaju i unose podatke kojima se analizira odnos među zemljama EU).
11. Poznate osobe Europske unije (Učenici istražuju podatke poznatih osoba iz svake države članice EU, izrada kviza).
12. Kulturna baština zemalja EU
13. Primjeri kulturne baštine Republike Hrvatske
14. Glagoljica (glagoljski fontovi, izrada igara s glagoljicom, glagoljičke znamenitosti i spomenici).
15. Službeni jezici Europske unije i Europski dan jezika (Učenici izrađuju plakat, prezentaciju, prilikom izrade plakata služe se s izvorima na internetu).
16. Putovanje u EU – izrada brošure o putovanju (Učenici planiraju putovanje u zemlju EU po vlastitom izboru. Trebaju istražiti kako doći tamo, što će vidjeti, kako organizirati prijevoz, itd. Uporabom svojih istraživanja, učenici bi trebali stvoriti virtualan budžet putovanja. Učenici će saznati sve o mjestima gdje putuju, opisati odredišno mjesto, zabavne stvari koje tamo mogu vidjeti i činiti, kao i razloge zašto su ga odabrali za odredište putovanja. U brošuri su okviri za crtanje ili kopiranje slika mjesta za odmor).
17. Izrada karte putovanja (Karta će biti kreirana pomoću Google karata - Google My Maps uz dodavanje praktičnih informacija koje će učenici pronaći na internetu).
18. Poziv turistima (Nakon učenja o Europskoj uniji, učenici će izraditi kratki jingle (spot) koji će privući turiste iz svih krajeva svijeta da posjete odabranu zemlju EU. Spot bi trebao trajati do 60 sekundi. Učenici će uključiti dva-tri razloga zašto bi ljudi htjeli posjetiti odabranu zemlju.)

19. Moodle tečaj o Europskoj uniji (Učenici uz pomoć nastavnika izrađuju online Moodle tečaj o Europskoj uniji. Koriste sve materijale, digitalne sadržaje koje su izradili u prethodnim zadacima. Učenici tečaju dodaju forum i kviz/test za polaznike tečaja. Tečaj mogu koristiti svi učenici škole, kao i svi ostali zainteresirani učenici).
20. Izbori za Europski parlament (Učenici će istražiti podatke o prijašnjim izborima za Europski parlament, koje su ovlasti i tko čini Europski parlament, prikazati raspodjelu zastupničkih mjesta prema državama, koje europske stranke postoje, tko su hrvatski zastupnici u Europskom parlamentu - izrada grafikona, plakata, brošura).
21. Priča o euru (Učenici će prezentacijom prikazati osnovne činjenice o euru, kratku povijest eura, razloge za njegovo uvođenje i prednosti koje nudi).

Kroz zadatke i aktivnosti učenici će upoznati značenje EU, narode i običaje te osnovne karakteristike država članica EU. Učenicima će u istraživanju pomoći sadržaji službene web stranice Europske unije: europa.eu, poseban dio posvećen djeci i mladima „Dječji kutak“ (slika 5) pri čemu biraju materijale i prikaz na hrvatskom jeziku [12]. Dodatno će pomoći materijali koji se nalaze u „Kutku za nastavnike“ [13].

Učenici mogu koristiti različite digitalne alate i interaktivne sadržaje za izradu svojih zadataka. Veliki izbor nudi im CARNet e-Laboratorij [14]. Pojedine igre i kvizove o EU učenici mogu programirati.

Kuća europske povijesti u Bruxellesu prostor je za učenje, promišljanje i raspravu. Namijenjen je svima, neovisno o dobi i porijeklu. Njihova misija je povećati razumijevanje europske povijesti u svoj njezinoj složenosti, poticati razmjenu ideja i preispitivati pretpostavke. Internetska stranica Kuće europske povijesti omogućuje pristup nastavnim materijalima za razredne aktivnosti.

Sadržaji su vezani za migracije, identitet, ljudska prava, te informacijsko-komunikacijsku tehnologiju [15].



Slika 5. Detektivska igra potrage za kulturnom baštinom [12]

V. RAZVOJ KOMPETENCIJA UČENIKA I NASTAVNIKA KROZ EUROPSKE PROJEKTE

Ključne kompetencije su one koje svi pojedinci trebaju za osobno ispunjenje i razvoj, zapošljivost, socijalnu uključenost i aktivno građanstvo. Razvijaju se u okviru cjeloživotnog učenja, od ranog djetinjstva do odrasle dobi, te kroz formalno, neformalno i informalno učenje.

Razlikujemo osam ključnih kompetencija: kompetencija pismenosti, jezična kompetencija, matematička kompetencija te kompetencija u prirodnim znanostima, tehnologiji i inženjerstvu, digitalna kompetencija, osobna i socijalna kompetencija te kompetencija učenja, građanska kompetencija, kompetencija poduzetnosti, kompetencija kulturne svijesti i izražavanja [16].

Programi Erasmus+, Europa za građane i Kreativna Europa imaju veliku ulogu u promicanju obrazovanja i osposobljavanja, jezičnih vještina, aktivnog građanstva, kulturne osviještenosti, međukulturnog razumijevanja i ostalih vrijednih vještina i transverzalnih sposobnosti. Važan je širi pristup mobilnosti uz poseban naglasak na nastavnike i ostale pedagoške djelatnike, mlade različitog socijalno-ekonomskog podrijetla te skupine u teškom ili nepovoljnom položaju kao i osobe s posebnim potrebama.

Digitalne tehnologije pružaju mogućnost razvoja prekograničnog učenja kroz digitalne tečajeve i video-konferencije, čime se učenicima olakšava otkrivanje drugačijih pogleda i pristupa njihovim disciplinama.

Motiviranost nastavnika i učenika da nauče više o Europskoj uniji ojačati će kroz njihova vlastita iskustva iz prve ruke, primjerice posjetima škola drugim zemljama, posjetima europskim institucijama, kontaktima sa službenicima EU-a, obrazovanjem kroz medije kao što je Europski portal za mlade, uz iskorištavanje svih mogućnosti koje pružaju nove informacijske i komunikacijske tehnologije i otvorena sredstva obrazovanja [17].

Učenje stranih jezika može imati ključnu ulogu u jačanju interkulturne osviještenosti i u tome da se građanima osiguraju vještine za život i rad u sve složenijem i globaliziranijem svijetu. Stoga je potrebno promicanje i poticanje višejezičnih i interkulturnih kompetencija nastavnika te mogućnosti za mobilnost, uzajamno podučavanje i razmjenu najbolje prakse među nastavnim osobljem, što pružaju organizacije seminara na europskoj razini.

Erasmus+ najveći je program Europske unije za obrazovanje, osposobljavanje, mlade i sport. Provodi se od 2014. do 2020. godine. Organizacijama i pojedincima omogućuje sudjelovanje u međunarodnoj suradnji. Erasmus+ usmjeren je jačanju znanja i vještina te zapošljivosti europskih građana, kao i unaprjeđivanju obrazovanja, osposobljavanja te rada na području mladih i sporta. Program uspješno povezuje europske građane potičući mobilnost, učenje jezika, studiranje ili stručno osposobljavanje u inozemstvu, kao i upoznavanje novih kultura te razmjenu akademskih i stručnih znanja.

Sve veći broj škola uključuje se u Erasmus+ projekte mobilnosti, kao i eTwinning projekte. Nastavnici su proveli brojne projekte koji su učenicima pružili priliku da upoznaju kulturne karakteristike svojih vršnjaka, istraže europsku baštinu, otkriju sličnosti i razlike i konačno stvore zajedničke resurse. Informatika je među nastavnim predmetima koji su uključeni u ove projekte a aktivnosti omogućuju razvoj kompetencija učenika i nastavnika.

VI. ZAKLJUČAK

Članstvo Republike Hrvatske u Europskoj uniji izravno utječe na svakodnevni život građana u raznim područjima, kao što su gospodarstvo, poljoprivreda, promet, zaštita okoliša, zaštita potrošača, obrazovanje, mogućnost putovanja i rada, te omogućuje Hrvatskoj da u tim okvirima štiti i promiče vlastite ciljeve i interese.

Škole su jedine obrazovne ustanove koje dopiru do svih europskih građana. Podučavanje o EU u školi je stoga korak prema pružanju znanja građanima potrebnim da se njihov glas čuje u njihovim vlastitim zemljama i u EU-u. Podučavanje o EU u školi omogućuje aktivno sudjelovanje građana što je ključni element svake funkcionalne demokracije.

Ako želimo informiranu i kritičku raspravu o Europi, onda je od ključnog značaja obrazovanje, obrazovanje demokracije, kulturna svijest i znanje o EU.

Podučavanje o EU-u trebalo bi navesti učenike na razvijanje razumijevanja EU-a koje nadilazi poznavanje osnovnih činjenica. Trebaju imati alate koji im omogućuju da se uključe u kritičko promišljanje o europskim pitanjima i kako oni utječu na njihovu zemlju i vlastite aktivnosti. Učinkovito učenje o EU-u zahtijeva sadržajne i djelotvorne metode kako bi se razvile kompetencije aktivnog europskog građanina. Nastavnici trebaju uključiti primjere kako je EU relevantna za svakodnevni život učenika kao polaznu točku za uvođenje tema EU-a u njihovu učionicu.

Nastavnicima u pripremi sadržaja za nastavu pomažu seminari i publikacije Foruma za slobodu odgoja, kao i mrežne stranice Europske unije posvećene ovoj edukaciji. Sadržaji se mogu uključiti u nastavu informatike kod razrade brojnih odgojno-obrazovnih ishoda kurikuluma informatike.

Dodatnu ulogu u upoznavanju EU kroz nastavu informatike imaju aktivnosti u međunarodnim projektima. Pri tome učenici izražavaju svoja mišljenja, postavljaju pitanja, podsjećaju na ono što već znaju i formiraju asocijacije s drugim trenutnim znanjem. Surađuju sa svojim vršnjacima, shvaćaju da mogu sačuvati vlastitu kulturu, ali i poštivati kulturu svojih partnera. To je zapravo kreativan način upotrebe prošlosti, s ciljem promjene budućnosti.

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Projekt Coding4Girls

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Sažetak **- Coding4Girls je projekt sufinanciran Erasmus+ programom u okviru Ključne aktivnosti 2, Strateška partnerstva za područje općeg obrazovanja. Koordinator projekta je Sveučilište u Ljubljani (Slovenija), a partneri su iz Portugala, Grčke, Turske, Italije, Bugarske i Hrvatske koju predstavlja Odjel za informatiku Sveučilišta u Rijeci.**

Krajnji cilj projekta je poticanje žena na uključivanje u obrazovanje za računalne znanosti. To je jedno od područja u kojem tradicionalno prevladavaju muškarci pa će se primjenom odgovarajućih metodoloških pristupa učenju nastojati prevladati postojeća neravnopravnost i učiniti računalne znanosti atraktivnim za sve. Coding4Girls za ciljnu skupinu ima učenike starijih razreda osnovne i mlađih razreda srednje škole (uzrast od 10 do 15 godina) jer je uočeno da upravo tada mnoge učenice gube interes za STEM i računalne znanosti. Glavni rezultat projekta bit će metodološki okvir za učenje prikladan za razvoj vještina programiranja, posebice kod djevojaka, temeljen na pedagoškom pristupu *design-thinking* i učenju uz pomoć obrazovnih igara.

U radu se predstavlja projekt Coding4Girls te se opisuje njegov kontekst i razlozi za pokretanje, intelektualni rezultati koji će nastati u okviru projekta, najvažnije aktivnosti projekta te njegov očekivani učinak.

Ključne riječi - projekt Coding4Girls; programiranje; učenje uz pomoć igara; pedagoški pristup design-thinking

I. UVOD

Projekt Coding4Girls sufinanciran je Erasmus+ programom u okviru Ključne aktivnosti 2, Strateška partnerstva za područje općeg obrazovanja i kao cilj ima potaknuti uključivanje djevojaka u obrazovanje u području računalnih znanosti te informacijsko-komunikacijskih tehnologija (IKT). Radi se o područjima u kojima tradicionalno prevladavaju muškarci, kako u Europskoj uniji (EU) tako i šire. Međutim, osim djevojaka, u aktivnostima projekta Coding4Girls će aktivno sudjelovati i dječaci jer je jedna od ideja projekta promicanje jednakosti spolova.

Primjenom odgovarajućih metodoloških pristupa učenju koji će se većinom temeljiti na učenju uz pomoć igara (eng. *Game Based Learning* – GBL) [1] i na pedagoškom pristupu učenja zasnovanog na dizajnu (eng. *design-thinking*) [2] nastojat će se upoznati učenice i učenike starijih razreda osnovne i mlađih razreda srednje škole (uzrast od 10 do 15 godina) s osnovama programiranja na zabavan način te ih tako potaknuti na kasnije upisivanje studija iz područja računarstva i IKT-a, ali i ostalih STEM područja.

Projekt je započeo 1. rujna 2018. godine i traje dvije godine, do 31. kolovoza 2020. godine. Koordinator projekta je Sveučilište u Ljubljani (Slovenija), a partneri su: Virtual Campus (Portugal), Sveučilište u Tesaliji (Grčka), Sveučilište u Rijeci, Odjel za informatiku (Hrvatska), EU-Track (Italija), Istanbul Valiligi (Turska) i Jugozapadno sveučilište „Neofit Rilski“ (Bugarska). Članovi projektnog tima su stručnjaci iz područja programiranja i metodike programiranja, e-učenja, učenja uz pomoć obrazovnih igara te razvoja računalnih igara. Konzorcij je okupljen kako bi se osigurala multidisciplinarnost osmišljenog pristupa u projektu te rezultati u skladu s potrebama ciljnih skupina. Mnogi članovi projektnog tima koordinatora i partnera su žene kako bi svojim primjerom pokazale prednosti karijere u računalnoj znanosti i području IKT.

Ciljevi projekta Coding4Girls će se provoditi kroz intervencije koje se odnose na čimbenike koji dovode do toga da djevojke ne biraju računalnu znanost i područje IKT za svoja buduća zanimanja. Nastojat će se prevladati pogrešne predodžbe o obrazovanju i karijeri u tim područjima pokazujući kako su ona povezana sa svakodnevnim životom i konkretnim problemima u društvu kroz konkretna rješenja usmjerena na ljude i poboljšavanje kvalitete života.

Nadalje, Coding4Girls će podići svijest o širokim mogućnostima za profesionalni i osobni razvoji koji nude računalne znanosti i područje IKT-a te pripremati djevojke (i dječake) za buduće sudjelovanje u ovim područjima putem upisa u odgovarajuće srednje škole te kasnije i na fakultete. Prepoznajući važnost koju nastavnici i socijalno okruženje mogu imati na budući akademski i profesionalni izbor učenika, projekt će nastojati utjecati i na izgradnju pozitivnih percepcija i stavova u vezi sudjelovanja djevojaka u računalnim znanostima i području IKT-a i kod njihovih nastavnika i roditelja.

Rad je organiziran na sljedeći način: u drugom poglavlju opisuje se kontekst pokretanja i izvođenja projekta, u trećem poglavlju je navedena važnost projekta za rješavanje prepoznatih problema, a u četvrtom poglavlju očekivani intelektualni rezultati. Peto poglavlje donosi zaključke rada.

II. KONTEKST

Prema Nacionalnom centru za statistiku obrazovanja u SAD-u [3], žene čine samo 18% sveučilišnih diplomanata u računalnim znanostima. Uz to, ne samo da u proteklih 30-ak godina nije bilo napretka u postizanju većeg sudjelovanja žena u računalnim znanostima, već je došlo i do pada. Uočava se i trend da se broj muških sudionika povećava mnogo brže nego broj žena. U Europi je situacija još nepovoljnija. Tako je Europska komisija izvijestila: “Od 1.000 žena s preddiplomskim obrazovanjem, samo 29 ima diplomu iz područja

informacijskih i komunikacijskih tehnologija (u usporedbi s 95 muškaraca), a samo 4 od 1000 žena će naposljetku raditi u području IKT-a" [4]. Razlika između sudjelovanja muškaraca i žena se nastavlja i na profesionalnoj razini: 80% zaposlenika najvišeg ranga u Silicijskoj dolini su muškarci i samo 10% tehničkih pozicija u istim tvrtkama zauzimaju žene. Isto izvješće pokazuje da su u Europi samo 30% od oko 7 milijuna ljudi koji rade u području IKT-a žene i da su nedovoljno zastupljene na svim razinama, posebice na pozicijama odlučivanja. Ove statistike su posebice iznenađujuće ukoliko se uzme u obzir i povećana potražnja za diplomantima informatike koji su potrebni za poticanje brzo rastućih industrija softverskih usluga koje dizajniraju i isporučuju rješenja za široki spektar potreba današnjeg i budućeg tehnološkog društva. Prema Inicijativi za nove vještine za nova radna mjesta [5], očekuje se da će potražnja za kvalificiranim kadrovima u područjima vezanim uz inovacije u EU rasti tijekom sljedećih godina. Ista inicijativa ističe da u Europi nedostaje kadrova s digitalnim vještinama koji u današnjem društvu postaju neophodni.

Nedostatak zaposlenika s digitalnim kompetencijama i istovremeno visoka nezaposlenost mladih pokazuje jaz između vještina stečenih formalnim obrazovanjem i onih zaista potrebnih industriji. Prema [6], „zbog razlika u zahtjevima i vještinama, i unatoč rastućoj nezaposlenosti, može se dogoditi da će u 2020. godini nedostati 900 000 kvalificiranih IKT radnika". Taj jaz nije specifičan za određenu zemlju. Na europskoj je razini uočeno kako su potrebne intervencije usmjerene na jačanje održivog gospodarskog rasta kroz razvoj ljudskog kapitala, jačanje europske konkurentnosti, smanjenje nezaposlenosti i promicanje socijalne kohezije. Prema navedenom, postoji velika potreba za daljnjim razvojem vještina djevojčica i dječaka za učinkovito uključivanje u karijere iz područja računalnih znanosti i IKT-a.

Razlozi zbog kojih računalna znanost, IKT i općenito obrazovanje u području STEM-a ne privlače više djevojčica su povezani s pogrešnom percepcijom među odgojiteljima, učenicima, roditeljima i mladima o prikladnosti karijera računalnih znanosti za djevojke i pogrešnoj pretpostavci o njihovoj nedovoljnoj spremnosti da to učine uspješno. Upravo zbog toga će projekt Coding4Girls pridonijeti boljem razumijevanju opisanog problema te osmišljavanju i primjeni mogućih intervencija u obrazovanju kako bi se on riješio na europskoj razini.

III. ZNAČAJ PROJEKTA

Codig4Girls uvodi inovacije u nekoliko različitih aspekata: u pedagoški pristup, u područje korištenja tehnologije i na razini intervencija u učenju. Projekt se bavi stvarnim i trenutnim potrebama u školskom obrazovanju na europskoj razini: potrebom poticanja talentiranih djevojaka na odabir karijera iz područja računalnih znanosti i IKT-a te potrebom za rješavanjem jaza u sudjelovanju djevojaka u obrazovanju na području računalnih znanosti i IKT-a, promovirajući jednake mogućnosti u obrazovanju i zapošljavanju djevojčica i dječaka.

U pogledu pedagoškog pristupa, projekt će uvesti način učenja zasnovan na dizajnu (*design thinking*) u kontekstu računalnih znanosti i IKT-a. Ta je metodologija odabrana jer je razmišljanje o dizajnu u velikoj mjeri povezano s rješenjima usmjerenim na čovjeka i izgradnjom usluga, proizvoda i alata koji na inovativan način rješavaju probleme iz stvarnoga svijeta. Ona izaziva učenike da vide širu sliku i razmotre šire interese zajednice u oblikovanju rješenja problema. Dodatno, potiče učenike da poduzetnički razmišljaju o tome kako računalna znanost i IKT mogu riješiti probleme iz stvarnog svijeta [2].

Na razini učenja uz pomoć tehnologije, Coding4Girls će validirati predloženi pedagoški pristup *design thinking* kroz razvoj i implementaciju didaktičkih igara [7], [8]. Učenici će se poticati da osmisle i razviju rješenja temeljena na igrama koja se odnose na probleme iz stvarnog svijeta. Uvest će se pristup koji omogućuje učenicima da započnu s rješavanjem lakših problema, postepeno im uvodeći one teže kako bi se potaknulo kontinuirano sudjelovanje i zadržavanja interesa (eng. *low entry high ceiling approach*) [9]. Učenicima će se prezentirati polugotovi scenariji koje će oni dovršavati implementacijom manjih modula tako da sve zajedno čini smislenu cjelinu.

Na razini intervencije učenja Coding4Girls će promicati aktivno učenje kroz učenje temeljeno na igri (GBL) za koje se smatra da značajno doprinosi mogućnosti naknadne primjene naučenog. Projektom će se povezati specifični ciljevi učenja sa scenarijima koji su inspirirani situacijama iz stvarnog svijeta i promicati kritičko mišljenje, koje je sastavni dio programiranja [10], [11]. Poticat će se i razvoj kompetencija vezanih uz poduzetništvo koje su povezane s pristupom *design thinking* jer će se tražiti od učenika da osmisle rješenja koja zadovoljavaju potrebe zajednice. Također, promicat će se dugoročno uključivanje u područja računalnih znanosti i IKT-a ukazujući na njihovu važnost u rješavanju problema od šireg društvenog interesa.

Logo projekta prikazan je na Slici 1.

IV. INTELEKTUALNI REZULTATI I AKTIVNOSTI

U okviru projekta Coding4Girls su planirana tri intelektualna rezultata: O1 – Metodološki okvir za učenje, O2 –Promicanje razvoja vještina programiranja među djevojčicama kroz obrazovne igre i O3 – Obrazovni sadržaji za nastavnike.



Slika 1. Logo projekta Coding4Girls

A. *O1– Metodološki okvir za učenje*

Cilj je razviti okvir metodologije učenja temeljen na pristupu *design thinking* za razvijanje vještina programiranja kod djevojčica (i dječaka) u osnovnoškolskom i srednjoškolskom obrazovanju. Pri izradi okvira će se uzeti u obzir trenutno stanje u školama i pomoći pri preuzimanju inicijative za razvoj vještina programiranja povezujući ih s potrebama industrije. Predloženi okvir potaknut će učenike da se usredotoče na rješenja usmjerena korisnicima uzimjaući u obzir širu sliku potreba zajednice te pokazujući vezu između IKT-a i stvarnog života. Rad će biti organiziran u dva smjera. Započet će se s definiranjem potrebnih kompetencija, a na temelju toga s osmišljavanjem pouzdane metodologije za razvoj vještina programiranja među djevojčicama i dječacima, poticanje načina razmišljanja u čijem se središtu nalazi korisnik i za promicanje inovativnog razmišljanja. Okvir će uključivati popis dionika koji bi mogli imati korist od inovativnih pedagoških intervencija za promicanje razvoja vještina programiranja u skladu s potrebama zajednice i stvarnog svijeta.

U zemljama partnerskih institucija će se napraviti analiza trenutne prakse u nastavi i primjeni obrazovnih igara. Dokumentirat će se ciljevi učenja, očekivani ishodi učenja i metode za procjenu dodatne obrazovne vrijednosti uvođenja predložene metodologije obrazovnih igara za razvoj digitalnih vještina. Analizirat će se postojeće vještine nastavnika i dati smjernice za njihovo unapređivanje kako bi se olakšala primjena IKT-a u nastavi.

Metodologije za poticanje razvoja vještina programiranja će se definirati na način da pripremaju učenike za buduću ulogu profesionalaca. Učenike će se izložiti industrijskim pristupima koji su dobro prihvaćeni za projektiranje i implementaciju proizvoda koji učinkovito zadovoljavaju potrebe krajnjih korisnika. Predloženim okvirom će se prilagoditi pristup *design thinking,* koji je sam po sebi usmjeren na korisnika, praksama učenja u području IKT-a. *Design thinking* je prikladan za IKT budući je u skladu s praksom programskog inženjerstva koje od korisnika zahtjeva da rješavanje problema započne s odgovorom na potrebe prakse prije dizajniranja (projektiranja) detalja učinkovitog rješenja. Pristup temeljen na igrama upotpunit će pristup *design thinking* potičući učenike na igranje uloga, simulirajući zadatke kojima će učenici u budućnosti biti izloženi kao programski inženjeri.

Materijali s predloženim metodološkim okvirom za učenje programiranja bit će objavljeni i dostupni na engleskom jeziku.

B. *O2 – Promicanje razvoja vještina programiranja među djevojčicama kroz obrazovne igre*

U aktivnostima s ciljem ostvarivanja ovog intelektulanog rezultata fokus će biti na dizajnu i izradi obrazovne igre za poticanje razvoja vještina programiranja među djevojčicama (i dječacima) u osnovnim i srednjim školama. Za razliku od igara dizajniranih za zabavu, obrazovne igre su prilagođene specifičnim potrebama obrazovnog konteksta i dizajnirane tako da potpomognu ostvarivanje odgojno-obrazovnih ishoda.

Cilj korištenja obrazovne igre u projektu Coding4Girls je razvoj vještina programiranja te potacanje učenika na primjenu stečenih vještina programiranja u stvarnom svijetu te priprema učenike za odabir karijera u područjima računalne znanosti i IKT-a. Učenike će se poticati na razvoj transverzalnih kompetencija vezanih za programiranje kao što su analitičko i kritičko razmišljanje. Nadalje, poticat će se pozitivne stavove prema računalnoj znanosti, podići svijest o povezanosti IKT-a i stvarnog svijeta kroz scenarije učenja koji pokazuju kako rješenja koja koriste IKT mogu poboljšati kvalitetu života. Također, cilj je osposobiti učenike za poduzetničko razmišljanje pri rješavanju problema iz stvarnog svijeta koristeći pristup *design thinking*. Stoga će se ciljeve igre povezati sa školskim kurikulumom i vještinama potrebnim za karijere u računalnim znanostima.

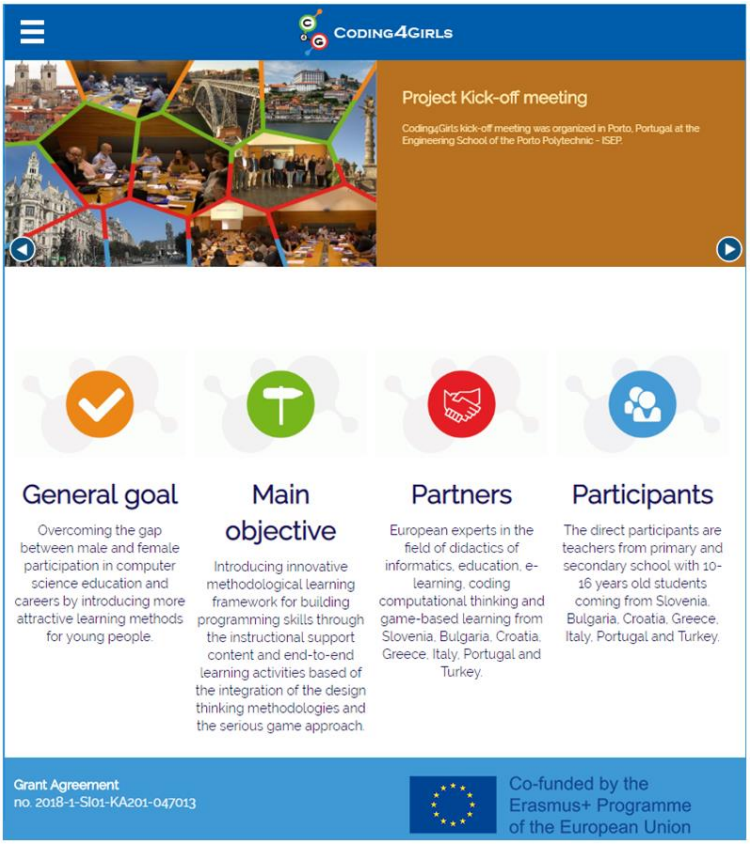
Djevojčice (i dječaci) će učiti programirati stvaranjem vlastitih obrazovnih igara na temelju scenarija koji uključuju probleme iz stvarnog svijeta tako što će im se predstaviti djelomično rješenje, a onda ih izazvati da ga dovrše izradom manjih dijelova. Kroz dizajn igre utvrdit će se elementi igrifikacije prikladni za promicanje uključenosti učenika u proces učenja kao što su nagrade, tablica bodova i dr. Osmislit će se i mehanizmi pružanja povratnih informacija te odlučiti o primjenjivosti različitih razina težina i kako ih integrirati u igru.

Strategija vrednovanja će biti razvijena u ranoj fazi, a provoditi će se tijekom cijelog razdoblja implementacije. Identificirat će specifične pokazatelje uspješnosti u smislu učinkovitosti i kvalitete. Evaluacija će biti formativna (odvijat će se tijekom dizajna proizvoda) i sumativna (na kraju razdoblja implementacije projekta rezultati će se dokumentirati u izvješću koje će biti javno dostupno zainteresiranim stranama). Evaluacija će se odvijati na nekoliko razina. Provest će se unutarnja evaluacija (angažirajući partnere projekta), vanjska evaluacija (provodit će je učenici i nastavnici kroz aktivnosti učenja), a stručno mišljenje o učinkovitosti rezultata projekta i njegovoj kvaliteti će po završetku projekta dati i vanjski ekspert.

C. *O3 – Obrazovni sadržaji za nastavnike*

Izradit će se materijal s uputama za nastavnike i s primjerima dobre prakse o mogućnostima integracije predložene metodologije učenja i alata (intelektualni rezultati O1 i O2) u postojeću nastavnu praksu kako bi unaprijedili poučavanje o programiranju kroz predloženi pristup integracije obrazovnih igara i učenja po principu *design thinking*. Nastojat će se pomoći nastavnicima u stjecanju vještina za uvođenje IKT-a u nastavu, kao i u podizanju samopouzdanja i motivacije u primjeni novih metoda, a posebno obrazovnih igara kao komplementarnog alata za učenje kojim će se omogućiti učinkovitije razvijanje programerskih vještina kod djevojčica.

Materijal dostupan nastavnicima uključivat će scenarije poučavanja koji opisuju na koji način integrirati aktivnosti učenja temeljenog na igri u nastavni proces. Scenariji će uključivati nastavne ciljeve, očekivane ishode učenja, obuhvaćene koncepte, odgovarajuće nastavne aktivnosti i metode procjene usvojenosti ishoda učenja.



Slika 2. Početna stranica mrežnog sjedišta projekta Coding4Girls: www.coding4girls.eu

Postupci integracije obrazovnih igara bit će opisani postupno, korak po korak zajedno s motivacijskim pitanjima za pokretanje rasprave među učenicima i primjerima primjene obrazovnih igara u kontekstu nastavnih aktivnosti. Izradit će se i korisnički priručnik o pristupu za savladavanje vještine programiranja prilagođenom djevojčicama. Priručnik će pružiti pregled mogućnosti odabrane igre kao i opis načina interakcije s igrom, dobivanja povratnih informacija, elemenata igrifikacije (eng. *gamefication*), na primjer dobivanja nagrada i dr.

Dodatno, za lakšu integraciju predloženih pristupa u nastavni proces i povećanje kompetencija nastavnika za njihovu primjenu, bit će razvijeni i video materijali kao vizualna pomoć. Zbirkom multimedijalnih materijala će se prikazati mogućnosti izrađene igre za stjecanje vještina programiranja, opis mehanizama korištenih u dizajnu igre, opis korisničkog sučelja, načina interakcije i elemenata igrifikacije, zadatke, aktivnosti vrednovanja i dr.

Pripremljeni materijali bit će najprije dostupni na engleskom jeziku, a nakon evaluacije će se prilagoditi, prevesti na jezike partnera projekta i diseminirati.

V. OSTALI REZULTATI I AKTIVNOSTI

Važan element projekta su i različite aktivnosti za diseminaciju i popularizaciju rezultata koje će se kontinuirano provoditi u zemljama svih partnera.

Kako bi se olakšao pristup obrazovnim sadržajima i pružila podrška dionicima u školskom obrazovanju izradit će se mrežno sjedište (Slika 2) odnosno Internet portal projekta te objaviti internetske i medijske publikacije (letci, bilteni i sl.) za učenike i nastavnike kako bi se omogućila široka dostupnost materijala identificiranoj skupini dionika i javnosti općenito. Informacije o projektu i projektnim aktivnostima diseminirat će se i putem društvenih mreža (kao na primjer stranicom https://www.facebook.com/coding4girls na Facebooku). Informacije o ciljevima projekta, aktivnostima provedbe projekta, ishodima evaluacije, primjeni izrađene metodologije u obrazovnom kontekstu i znanstvenim doprinosima prezentirat će se akademskoj zajednici na konferencijama te putem zbornika i drugih publikacija.

U cilju promicanja rezultata projekta i promicanja prihvaćanja ishoda u različitim obrazovnim, kulturnim i ekonomskim okruženjima u svim zemljama partnerima, uspostavit će se kontakt s kreatorima obrazovne politike, nastavnicima, i svim ostalim dionicima uključenim u formalno i neformalno obrazovanje. Tijekom druge godine provedbe projekta, u svim zemljama će se održati predstavljanje ostvarenih rezultata (*multiplier event*) kako bi se pospješilo njihovo prihvaćanje od strane dionika.

VI. ZAKLJUČAK

Projektom Coding4Girls se želi privući i uključiti nadarene učenike (djevojčice i dječake) u obrazovanje iz područja računalnih znanosti i IKT-a te ih potaknuti na odabir karijera u tim područjima za dobrobit samih učenika, industrije tj. malih i srednjih poduzeća koja će moći zaposliti educirane djelatnike za razvoj poslovanja te zajednice koja će imati koristi od povećane zapošljivosti, održivog rasta i socijalne kohezije.

Dodatno, na lokalnoj i regionalnoj razini je cilj promicati dobre obrazovne prakse kojima će se ojačati spremnost za rad u području računalnih znanosti i IKT kao i uključivanje odgojitelja, kreatora politika i drugih dionika u suradničke inicijative za izgradnju vještina programiranja.

Za vrijeme trajanja projekta će se nastojati učinkovito informirati sve dionike i zainteresirane skupine o provedenim aktivnostima i postignutim rezultatima na različitim događanjima i korištenjem različitih komunikacijskih kanala. Također, pružit će se podrška nastavnicima pri uvođenju i primjeni predloženih pristupa u nastavnom procesu.

ZAHVALE

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Istraživačka analiza i model logističke regresije aktivnosti u LMS sustavu

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Sažetak **- Vrijedan resurs koji se generira u okviru sustava za e-učenje su podaci koji se bilježe i iz kojih analizom možemo otkriti zanimljivo i novo ekspertno znanje o ponašanju i aktivnosti studenata pri korištenju samog sustava u procesu učenja. Primjerice, otkrivanje atipičnih ponašanja i karakterističnih tipova modela ponašanja studenata je temelj za slanje poruka studentima da bi na vrijeme dobili korisnu informaciju o svojem napretku i uspjehu u učenju. Naime, nisu samo bodovi iz raznih provjera i zadaća na kojima se direktno temelji ocjena bitni za konačni uspjeh. Podaci sustava za e-učenje sadrže znanje o aktivnostima kao što je primjerice gledanje video lekcija, odgovaranje na pitanja u samoprovjerama i druge aktivnosti temeljene na suvremenim edukativnim smjernicama koje se ne boduju. Te su aktivnosti izvrsni pokazatelji na temelju kojih se u svakom trenutku može predvidjeti u značajnoj mjeri i konačan uspjeh studenta. U radu se bavimo otkrivanjem znanja o takvim aktivnostima podatkovnom analizom izvedenom istraživačkom analizom podataka i logističkom regresijom u okviru e-kolegija Programiranje 2 Odjela za informatiku Sveučilišta u Rijeci.**

Ključne riječi – dubinska analiza podataka; logistička regresija; Moodle; istraživačka analiza podataka

I. UVOD

Za generaciju Z koja je već prisutna na svim razinama obrazovanja važno je da se aktivnosti i sadržaji e-učenja temelje na novim tehnologijama s kojima je ta generacija odrasla, a koje omogućavaju dinamično i mobilno učenje [1]. U radu se bavimo procjenom značenja dodatnih aktivnosti i sadržaja u LMS sustavu (engl. *Learning Management System*) koje se ne boduju već imaju zadatak omogućiti studentu učenje na prihvatljiviji, personalizirani i mobilni način neovisno o računalnoj platformi, vremenu i mjestu učenja.

Proces učenja u sustavu e-učenja ostavlja svoj trag u podacima koji se bilježe i skrivaju vrijedne informacije koje mogu obogatiti ekspertizu nastavnika i pružiti korisne povratne informacije studentu. Dubinska analiza podataka na području edukacije već je više od dva desetljeća vrlo aktivno područje istraživanja u nastojanjima da se otkriju nova i korisna znanja i podigne kvaliteta procesa učenja [2, 3]. U radu predstavljamo istraživanje u okviru predmeta Programiranje 2 na Odjelu za informatiku Sveučilišta u Rijeci. Predmet je oblikovan u okviru sveučilišne Moodle platforme za e-učenje. Istraživanje se nastavlja na prethodno istraživanje opisano u [4, 5, 6].

Početni uvid u karakteristike skupa podataka stječemo istraživačkom analizom podataka, posebno raznim metodama vizualizacije podataka. U nastavku analize primjenjujemo model logističke regresije kao tip modela koji omogućava uz relativno zadovoljavajuću točnost predviđanja i interpretaciju modela, te se često koristi u analizi podataka u području edukacije. Istražujemo hipotezu da gledanje video lekcija i samoprovjere, tj. dodatne aktivnosti na predmetu koje se ne boduju, imaju značenje za predviđanje uspjeha studenta na predmetu.

Rad je organiziran na sljedeći način. U drugom poglavlju dan je pregled područja istraživanja problema kojim se bavimo. U poglavlju tri predstavljen je skup podataka i metode koje koristimo u analizi online aktivnosti studenta. U četvrtom poglavlju dana je diskusija rezultata, te zaključujemo sa smjernicama za budući rad.

II. PREGLED ISTRAŽIVANJA

Najuspješniji postupci dubinske analize podataka na području edukacije su vizualizacija, grupiranje, klasifikacija i učenje asocijacijskih pravila. Ovim postupcima se otkriva novo, zanimljivo i korisno znanje analizom podatkovnog traga koji su studenti proizveli u aktivnostima procesa učenja [7]. Problemi i zadaci kojim se dubinska analiza bavi su uspjeh studenta, unaprjeđenje predmeta, preporuke u procesu učenja, prilagodba sadržaja na temelju ponašanja studenta, povratna informacija namijenjena nastavniku i studentu te detekcija atipičnih ponašanja studenata vezano uz učenje.

Veliki broj radova koji primjenjuje dubinsku analizu podataka na području edukacije bavi se predviđanjem uspjeha studenata na temelju različitih značajki skupa podataka. U [8] autori koriste logističku regresiju za predviđanje odustajanja studenata od studija. U drugom istraživanju predstavlja se studija složenih odnosa između nekoliko ulaznih varijabli koje predstavljaju aktivnosti individualnog online učenja i njihov učinak (video lekcije, broj pogleda na materijale za učenje, odgovaranje na pitanja s više točnih odgovora i sl.) [9].

U [10] autori razmatraju rezultate tri različite metode predviđanja logističke regresije, višeslojnog perceptrona i neuronske mreže koja se temelji na vjerojatnosti u predviđanju, u predviđanju odustajanja studenata od studija. U pristupu [11] se koristi model predikcije za

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preporučivanje predmeta prve godine studija pri čemu najbolji rezultat daju metode slučajne šume i logistička regresija.

III. OPIS SKUPA PODATAKA, PROBLEM I METODE

A. Skup podataka i problem

Podaci koje analiziramo prikupljeni su u okviru predmeta Programiranje 2 u procesu učenja u interakciji sa Moodle sustavom. Skup podataka sadrži 77 instance i predstavljen je sa 14 atributa. Tablica 1 daje opis pojedinih značajki čije vrijednosti su karakteristične za pojedine instance. U radu istražujemo značaj koji pojedina značajka (ulazna varijabla ili prediktor) ima na konačnu ocjenu (izlazna varijabla odnosno značajka *grade*).

B. Istraživačka analiza podataka

U istraživačkoj analizi podataka dobivamo prvi uvid u podatke vizualizacijama i tablicama koji često otkrivaju važne odnose i daju smjernice za istraživanje [12].

C. Logistička regresija

Logistička regresija se tipično koristi uz kategorijsku binarnu varijablu odgovora. Zbog toga se često koristi kao postupak klasifikacije. Kako logistička regresija predviđa vjerojatnost klase, možemo o njoj razmišljati i kao o postupku regresije [13].

U skupu podataka EDU77 varijabla izlaza grade može poprimiti jednu od dvije vrijednosti: PASS ili FAIL. Umjesto da se direktno modelira odgovor Y, logistička regresija modelira vjerojatnost da Y pripada određenoj kategoriji. Za skup podataka EDU77 logistička regresija modelira vjerojatnost za *grade*. Primjerice, vjerojatnost varijable *grade* za danu vrijednost ulazne varijable *videos* pišemo Pr(grade = PASS|videos).

Vrijednosti za Pr(grade = PASS|videos), što možemo kraće pisati kao p(videos), imat će raspon između 0 i 1. Za bilo koju danu vrijednost varijable videos može se izvršiti predviđanje za grade. Primjerice, možemo definirati predviđanje grade = PASS za studenta za kojega je p(videos) > 0.5. Ako želimo biti oprezni u predviđanju uspjeha studenta jer ipak kod tog odabira postoji i određeni rizik da neće položiti predmet, tada se možemo odlučiti za viši prag, primjerice p(videos) > 0.8.

Kako bi trebali modelirati odnos između p(X) = Pr(Y = PASS|X) i X? Za modeliranje p(X) moramo koristiti funkciju koja na izlazu daje vrijednost između 0 i 1 za sve vrijednosti X. Taj uvjet zadovoljava veći broj funkcija. U logističkoj regresiji koristimo logističku funkciju (1).

$$\frac{p(X)}{1-p(X)} = e^{\beta_0+\beta_1 X} \quad (1)$$

Izračun logaritma za lijevu i desnu stranu jednadžbe daje oblik jednadžbe čiji član na lijevoj strani zovemo logit funkcija ili logaritam omjera šansi (engl. log-odds) i linearno je zavisan o X (2).

$$\log\left(\frac{p(X)}{1-p(X)}\right) = \beta_0 + \beta_1 X \quad (2)$$

TABLICA I. ZNAČAJKE SKUPA PODATAKA I NJIHOV OPIS

ID	*Značajka*	*Opis*
1	lectures	Ukupni broj bodova za aktivnost na predavanju (0-7 + bonus do 12)
2	quizzes	Ukupni broj bodova na online provjerama (0-36)
3	labs	Ukupni broj bodova na vježbama (0-57)
4	videos	Ukupni broj gledanja video lekcija
5	selfassesm	Ukupni broj klikova u okviru aktivnosti samoprovjera (odgovaranje na pitanja sa više ponuđenih odgovora)
6	grade	Uspjeh studenta na predmetu (PASS/FAIL)
7	red	Binarna varijabla, ima vrijednost 1 ako je student pristupio prezentaciji Red najmanje jednom, inače 0
8	stog	Binarna varijabla, ima vrijednost 1 ako je student pristupio prezentaciji Stog najmanje jednom, inače 0
9	dinamicko	Binarna varijabla, ima vrijednost 1 ako je student pristupio prezentaciji Dinamičko programiranje najmanje jednom, inače 0
10	kruzna	Binarna varijabla, ima vrijednost 1 ako je student pristupio prezentaciji Kruzna lista najmanje jednom, inače 0
11	stabla1	Binarna varijabla, ima vrijednost 1 ako je student pristupio prezentaciji Uvod u stabla 1 najmanje jednom, inače 0
12	stabla2	Binarna varijabla, ima vrijednost 1 ako je student pristupio prezentaciji Uvod u stabla 2 najmanje jednom, inače 0
13	demons	Binarna varijabla, ima vrijednost 1 ako je student pristupio demonstraturama, inače 0
14	forum	Binarna varijabla, ima vrijednost 1 ako je student pristupio forumu najmanje jednom, inače 0

Za učenje modela koristi se postupak najveće vjerodostojnosti (engl. maximum likelihood) [13].

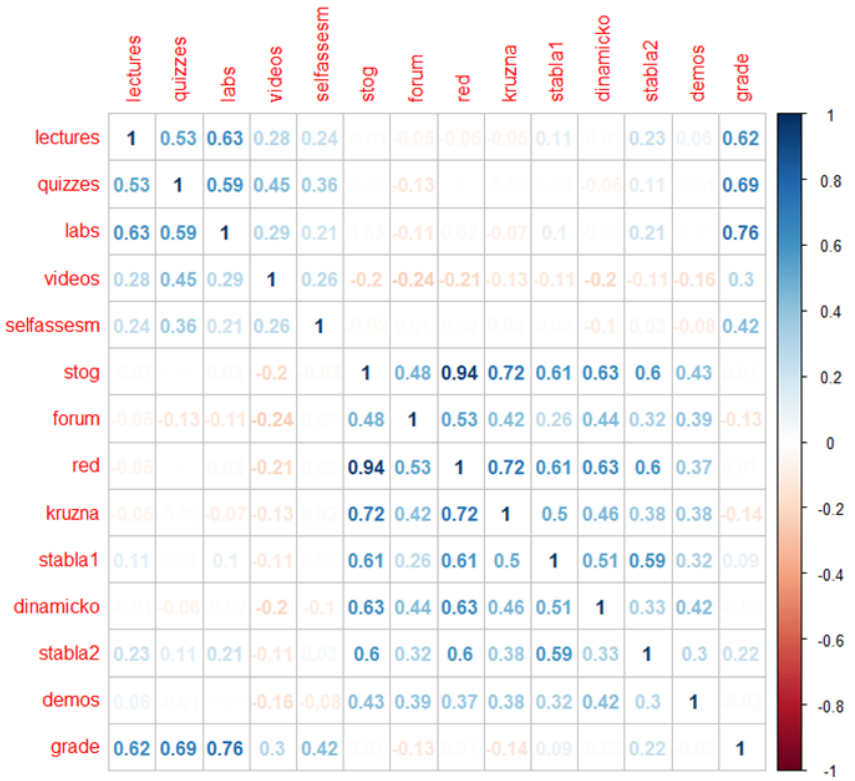
IV. REZULTATI

A. Istraživačka analiza podataka

Slika 1 prikazuje prvih deset instanci skupa podataka EDU77. Za vizualizaciju koristimo generičke R funkcije i R pakete ggplot2 i corrplot (verzija 3.1.0 i verzija 0.84) [14]. Slika 2 prikazuje korelacije značajki skupa podataka na temelju koda na slici 3. Pozitivne korelacije su prikazane plavom, a negativne crvenom bojom. Aktivnosti koje se boduju *labs*, *quizzes* i *lectures* su u većoj korelaciji s *grade*, a i međusobna korelacija im je značajna. Na temelju aktivnosti *videos* i *selfassesm* čije značenje istražujemo se može predvidjeti izlazna varijabla *grade* sa većom točnosti nego na temelju primjerice značajki *forum*, *stog* ili *dinamicko*. Problem za učenje modela logističke regresije predstavlja korelacija između pojedinih prediktora, jer takve redundantne informacije smanjuju kvalitetu naučenog modela.

id	lectures	quizzes	labs	videos	selfassesm	stog	forum	red	kruzna	stabla1	dinamicko	stabla2	demons	grade
1	0	19.33	32.0	0	116	1	1	1	1	1	1	1	1	PASS
2	5	22.00	27.0	6	232	0	0	0	0	0	0	0	0	PASS
3	5	15.00	7.0	10	132	0	1	0	1	1	0	0	1	FAIL
4	6	27.66	27.5	13	451	1	1	1	1	1	1	1	1	PASS
5	3	28.66	0.0	51	260	0	0	0	1	0	0	0	1	FAIL
6	11	32.66	54.0	20	96	0	0	0	0	0	0	0	0	PASS
7	2	24.33	23.5	11	385	0	0	0	0	0	0	0	0	PASS
8	8	24.33	14.0	6	741	1	1	1	1	1	0	1	1	PASS
9	2	12.66	26.0	7	585	0	0	0	0	0	0	0	0	PASS
10	5	24.33	18.0	10	182	1	1	1	1	1	1	0	1	PASS

Slika 1. Prvih deset instanci skupa podataka EDU77

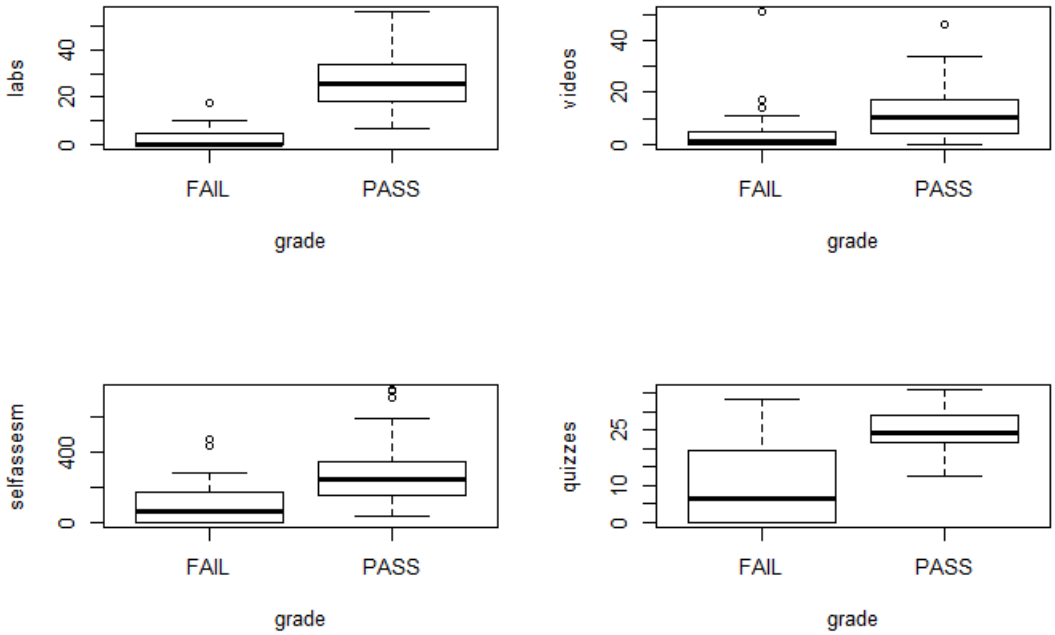


Slika 2. Korelacija značajki skupa podataka. Značajke koje boduju *labs*, *quizzes* i *lectures* imaju veću korelaciju sa varijablom izlaza *grade*. Značajke *videos* i *selfassesm* slabo koreliraju sa aktivnostima koje se boduju, a ipak imaju veću korelaciju sa *grade* nego primjerice *stabla2*.

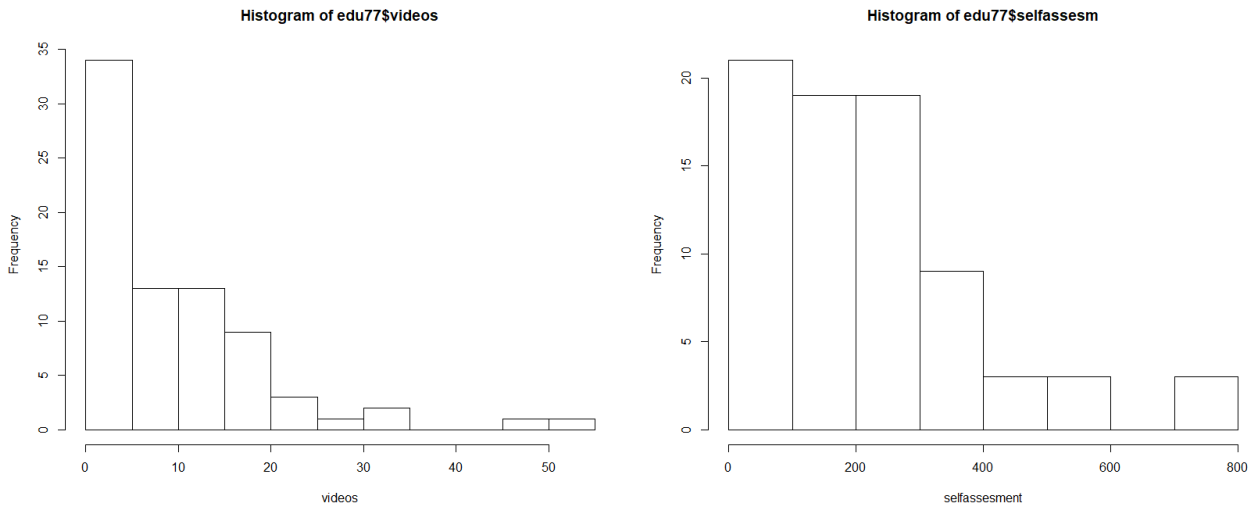
```
library(corrplot)
M <- cor(edu77)
corrplot(M, method = "number")
```

Slika 3. Kod za prikaz korelacije značajki

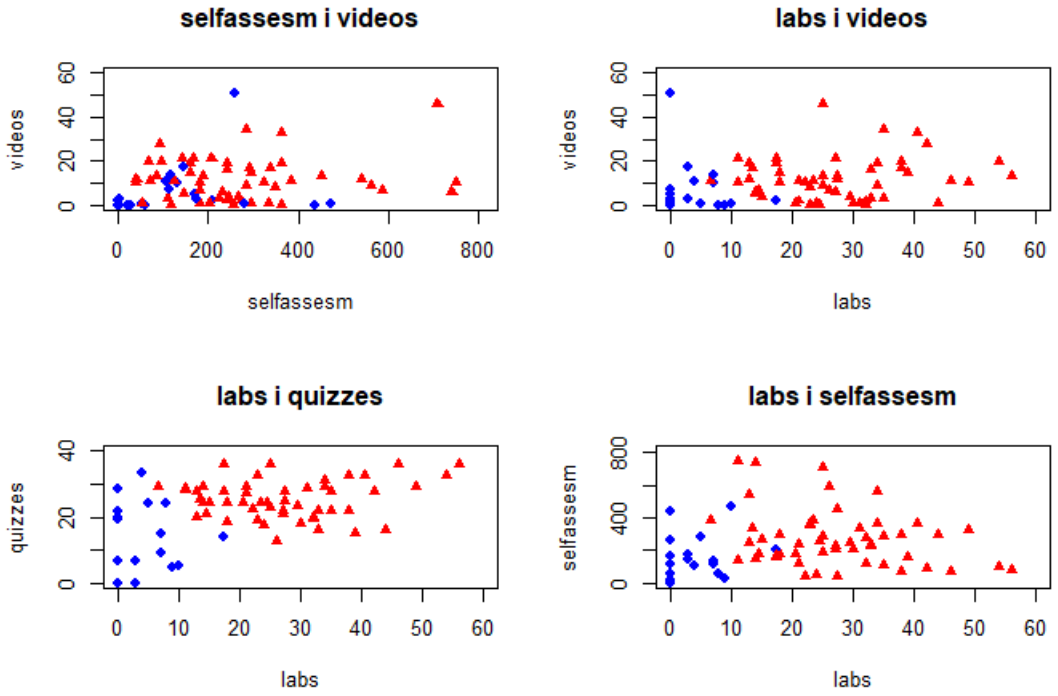
Iz dijagrama s pravokutnikom (Slika 4) uočavamo da se na temelju prediktora *labs* može sa velikom sigurnošću predvidjeti vrijednost za *grade*, što nije slučaj sa prediktorima *videos* i *selfasessm*. Za prediktore *videos* i *selfassesm* možemo uočiti anomalije koje se očituju u gledanju video lekcija više od 30 puta odnosno više od 400 klikova u aktivnosti *selfassem* (Slike 4 i 5). Na dijagramima raspršenja prikazani su odnosi parova prediktora uz prikaz vrijednosti izlazne varijable *grade* (crveni trokuti označavaju vrijednost PASS, a plavi krugovi označavaju FAIL) (Slika 6). Vizualizacije dostupnih podataka mogu i za vrijeme izvođenja predmeta pomoći u ocjeni ponašanja studenata, a logističkim modelom moglo bi se uz određenu točnost predvidjeti vrijednost varijable *grade* u svakom trenutku.



Slika 4. Dijagrami s pravokutnikom prikazuju medijan, udio instanci u kvartilima i anomalije za vrijednosti PASS i FAIL za značajke *labs, videos, selfassesm* i *quizzes*



Slika 5. Histogrami prikazuju frekvenciju značajki *videos* i *selfassesment* i otkrivaju anomalije: više od 25 puta pogledane video lekcije, više od 400 klikova u okviru samoprovjera



Slika 6. Dijagrami raspršenja prikazuju parove značajki uz prikaz izlazne varijable *grade* (crveni trokuti – PASS, plavi krugovi - FAIL)

B. *Logistička regresija*

Za učenje modela logističke regresije koristimo funkciju glm() za učenje općeg linearnog modela uz vrijednost parametra family=binomial (inače bi funkcija izvodila linearnu regresiju).

Korelacija značajki skupa podataka je za određene skupove značajki prevelika da bi ih sve uključili u logistički model, jer bi njihova korelacija smanjila kvalitetu modela [13]. Isključivanjem značajke *labs* koja najviše korelira sa ostalim značajkama smanjit ćemo taj negativni učinak. Uz učenje modela logističke regresije izvodimo i evaluaciju modela logističke regresije postupkom unakrsnog vrednovanja pri čemu koristimo funkciju cv.glm() definiranu u R paketu boot (version 1.3-20) [15]. Postupak izvodimo za k=10 preklapanja. Inicijaliziramo generator slučajnih brojeva i vektor u koje će se pohraniti pogreške iz pojedinih iteracija vrednovanja modela (Slika 7). Slika 8 prikazuje pogreške za svih 10 iteracija postupka unakrsnog vrednovanja i konačnu pogrešku. Model logističke regresije naučen na skupu podataka EDU77 ima točnost 80%.

Postupkom najveće vjerodostojnosti (engl. maximum likelihood) procijenjeni su koeficijenti $\beta 0$ i $\beta 1$ logističkog modela (2). Tablica II prikazuje procjenu koeficijenata i dodatne informacije o modelu logističke regresije za skup podataka EDU77. Zadatak modela je predviđanje vjerojatnosti za grade=PASS na temelju navedenih prediktora: forum + videos + selfassesm + stabla1 + stabla2 + stog + red + kruzna + dinamicko. Prema stupnju značajnosti za zadatak predviđanja, model je ulazne značajke označio sa dvije i jednom zvjezdicom te točkom.

```
F2=function()
{
 set.seed(15)
 cv.error.10=rep(0,10)
 for (i in 1:10){
  glm.fit=glm(grade ~ forum + videos + selfassesm +
stabla1 + stabla2 + stog + red + kruzna + dinamicko,
data = edu77, family = "binomial")
   cv.error.10[i]=cv.glm(edu77,glm.fit,K=10)$delta[1]
 }
 print(cv.error.10)
 print("Prosjek greške: ")
 mean(cv.error.10)
}
summary(glm.fit)
```

Slika 7. Učenje modela logističke regresije za skup podataka EDU77 uz izračun točnosti modela

```
> print(cv.error.10)
 [1] 0.2046300 0.1978820 0.1916990 0.2035030
0.1997910 0.2177027
 [7] 0.1876707 0.2075789 0.1875771 0.2107466
> mean(cv.error.10)
[1] 0.2008781
```

Slika 8. Pogreška modela računa se unakrsnim vrednovanjem

Gledanje video lekcija i samoprovjera su statistički značajni čime smo potvrdili hipotezu o njihovoj važnosti. Značajnije su od svih ostalih značajki koje predstavljaju aktivnosti predmeta koje se ne boduju (osim *stabla2*, dakle važno je pristupanje materijalima).

TABLICA II. KARAKTERISTIKE MODELA LOGISTIČKE REGRESIJE

D	Coefficient	Std.Error	z value	Pr(>|z|)
(Intercept)	-1.613859	0.919375	-1.755	.07919 .
forum	-1.141128	0.910228	-1.254	0.20996
videos	0.079757	0.041039	1.943	**0.05196** .
selfassesm	0.009336	0.002967	3.146	**0.00165** **
stabla1	-0.142393	0.922034	-0.154	0.87727
stabla2	1.814746	0.844896	2.148	0.03172 *
stog	1.155727	2.877952	0.402	0.68799
red	0.248721	2.932770	0.085	0.93241
kruzna	-2.265067	1.322486	-1.713	0.08676 .
dinamicko	0.787115	0.976089	0.806	0.42001

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

V. ZAKLJUČAK

Istraživačkom analizom podataka potvrđena je važnost dodatnih aktivnosti na predmetu, gledanja video lekcija i samoprovjera u otkrivanju atipičnih ponašanja studenata. Utvrđena je korelacija značajki skupa podataka, koja je u određenoj mjeri pomogla u odabiru značajki za učenje modela logističke regresije. Naučeni model je potvrdio umjereno značenje samoprovjere i gledanja video lekcija te je time početna hipoteza potvrđena. Smjernice za budući rad uključuju primjenu dodatnih postupaka za odabir značajki modela da bi povećali kvalitetu modela.

VI. ZAHVALA

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Razvoj kreativnosti i suradnje upotrebom GitHub platforme u srednjoškolskom strukovnom obrazovanju

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Sažetak - Važno mjesto u preporukama Vijeća Europe posvećenim poboljšanju iskustva učenja zauzima kolaborativno učenje i poučavanje uz mogućnosti aktivne participacije i utjecaja učenika. U realizaciji strukovnog obrazovanja u sektoru Elektrotehnika i računalstvo takav pristup prilikom usvajanja vještina razvoja programskih rješenja može biti potenciran kolaborativnim mogućnostima GitHub digitalne platforme. Kako savladavanje obrazovnih ishoda za stjecanje kompetenecija u zanimanju Tehničar za računalstvo obuhvaća usvajanje znanja i vještina vezanih uz različite programske jezike odnosno tehnologije (C, C++, C#, HTML, JavaScript, Java, CSS…) koje ova platforma podržava čini se korisnim osvrnuti se na njene mogućnosti korištenja u nastavne svrhe što je podržano primjerice i kroz GitHub Education. U radu su navedena neka iskustva kako GitHub okolina može pomoći i pridonijeti kvaliteti obrazovnog procesa za učenike i nastavnike, te se predlažu neke mogućnosti primjene u domeni srednjoškolskog obrazovanja.

I. UVOD

Primjena računala u raznim oblicima on-line učenja kroz ostvarenje i komunikaciju zajednica oblikovanih korištenjem tehnologija kao što su računalstvo u oblacima, društveno umrežavanje ili Massive Open Oline Courses (MOOC) u obrazovno procesu potvrđuje bitan utjecaj tehnologije na obrazovanje u svrhu poboljšanja učinkovitosti procesa učenja i poučavanja.

Neprijeporne su dobrobiti suradničkog učenja potpomognutog tehnologijom. Mrežni (na web-tehnologijama bazirani) sustavi suradničkog učenja pri kojem je svaki pojedinac svjestan rada drugih suradnika i upoznat je sa planovima i razumijevanjem drugih uključenih osoba, učenicima omogućuju realističniju, izrazitiju i izazovniju participaciju što u konačnici poboljšava rezultate kako na razini tima, tako i pojedinca. U tom smislu, GitHub je sustav koji nudi većinu obilježja Learning Management (LM) sustava uz značajnu potporu suradničkim aktivnostima korisnika.

U radu su iznijeta razmatranja i neka praktična iskustva primjene ove platforme (namijenjene primarno za distribuirano upravljanje razvojem inačica programa) kao potvrda mogućeg pozitivnog utjecaja na obrazovno iskustvo učenika i nastavnika: mogućnosti upotrebe, utjecaj na motivaciju, transparentnost rada i djelotvornost rada kroz stvaranje otvorenih repozitorija. Spomenute su dobrobiti, ali i neki izazovi koje donosi svojim suradničkim i poslužiteljskim mogućnostima.

II. ŠTO JE GITHUB?

GitHub je važna platforma za upravljanje softverskim projektima. Svojim funkcionalnostima naočigled povećava učinkovitost rada korisnika profesionalaca i to ne samo kroz repozitorij projekata već i kao kvalitetna potpora suradnji (primarno programerskog) tima kao zajednice. Korisnici mogu slijediti druge korisnike određenog projekta te međusobno dijeliti aktivnosti.

Repozitorij (često se koristi skraćenica "repo") je mjesto na kojem se spremaju sve datoteke nekog projekta, a može mu se pristupiti preko jedinstvenog URL-a.

Korisnik koji sudjeluje u nekom projektu, klonira taj projekt čime kreira cjelovitu kopiju projekta u svom lokalnom okruženju, ali pri čemu izvedene promjene mogu imati utjecaj na originalni projekt (model dijeljenog repozitorija). Pri tom se po potrebi obavljaju konverzacije o predloženim promjenama prije nego što se promjene spoje u tzv. *master branch*, odnosno korisnik može račvati (*fork*) čitav projekt kako bi kreirao paralelni projekt u kojem predane promjene ne utječu izravno na originalni projekt. Takav se model naziva *Fork&Pull* [8], a karakterizira ga obavještavanje autora originalnog projekta o promjenama koje se predlažu za razmatranje.

Forking (*a Repo*) je postupak stvaranja novog projekta utemeljenog na nekom postojećem projektu. Poticaj je daljnjem razvoju programa i drugih projekata, a ako se originalni repozitorij ažurira, ista se ažuriranja mogu dodati novom projektu koji se granao iz njega.

Najvažnija osobina u takvom pristupu suradničkom razvoju projekata je *Pull Request* (PR) mehanizam koji predstavlja način inicijalizacije diskusije sa drugim korisnicima, odnosno dijeljenje ili komentiranje različitih sastavnica projekta. Pri tom rasprava može uključivati javno dostupan kod uz točan prikaz promjena koje će biti pripojene ako se PR prihvati. Primjerice, ako neki programer prilikom značajnije revizije određenog projekta želi biti prepoznat od strane autora izvrnog projekta ili biti uključen u službeni projekt, on kreira PR. Pri tome GitHub otvara komunikacijski kanal u kojem autori originalnog repozitorija mogu vidjeti predloženi rad te odlučiti žele li prihvatiti programera u okvir službenog projekta.

Uz to, PR može sadržavati i drugi za raspravu važan sadržaj (npr. *screenshot*) ili uključivati promjene drugih resursa projekta.

Sasvim je razumljivo da je spomenuti suradnički potencijal platforme upotrebljiv i za upravljanje, poboljšanje i svojevrsnu transformaciju iskustva učenja u procesu obrazovanja.

III. GITHUB I DRUŠTVENO UMREŽAVANJE

Osnova GitHub-a je Git, sustav otvorenog koda za upravljanje verzioniranjem prilikom razvoja softverskih aplikacija (autora L. Torvaldsa). U cilju bilježenja revizija koda, sustav promjene sprema u središnji repozitorij, čime se omogućuje jednostavno sudjelovanje, dijeljenje, suradnja i uvid u promjene u cilju stvaranja novih inačica programskog koda. Pri tome je kod vidljiv i dostupan tako da svaki programer koji to želi može sudjelovati u postupku razvoja, ali i oni koji ne sudjeluju u razvoju projekta mogu datotekama pristupiti, pogledati ih i koristiti.

Git je alat sa komandnom linijom (*command-line tool*), no središnje mjesto oko kojeg se razvija je hub, odnosno GitHub.com, mjesto na kojem programeri spremaju svoje projekte umrežavajući se sa sebi sličnima. S obzirom da na projektu sudjeluje veći broj autora, GitHub omogućuje čuvanje i održava zapise o svim promjenama, odnosno revizijama koje su stavljene na određeni repizotorij: tko je mijenjao, što, kada i gdje su te datoteke spremljene. Spremljene revizije projekata mogu se diskutirati javno, tako da velik broj stručnjaka može pridonositi znanjem i sudjelovati u napretku projekta.

Na taj način GitHub nudi uslugu dijeljenja koda kroz Git sustav distribuiranog upravljanja verzijama. Pri tom je važna snaga GitHub-a osobina transparentnosti koju daje timu, projektu i članovima zajednice korisnika. Svaki GitHub korisnik ima vlastiti profil kroz koji se vidi prethodno iskustvo, rad i suradnja na drugim projektima kroz (kroz PR-ove). Tako koncipiran aspekat društvenog umrežavanja GitHub-a omogućuje brži rast projekata, ali funkcionira i kao svojesvrstan životopis autora.

No, GitHub nije sustav samo za razvojne programere, mnogo je manje uobičajeno, ali GitHub se može koristiti za dijeljenje bilo koje vrste datoteka, npr. za *Word* dokumente. Uz to, Git posjeduje niz prednosti pred drugim sličnim, odnosno alternativnim sustavima (*Subversion*, *CVS*, *Mercurial*): učinkovitiji je u čuvanju promjena datoteka te osigurava bolji integritet datoteka [10]. Zato je svojim pozitivnim osobinama zauzeo mjesto prioritetnog alata u područjima u kojima se zahtjeva suradnja u tehničkim projektima, primarno razvoju softvera preko dijeljenih repozitorija.

IV. GITHUB KAO POTPORA UČENJU I POUČAVANJU

U početku je GitHub bio fokusiran na upravljanje kodom i projektima razvoja softvera, no te su njegove mogućnosti kasnije proširene i na druge domene koje podrazumijevaju suradnički rad. Da bi se uspješno primjenjivao u području obrazovanja, potrebno je učiniti i dodatne prilagodbe tehnika poučavanja (npr. PR-ovi mogu donositi bodove za više ocjene). Obogaćivanje obrazovnog procesa ovakvim sustavom smanjuje nastavnicima količinu i složenost administrativnih poslova dopuštajući im da više vremena provode fokusirajući se na stručne i pedagoške teme.

GitHub slijedi glavne osobine učenja karakteristične za tradicionalne LM sustave, ali nudi i dodatne funkcionalnosti korisne učenicima i nastavnicima: transparentnost aktivnosti, pozitivna potpora participaciji i suradnji, te potpora višestrukom korištenju i dijeljenju nastavnih materijala i znanja [1].

No, "GitHub u obrazovanju" nije nužno, "Stavimo obrazovne materijale na GitHub", nego je više, "Omogućimo kulturu spontane ali strukturirane suradnje i napretka." [2].

Dva su osnovna načina na koja se GitHub platforma može integrirati u učionicu: za dostavljanje i manipulaciju radovima učenika te kao način posluživanja nastavnim sadržajima, što oslikava uobičajenu upotrebu tipičnih LM sustava. Usporedba skupa mogućih interakcija između nastavnika, učenika i nastavnih sadržaja u slučaju korištenja LM okoline i Git sustava ukazuje na niz dodatnih interakcija prirodno podržanih GitHub platformom koje nisu uobičajene kod tradicionalnih okolina učenja (npr. jednostavnost doprinosa nastavnom materijalu).

A. GitHub kao platforma za dostavljanje radova učenika

U ovom se načinu GitHub koristi primarno kao poslužitelj za radove učenika, dostavu zadataka i projekata.

Pri tom je moguće postaviti osnovni repozitorij za razredni odjel kojeg svaki učenik grana pri čemu može vidjeti i sva ostala grananja. Time se omogućuje unakrsno referenciranje različitih rješenja, a podupire se i kolegijalno učenje i učenička suradnja.

Moguć je i pristup postavljanja privatnih repozitorija za svakog učenika tako da pojedini učenik može repozitorije drugih učenika vidjeti samo u slučaju eksplicitne dozvole pristupa. Pri tom se repozitoriji i dozvole postavljaju ručno što može otežati administriranje u slučaju velikog broja učenika.

B. GitHub kao poslužiteljska platforma za nastavne materijale

GitHub se u ovoj inačici koristi za udomljavanje i dostavu nastavnih materijala (program, prikaznice, bilješke, vježbe, domaći zadaci, priručnici i dr. materijali) ili se koristi kao poslužitelj mrežnog sjedišta predmeta (npr. upotrebom GitHub stranica). Učenici i nastavnici mogu suradnjom u takvoj zajednici dijeljene sadržaje poboljšavati i unaprijeđivati.

V. DOBROBITI KORIŠTENJA GITHUB-A U OBRAZOVANJU

U pozitivne strane korištenja GitHub platforme u obrazovanju mogu se navesti:

- Učenici stječu iskustvo korištenja sustava za upravljanje verzijama
- Eliminacija papira prilikom predavanja radova
- Olakšana rasprava i suradnja među studentima
- Pojednostavljeni grupni projekti/zadaci
- Nastavnicima je omogućen daljinski pregled i komentiranje rada tijekom izrade
- Postojanje prostora na kojima su smješteni sadržaji predmeta

U pozitivna se obilježja GitHub-a također navode [1]:

A. Transparentnost aktivnosti

Svojom potporom vidljivosti i transparentnosti učeničkih aktivnosti, GitHub (kao platforma za dostavu/prikupljanje) omogućuje praćenje aktivnosti, participacije i napretka učenika (također u obliku grafičkog prikaza povijesti aktivnosti vezanih uz pojedini dokument ili projekt). Pri tom praćenje napretka nije isključivo pasivno, nego učenici mogu i sami vlastitim aktivnostima privlačiti pozornost nastavnika ili tražiti pomoć, a takav oblik komunikacije između nastavnika i učenika nije osobina tradicionalnih LM sustava.

B. Poticanje aktivnog sudjelovanja

Učenici mogu predlagati promjene (na dokumentima, nastavnim materijalima i dr.) slanjem relevantnih komentara ili mogu promjene raditi i sami te poslati PR koji nastavnik može (ako se s promjenama složi) prihvatiti. I za ove postupke postoji povijest aktivnosti koja nastavnicima pomaže praćenje tko je i koliko sudjelovao, što je poticajno za učenike jer se njihova aktivnost bilježi te može dovesti do boljih ocjena. Spremljeni zapisi također mogu i inicirati ili povećati kvalitetu rasprave i tumačenja u samom nastavnom procesu u učionici.

C. Ponovna upotreba i dijeljenje nastavnih materijala i znanja

Dijeljenje i ponovna upotreba nastavnih materijala i znanja između učenika i nastavnika u GitHub-u se ostvaruje s lakoćom. Kontrola pristupa sadržaju omogućuje da on može biti privatni, privatni među sudionicima ili potpuno javni pri čemu se može dijeliti te tako biti potpora uzajamnoj suradnji uz povratne informacije o aktivnostima. Sadržaj se može dijeliti i samo među nastavnicima (uključujući povijest promjena).

D. Profesionalna relevantnost

Činjenica da je poznavanje rada sa Git-om i GitHub-om korisno i da se ubraja u relevantne vještine u području struke utječe na motivaciju za učenjem. Učenici u bilo koje vrijeme tijekom svog školovanja mogu ostvariti (softverski) proizvod (seminarski ili drugi rad) koji mogu prezentirati budućim poslodavcima kao oblik životopisa.

E. Jednostavnost upotrebe

Nakon uspostave osnovnih postavki (stvaranje repozitorija, prava pristupa i dr.) administriranje GitHub-om relativno je jednostavno.

F. Besplatne akademske licence

GitHub dozvoljava korisnicima stvaranje besplatnih javnih repozitorija, no nastavnici i učenici mogu besplatno stvarati i privatne repozitorije. Uz to, nastavnici mogu raspolagati i besplatnim organizacijskim računom koji im olakšava upravljanje i administriranje grupama.

G. Dijeljeni prostor i verzioniranje

Kao poslužiteljska platforma za dijeljenje GitHub omogućuje učenicima i nastavnicima jednostavno dijeljenje bilješki i drugih materijala. Verzioniranjem i grananjem moguće je ostavljati pristup do promijenjenih, djelomičnih ili starijih inačica materijala.

VI. IZAZOVI POVEZANI SA POVEZANI SA UPOTREBOM GITHUB-A U OBRAZOVANJU

Temeljni izazov je otežana krivulja učenja za učenike. Naime, kako je GitHub Git baziran sustav, za potpuno razumijevanje i pristup najvećem opsegu njegovih mogućnosti upravljanja zadacima ili projektima koji uključuju suradnju potrebno je razumjeti Git i njegovu komandnu liniju (naredbe i argumente). Takvo, naprednije korištenje, posebno pomaže u postupcima rješavanja spajanja i mogućih konflikata.

VII. PRIMJERI UPOTREBE: GITHUB CLASSROOM

Osnovna ideja prve izvedbe [3] je da platforma GitHub učenicima omogući predaju radova, a nastavnicima pregled i ocjenjivanje. Pri tom se učenicima može dati uvid u radove drugih učenika i prije predaje. U tu svrhu postavljen je jedan repozitorij po učeniku po zadatku (omogućena najveća fleksibilnost i precizna kontrola). Nešto veći broj repozitorija kod toga ne predstavlja ozbiljniji problem. Repozitoriji nisu privatni pa učenici ne mogu preimenovati repozitorije niti određivati mogućnosti i prava pristupa.

Za prateće nastavne materijale odabran je pristup jedan nastavnički repozitorij i jedan učenički po predmetu. Nastavne materijale koje stvaraju i razvijaju nastavnici stavljaju u nastavnički repozitorij i kopiraju pripremljene relevantne informacije u učeničke repozitorije (vidljive učenicima).

Naime, Preko GitHub/Slack integracije učenici dobivaju obavijest (notifikaciju) u odgovarajućem Slack kanalu prilikom svake predaje sadržaja (*commit*) u svrhu aktualizacije učeničkog repozitorija odgovarajućeg predmeta. Općenito, takvo rješenje nije idealno s obzirom da uključuje određeno ručno kopiranje i redundanciju između dva repozitorija (u suprotnosti s DRY principom (*Don't Repeat Yourself*) ponavljanja koda).

Zato neki nastavnici razvijaju nastavne materijale u učeničkim repozitorijima čime omogućuju učenicima uvid u napredak i povijest aktualizacije, a neki razvijaju nastavne materijale u nastavničkom repozitoriju te naknadno kopiraju konačnu inačicu neposredno prije nastave. Bez obzira na odabrani pristup, materijali poput ispita trebaju ostati privatni u nastavničkom repozitoriju sve do trenutka kad su spremni za podjelu.

Pri tom zadaci mogu sadržavati neki osnovni sadržaj (*seed*), kao što je to npr. djelomično napisan kod koji učenici trebaju kompletirati (često u obliku *Jupyter* [7] bilježnice ili R *Markdown* dokumenta).

Ovako koncipirana GitHub učionica koristi predložak repozitorija koji se kopira svakom učeniku prilikom iniciranja zadatka, no moguć je i pristup čuvanja svih nastavnih materijala u jedinstvenom repozitoriju nastavnika, sa različitim mapama za različite zadatke. Za kopiranje predloška repozitorija može se koristiti *Source Imports API*. Kod implementacije sustava sa podmapama repozitorija koristi se *Contents API*.

Izvedbom se učenicima može dopustiti da vide radove jedni drugima u trenutku nakon što istekne rok za predaju (*deadline*) što može biti vrijedno i potrebno ili se učenici mogu uputiti na skup službenih rješenja.

Nakon isteka roka za predaju zadataka, automatski se generira (*Markdown*) tablica u kojoj svaki redak sadrži ime učenika, poveznicu na njegov repozitorij za slanje te poveznicu na *JSON* datoteku sa ocjenama.

Kod predaje zadataka moguća su dva glavna pristupa. Prvi je oduzeti pravo pisanja (*write access*) učenicima u njihove repozitorije zadatka nakon što je prošao krajnji rok. Takav pristup zahtjeva ručno pokretanje skripte u trenutku isteka ili vremensko postavljanje poslužitelja da to učini automatski. Drugo rješenje je osloniti se na zapis o vremenu (*Git commit/push timestamp*) no ovo može biti nezgodno i nepouzdano jer učenici time mogu manipulirati. U sprečavanju manipulacije mogao bi poslužiti GitHub *Events API*. Automatski generirane poveznice mogu pokazivati na posljednje slanje prije krajnjeg roka, tako da se bilo kakav rad učenika nakon tog roka jednostavno ignorira.

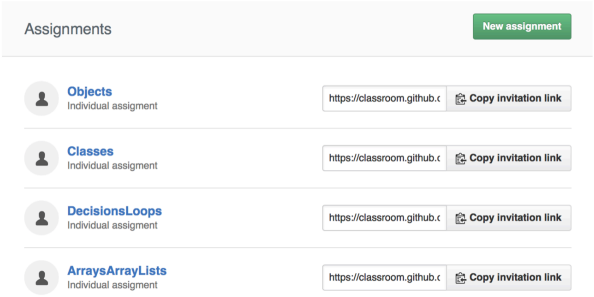
Izmjene nastavnika sa izmjenama učenika, spajaju se kroz upravljanje verzijama. Pri tom se kreira grana (*teacher update*) u svakom repozitoriju zadatka. Tako inicijalno grana nastavničkog ažuriranja sadrži samo kopiju originalnih materijala. Nakon nastavničkog ažuriranja, kreira se PR iz te grane *master* grani učenika. Ažuriranja nastavnika mogu biti zaštićena grana GitHub API-a čime se spriječava da učenici brišu ažuriranja nastavnika nakon spajanja PR-ova.

Drugi je primjer Naperville North High School [5], škola koja je uvela *GitHub Classroom* u jesen 2015. kako bi olakšali nastavnicima distribuiranje koda i prikupljanje radova preko GitHub-a. Učenici se tako pripremaju za lakše savladavanje STEM predmeta, ali i za kreativno i etičko inženjerstvo korištenjem stvarnih alata za upravljanje razvojem softvera. U repozitorije učenicima su stavljeni primjeri koda i potrebne biblioteke.

Planirano je da ova izvedba predstavlja potporu učenicima da pokažu inačice svog rada i prije izrade konačnog proizvoda. Takav tijek rada sličniji je stvarnom radu pri proizvodnji softvera. Ovako izveden *Clasroom* automatski kreira repozitorije učenika, kroz upravljačku ploču (*dashboard*) prati zadatke te omogućuje primjenu neovisnih alata za automatsko testiranje. Na slici 1. prikazan je primjer izgleda ekrana sa zadacima u pripremljenoj učionici.

Zadatke učenici primaju preko određene poveznice. Pri tom svi mogu pristupati dijeljenom repozitoriju ili biti podijeljeni u grupe. U ovom primjeru, dakle, GitHub *Classroom* [4] omogućuje jednostavnije umnožavanje cjelovitog zadatka u privatni repozitorij. U svrhu ocjenjivanja, kodovi učenika preuzimaju se preko GitHub desktop klijenta (*Classroom Assistant)* koji sve repozitorije uzima jednim klikom, nakon čega se provjerava ispravnost i pokreću programi.

U ovoj je izvedbi vidljiv trenutak u kojem učenici preuzimaju svoje zadatke i počinju raditi. Moguće je primjetiti kad su zapeli i pomagati im. Učenici mogu raditi individualno ili u grupama, privatno ili javno, te se mogu i određivati prava pristupa za nastavnike i učenike. Također, moguće je poveznicama povezati repozitorij sa njihovim zadacima i korišteni LMS.



Slika 1 Zadaci u GitHub učionici

VIII. ISKUSTVO U PRIPREMI GITHUB UČIONICE

U svrhu upoznavanja sa mogućnostima GitHub platforme kao obrazovnog alata, izveden je početno pojednostavljeni oblik inačice GitHub učionice primarno kao repozitorij zadataka za vježbu uz funkciju prikupljanja i pregleda rješenja.

Planirano je da se primjenom platforme omogući učenicima predaju rješenja zadataka, kako zadataka za vježbu na nastavi i kod kuće, tako i zadataka nakon pisane provjere kako bi i sami kod kuće mogli pogledati i analizirati svoja rješenja, te u slučaju interesa pokazati i roditeljima. Pri tom učenici mogu i međusobno uspoređivati rješenja, što je posebno dobro za učenike koji imaju problema sa razumijevanjem zadataka i oblikovanjem algoritma. Stvarno ispravljanje predanih rješenja nakon ispita izvodi se na izvornim kodovima spremljenim u mape na računalima u školi.

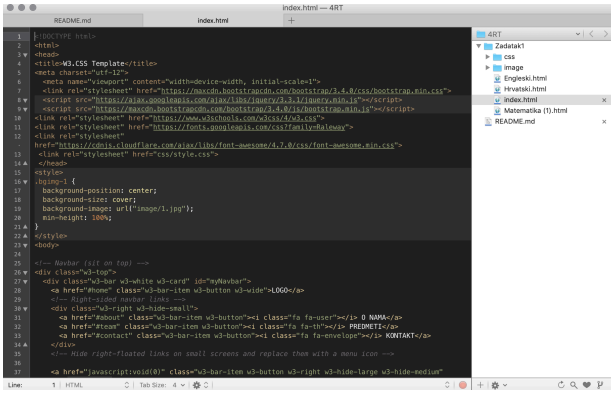
Uključeni su učenici razrednih odjela Tehničke gimnazije 2TG i 3TG, te učenici smjera Tehničar za računalstvo iz 2RT i 4RT razreda, te su na taj način kreirani i repozitoriji zadataka, po jedan za svaki razred. Unutar repozitorija predviđene su mape za pojedine zadatke. U početku uspostave sustava primjećene su nespretnosti oko formiranja mapa u učeničkim granama i spremanja rješenja zadataka u te grane, no to nije bio veći problem s obzirom da su rješenja najčešće spremljena u glavnu mapu učenika. Učenici 2TG, 2RT i 3TG razreda predavali su svoja rješenja zadataka u programskom jeziku C++, dok su učenici 4RT razreda radili sa web tehnologijama (HTML, CSS, JavaScript).

Svi su učenici trebali napraviti svoj račun (GitHub *account*) na sustavu. Većina učenika je taj dio zadatka izvela bez problema, dok su neki imali uobičajene poteškoće sa razumijevanjem prijavnog procesa ili određivanjem lozinke. Prijavljeni učenici upisani su u listu suradnika određenog repozitorija.

Od trenutka prijave, učenici zadatke preuzimaju iz odgovarajućeg repozitorija, te nakon izrade rješenja zadatka svoje rješenje mogu stavljati u granu koju su za zadatak stvorili (sa imenom i prezimenom). U osnove rada sa platformom učenike je uveo nastavnik, ali su upućeni i na odgovarajuće dostupne izvore informacija sa detaljima mogućnosti i načina korištenja [9].

Rješenja u pripremljenim mapama nakon isteka dogovorenog roka za dostavu spremna su za pregled i ocjenjivanje (slika 2.).

Izvedeni proces predstavlja svojevrsnu predfazu uvođenja GitHub učionice u kojoj se učenici upoznaju sa platformom kao važnim sredstvom u postupku razvoja softvera bez velikih preteznija sa ovladavanjem mogućnostima. U slijedećoj fazi izvedbe planirano je i oblikovanje stvarne GitHub učionice uključivo automatizirane mogućnosti rukovanja radovima učenika te smještanje nastavnih materijala što bi se u potpunosti moglo oblikovati od slijedeće školske godine.



Slika 2 Pregled učeničkih rješenja u GitHub desktop sučelju

Prva su iskustva pokazala da učenici dobro prihvaćaju ovaj sustav, te da smatraju za učenje korisnim imati pristup zadacima i rješenjima, analizirati ih, mijenjati i razvijati, čak i u ovoj sasvim pojednostavljenoj GitHub učionici.

IX. GitHub Education

U svrhu promocije GitHub-a u obrazovanju, pokrenuto je 2014. web sjedište GitHub Education [6]. Uključuje paket tehničkih alata, trening za nastavnike i drugu potporu, kao što je besplatan pristup GitHub Enterprise Server-u i GitHub Enterprise Cloud-u, automatski pristup premium GitHub Education mogućnostima (npr. GitHub Student Developer Pack), ekskluzivni pristup novim mogućnostima i GitHub Education-specific swag.

Da bi se kvalificirala, škola treba biti obrazovna ustanova fokusirana na učenje koja izdaje svjedodžbe i certificate, a nudi GitHub svim dijelovima u kojima postoji administrator koji će završiti program obuke nastavnika.

X. Zaključak

Namjena rada bila je osvijestiti rastući potencijal GitHub-a u obrazovnom kontekstu navođenjem njegovih prednosti i mogućnosti upotrebe. Ta je upotreba ovdje, naravno, značajno ispod njegovih mogućnosti kao profesionalnog alata, no predstavlja vrijednu presliku budućeg rada programera tijekom razvoja softverskog proizvoda, odnosno daje neka osnovna saznanja važna za budući profesionalni razvoj stručnjaka. Uz to, nastavnicima koji predaju predmete vezane uz učenje vještina programiranja korištenje ove platforme može olakšati rukovanje i administriranje programskim rješenjima.

U dobre strane integracije ove platforme u obrazovnu praksu, pokazalo se, svakako treba istaknuti vidljivost. Naime, prilikom učenja programiranja, uvid u rješenja zadataka kolega od velike je važnosti za razumijevanje, ali i stvaranje vlastitog stila programiranja. Pri tom različiti stilovi i pristupi uz traženje da se učenička rješenja razlikuju dodatno mogu potaknuti kreativnost učenika i potrebu za novim saznanjima.

Dodatna posljedica transparentnosti rada učenika je vidljivost njihovih aktivnosti, i to ne samo nastavnicima, nego i roditeljima. Poticaj pri tome predstavljaju sugestije roditelja vezane uz potrebu da učenici imaju više zadataka za vježbu. Uz to, korisno je i da roditelji mogu imati uvid u (ne)aktivnost učenika kod rješavanja zadataka za vježbu.

Vrijedi istaknuti i stvaranje repozitorija (u smislu baze) zadataka (i rješenja) za slijedeće generacije učenika.

Dakle, iako nije primarno dizajniran kao LMS ili CMS, GitHub sustav može se koristiti u tu svrhu predstavljajući mjesto za smještaj radova i projekata, ali i mjesto na kojem se osim radova dijele i aktivnosti, ideje i rasprave čime sustav omogućuje stvaranje kulture sudjelovanja, etičke suradnje, kreativnosti i smislenosti rada učenika.

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How faculty from Pula, Dubrovnik, Varaždin, Koprivnica and Osijek use Web-based scientific literature: analysis based on their age, gender, field of science and literature exchange practices

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***Abstract* - The research goal of this paper was to explore the use of web sources of scientific literature by members of the faculties from universities in Croatian cities of Pula, Dubrovnik, Varaždin, Koprivnica and Osijek. The questionnaire was sent to members of the faculties and their answers were analyzed with regard to these variables: age and gender of respondents; their practices of exchanging scientific literature; field of science in which they are working. It was found out that the most frequent users of Croatian web portals are participants from the field of humanities, participants of older age and female participants. The most frequent users of foreign web portals are participants from the field of social sciences and female participants, while participants of all ages use them equally. The most frequent users of pirate web portals are participants from the field of humanities, while participants of both genders use them equally. The Croatian web portal Hrčak is very frequently used by almost all participants from the field of humanities, about half of participants from the field of social sciences and only about one third of participants from the field of technical sciences.**

Keywords - digital library, faculty, web sources of scientific literature, Sci-Hub, universities, Google Scholar, Hrčak

I. INTRODUCTION

An essential condition to reach teaching and research quality is that teachers and researchers have access to a sufficient number of quality texts. They use various types of texts in their work, especially papers from scientific journals and books. Each year number of these texts grows very fast. For example, in the year 2004 there were 2000 scientific publishers from the field of technology, medicine and natural sciences who published about 1.2 millions of reviewed papers [1]. In 2011 there were around 3500 scientific publishers and at least 27000 scientific journals [2]. Before the advent of personal computers and internet, university teachers and researchers have primarily used printed literature. However, the situation is quite different today. Changes caused by the use of digital communication technologies have led to a situation where one can talk about change of the communication paradigm [3]. Many faculty members now also use e-literature which they can find on the web. Today, there are many new ways to find and access digital texts. They could be found, read or downloaded by using international search engines such as Google Scholar [4] or by using national web portals such as Hrčak in Croatia [5]. Scientists could also become members of academic social networks, for example, ResearchGate [6] or Academia.edu [7]. They could ask other scientists to send them emails with the texts they need. Web and related digital technologies have opened many ways for scientists to find and read the literature which they need. There is even a possibility to access literature by using hidden libraries, i.e., digital pirate libraries, for example, Sci-hub [8] and Library Genesis [9]. These libraries contain millions of scientific papers and books which are accessed by many people from all parts of the world.

II. INFORMATION PRACTICES AND LITERATURE IN DIGITAL ENVIRONMENT

It is not surprising that many scientists have changed their habits of looking for literature. For example, majority of Slovenian scientists, especially younger ones, prefer digital literature. Older Slovenian scientists equally often use digital and printed literature. It was also found in this study that in their research papers more than half of study participants cite texts which have digital origins [10]. In a study by Steinerova it was confirmed that Slovakian scientists often use electronic literature sources. Participants also talked about gaps in information infrastructure, about 'gaps between the information needs of scholars and access to information and funding' [11]. In a study written by Duić, Konjevod and Grzunov, the research goal was to explore the extent to which faculty at the University of Zagreb (Croatia) use various Web sources of scientific literature. Research findings clearly indicated that literature from Web sources is highly used by scientists. Google Scholar is the most popular Web source. It was also established that many Croatian scientists very often use portal Hrčak, Directory of open access journals, ResearchGate and Academia.edu. About one fifth of participants very often use pirate web portals Sci-Hub and Library genesis. They use them for the following reasons: texts are not available in other ways; legally available texts are expensive; ease of access. The huge majority of participants is dissatisfied with offer of international scientific journals and papers which are

available in Croatia [12]. This finding indicates the problem of securing the availability of scientific literature. In a study written by Zubac and Tominac it is emphasized that Croatian higher education institutions do not have enough financial resources for payment of expensive subscriptions for printed and electronic scientific journals [13]. This unfavourable situation is also confirmed in a study written by T. Krajna and H. Markulin. After exploring library budgets at the University of Zagreb they found out that the majority of libraries do not have enough financial resources for acquiring scientific literature. Croatian *Ministry of science and education* has co-financed literature procurement, but as support of *Ministry* gradually declined, libraries had to reduce their subscriptions to international scientific journals [14]. However, Croatian scientists have one huge open access source of literature: web portal Hrčak that was created in 2006. Hrčak offers easy tools for publishers of Croatian scientific journals to publish their journals on the web and in open access. The significance of this portal could be confirmed by the fact that 485 journals and 198452 scientific and professional papers were freely available on this portal in January 17, 2019 [7]. Open access policy and movement are answers to very high prices of subscriptions for scientific databases owned by large international publishers. The huge growth of open access movement is confirmed by the fact that the web portal *Directory of open access journals* includes 12422 journals from 129 countries. In these journals there were about 3.68 millions of scientific papers in January 17, 2019 [15].

III. RESEARCH METHODOLOGY

The research goal was to explore the faculty' use of web sources of scientific literature in relation to four variables: age of study participants; gender of participants; field of science in which they are working (social sciences, humanities, technical sciences); their practices of exchanging scientific literature (how often participants ask authors to send them their published texts). The questionnaire was published on the web in the second part of December 2018. Thereafter, the invitation to complete the questionnaire was sent to all employees with teaching and research responsibilities at the three Croatian universities: Juraj Dobrila University of Pula (located in the city of Pula) [16], University North (located in cities of Varaždin and Koprivnica) [17], University of Dubrovnik (located in the city of Dubrovnik) [18]. The invitation was also sent to employees of the four departments of the J. J. Strossmayer University of Osijek (located in the city of Osijek) [19]. Invitation e-mails were sent to 923 faculty employees of these four universities: 173 e-mails for employees in Pula, 123 e-mails for employees in Dubrovnik, 251 e-mails for employees in Varaždin and Koprivnica and 376 e-mails for employees in Osijek. By the beginning of January 2019, the questionnaire was completed by 116 employees of these universities, which work primarily in social sciences, technical sciences and humanities. The survey for this research paper was anonymous, so that participants could more freely give answers about their practices and opinions. Through this research many findings were acquired, however, only part of these findings is presented and analyzed in the paper: there was not enough space to present all findings, therefore, the focus of the paper was on the four aforementioned variables.

IV. FINDINGS

There are about 63% of female participants among 116 participants who answered the questionnaire. The majority of study participants are 40 to 49 years old (about 35%). The majority of study participants are working in the field of social sciences - about 34%. There are about 20% of participants from the field of technical sciences and about 14% of participants from the field of humanities. The questionnaire was filled by about 22% of participants who work at the university in Pula, about 20% of participants who work at the university in Dubrovnik, about 16% of participants who work at the university in Varaždin and Koprivnica, and about 37% of participants who work at the university in Osijek.

A. Analysis based on variable: field of science

In Table 1 the research results are presented in relation to the following fields of science in which study participants are working: humanities (13.8% or 16 participants), technical sciences (19.8% or 23 respondents) and social sciences (33.6% or 39 participants).

In the first line of Table 1, the frequency of their Google Scholar use for access to scientific literature is presented. Participants gave grades from 1 to 5 for this and other statements in the questionnaire. Grades 1 and 2 denote that they never or almost never use Google Scholar, while grades 4 and 5 denote that they often or very often use Google Scholar. The same meaning of these grades applies to all survey statements that are presented in the following text.

Answers to the first question already indicated differences in behavior between participants from different scientific fields. There are 59% of participants from the field of social sciences and about 56% of participants from the field of humanities who often or very often use Google Scholar, in relation to about 39% of participants from the field of technical sciences. In the second line of Table 1, participants' use of portal ResearchGate is presented. There are about 31% of participants from humanities, 48% of participants from the field of technical sciences and about 54% of participants from the field of social sciences who often or very often use this portal. In the third line of Table 1, participants' use of Croatian portal Hrčak is presented. About 81% of participants from humanities often or very often use this portal, in relation to about 69% of participants from the field of social sciences. Only about 26% of participants from the field of technical sciences, often or very often use Hrčak. In the fourth line of Table 1, we can see how often participants ask authors to send them their published texts. Participants from the field of humanities most frequently engage in this activity. There are about 31% of these participants who often or very often ask authors to send them their texts. They are followed by participants from the field of social sciences (about 26%), while the least inclined to engage in this activity are participants from the field of technical sciences (about 17%).

In the last lines of Table 1, the results are presented about how often study participants use three different types of web portals to access scientific literature: Croatian portals, foreign portals and pirate portals. In the seventh line of Table 1, participants' use of Croatian web portals is presented. They are mostly used by participants from the field of humanities - about 94% of those participants use them often or very often, in relation to 59% of participants from the field of social sciences who often or very often use these portals. A surprising fact is that Croatian portals are often or very often used by only about 30% of participants from the field of technical sciences. In the eighth line of Table 1, the results are presented about how often participants use foreign web portals. They are mostly used by participants from the field of social sciences - about 92% of these participants use them often or very often, in relation to about 65% of participants from the field of technical sciences and about 63% of participants from the field of humanities. In the ninth line of Table 1, the results are presented about how often participants use pirate web portals. They are mostly used by participants from the field of humanities - about 38% of them use them often or very often, in relation to about 26% of participants from the fields of social sciences and technical sciences.

TABLE I. PARTICIPANTS' ANSWERS IN RELATION TO THE FIELD OF SCIENCE IN WHICH THEY ARE WORKING

	Humanities		Technical sciences		Social sciences	
	Sources of literature		Sources of literature		Sources of literature	
	grade 1 &2	grade 4 &5	grade 1 &2	grade 4 & 5	grade 1 & 2	grade 4 & 5
Google Scholar	25%	56.3%	21.7%	39.1%	15.4%	59%
Research Gate	37.5%	31.3%	26.1%	47.8%	23.1%	53.9%
Hrčak	12.5%	81.3%	21.7%	26.1%	12.8%	69.2%
Request to auth.	43.8%	31.3%	43.5%	17.4%	48.7%	25.6%
Request to pers. in Cro.	50%	12.5%	47.8%	13.1%	66.7%	18%
Req. to persons from ab.	56.3%	18.8	60.87%	8.7%	76.9%	7.7%
Croatian web por.	0%	93.8%	39.1%	30.4%	15.4%	59%
Foreign web por.	25%	62.5%	8.7%	65.2%	0%	92.3%
Pirate web por.	43.8%	37.5%	43.5%	26.1%	64.1%	25.6%

grade1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

B. Analysis based on variable: age

In Table 2 the research results are presented in relation to the age of study participants. The answers of study participants who don't have more than 39 years of age are presented, in relation to the answers of study participants who are 40 years old and older. There are 43 participants (37.1%) who don't have more than 39 years, and there are 60 participants (60.3%) who are 40 years old and older. There are no age data for 13 participants (11.2%).

In the first line of Table 1, the frequency of their Google Scholar use for access to scientific literature is presented. About 46% of younger participants (up to 39 years of age) often or very often use this portal, in relation to about 50% of the older participants (40 years old and older). In the second line of Table 2, participants' use of portal ResearchGate is presented. About 46% of younger participants often or very often use this portal, in relation to 51% of older participants. In the third line of Table 2, participants' use of Croatian portal Hrčak is presented. Older participants are significantly more frequent users of Hrčak. There are about 58% of them who often or very often use this portal, in relation to 42% of younger participants. In the fourth line of Table 2, we can see how often study participants ask authors to send them their published texts. Older participants are significantly more frequent in this activity - about 33% of them often or very often ask authors for texts, in relation to about 19% of younger participants. Conversely younger participants are more often asking texts from people from Croatia who are not authors, but who have these texts. In the fifth line of Table 2, the results are presented about how often participants ask persons from Croatia who are not authors of requested texts, to send them these scientific texts. About 19% of younger participants often or very often ask for texts, in relation to about 10% of older participants.

TABLE II. PARTICIPANTS' ANSWERS IN RELATION TO THEIR AGE

	Participants who don't have more than 39 years		Participants who are at least 40 years old	
	Sources of lit.		Sources of lit.	
	grade 1 & 2	grade 4 & 5	grade 1 & 2	grade 4 & 5
Google Scholar	18.6%	46,5%	27.2%	50%
ResearchGate	25.6%	46.5%	24.3%	51.4%
Hrčak	23.3%	41.9%	14.3%	58.6%
Request to authors	55.8%	18.6%	50%	32.9%
Request to per. in Cr.	60.5%	18.6%	65.7%	10%
Req. to per. from abroad	67.5%	16.3%	65.7%	10%
Sci-Hub	39.5%	44.2%	69.6%	17.2%
Library Genesis	58.14%	18.6%	70%	14.3%
Croatian web portals	27.9%	41.9%	20%	60%
Foreign web portals	4.7%	76.7%	5.7%	77.2%
Pirate web portals	39.5%	44.2%	58.6%	21.4%

grade1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

In the sixth line of Table 2, the results are presented about how often study participants ask persons from abroad who are not authors of requested texts, to send them these texts. About 16% of younger participants often or very often ask for texts, in relation to about 10% of older participants. In the seventh line of Table 2, the results are presented about how often participants use Sci-Hub, pirate web containing millions of scientific papers. Younger participants are considerably more frequent users

- about 44% of them use it often or very often, in relation to about 17% of older participants. In the eighth line of Table 2, the results are presented about how often participants use another pirate web portal: Library Genesis, the portal containing millions of scientific books. Younger participants are also more frequent users of this portal - about 19% of them use it often or very often, in relation to about 14% of older participants.

In the last lines of Table 2, the results are presented about how often younger and older participants use three different types of web portals to access scientific literature: Croatian, foreign and pirate portals. In the ninth line of Table 2, participants' use of Croatian web portals is presented. They are mostly used by older participants - about 60% of those participants use them often or very often, in relation to about 42% of younger participants. In the tenth line of Table 2, the results are presented about how often participants use foreign web portals. They are used equally frequent by older and younger participants: 77% of older and younger participants use them often or very often. In the eleventh line of Table 2, the results are presented about how often participants use pirate web portals. They are mostly used by younger participants - about 44% of them use them often or very often, in relation to about 21% of older participants.

C. Analysis based on variable: gender

In Table 3 the research results are presented in relation to the gender of study participants. There were 62.9% or 73 female participants and 35.3% or 41 male participants. In the first line of Table 3, the frequency of Google Scholar use for access to scientific literature is presented.

TABLE III. PARTICIPANTS' ANSWERS IN RELATION TO THEIR GENDER

	Woman			Man	
	Sources of literature			Sources of literature	
	grade 1 & 2	grade 4 & 5		grade 1 & 2	grade 4 & 5
Google Scholar	19.2%	57.5%		31.7%	31.7%
ResearchGate	26%	52.1%		22%	43,9%
Hrčak	16.44%	63%		22%	31.7%
Croatian web portals	20.6%	61.7%		29.3%	36.6%
Foreign web portals	5.5%	82.2%		4.9%	65.9%
Pirate web portals	53.4%	30.1%		46.4%	31.7%

grade1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

Female participants are considerably more frequent users of Google Scholar - about 58% of them often or very often use it, in relation to about 32% of male participants. In the second line of Table 3, participants' use of portal ResearchGate is presented. Female participants are also more frequent users of this portal - about 52% of female participants often or very often use ResearchGate, in relation to about 44% of male participants. In the third line of Table 3, participants' use of portal Hrčak is presented. Female participants are considerably more frequent users. Hrčak is used often or very often by 63% of female participants, in relation to about 32% of male participants.

In the last lines of Table 3, the results are presented about how often male and female participants use three different types of web portals to access scientific literature: Croatian portals, foreign portals and pirate portals. In the fourth line of Table 3, use of Croatian web portals is presented. They are mostly used by female participants - about 62% of female participants use them often or very often, in relation to about 37% of male participants. In the fifth line of Table 3, the results are presented about how often participants use foreign web portals. They are also considerably more often used by female participants - about 82% of female participants use them often or very often, in relation to about 66% of male participants. In the sixth line of Table 3, the results are presented about how often participants use pirate web portals. They are used equally frequent by male and female participants: about 30% of participants of both genders use them often or very often.

D. Analysis based on variable: practices of scientific literature exchange

In Table 4 the research results are presented in relation to the frequency with which study participants are asking authors to send them their texts. In "Part 1a" and "Part 1b" of Table 4, there is a presentation of the characteristics and answers of study participants who almost never or never ask authors to send them their texts. There are 50.9% of participants in this group, i.e., 50 participants who gave grades 1 or 2, as an answer to the question about how often they ask authors to send them their texts. In "Part 2a" and "Part 2b" of Table 4, there is a presentation of the characteristics and answers of study participants who often or very often ask authors to send them their texts. There are 20.7% of participants in this group, i.e., 24 participants who gave grades 4 and 5, as an answer to the question about how often they ask authors to send them their texts.

In "Part 1a" of Table 4, there is a presentation of characteristics of study participants who never or almost never ask authors to send them their texts: they are mostly female - about 66%. About 32% of these participants are in the field of social sciences, 12% are in the field of humanities and 17% are in the field of technical sciences. In "Part 2a" of Table 4, there is a presentation of characteristics of participants who often or very often ask authors to send them their texts: they are mostly female - about 67%; about 42% are in the field of social sciences, 21% are in the field of humanities and about 17% are in the field of technical sciences. These findings indicate that, with regard to the field of science, there are some differences in characteristics of participants who never or almost never ask authors to send them their texts, in relation to characteristics of participants who often or very often ask authors to send them their texts. However, there are no considerable differences with regard to gender between these two groups of participants, because we found almost the same proportion of female and male participants in both groups.

TABLE IV. PARTICIPANTS' ANSWERS IN RELATION TO THEIR PRACTICES OF EXCHANGING SCIENTIFIC LITERATURE

	Part 1a. Participants who never or almost never ask authors to send them their published texts		Part 2a. Participants who often or very often ask authors to send them their published texts	
	Participants' characteristics		Participants' characteristics	
Woman	66.1%		66.7%	
Man	33.9%		33.3%	
Social sciences	32.2%		41.7%	
Humanities	11.9%		20.8%	
Technical sciences	17%		16.7%	
	Part 1b. Sources of literature		Part 2b. Sources of literature	
	grade 1 & 2	grade 4 & 5	grade 1 & 2	grade 4 & 5
Google Scholar	28.8%	50.8%	25.1%	54.2%
ResearchGate	39%	39%	12.5%	66.7%
Sci-hub	66.1%	28.8%	50%	37.5%
Croatian web portals	20.3%	55.9%	29.2%	50.1%
Foreign web portals	6.8%	72.9%	4.2%	91.7%
Pirate web portals	55.9%	28.8%	45.8%	41.7%

grade 1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

In "Part 1b" and "Part 2b" of Table 4, there is a presentation of answers of participants about the use of different web portals. Participants who never or almost never ask authors to send them their texts are using Google Scholar and foreign web portals with the similar frequency with which these portals are used by participants who often or very often ask authors to send them their texts.

V. CONCLUSION

Findings indicate that there are some significant differences in using web portals, with regard to various groups of study participants. Here are examples of findings with pronounced differences between groups.

Croatian web portals, for example portal Hrčak, are very frequently used by almost all participants from the field of humanities, almost two thirds of participants from the field of social sciences and only about one third of participants from the field of technical sciences. They are mostly used by older participants and female participants. One of the reasons why Hrčak is often used by participants from the fields of humanities and social sciences could be the fact that almost about 53% of 485 active journals freely available at Hrčak, belong to the fields of humanities (26.4%) and social sciences (26.3%). At Hrčak, there are only 11% of active journals from the field of technical sciences, (January 17, 2019) [5].

Foreign web portals are very frequently used by almost all participants. However, Google Scholar is a popular foreign portal, which is used in somewhat different pattern then average foreign web portal. Namely, there are about 60% of participants from the fields of social sciences and humanities who often or very often use it, in relation to about 39% of participants from the field of technical sciences. One of the possible reasons why participants from the field of technical sciences considerably less often use Google Scholar could be that they have their specialized international web portals so they have less need to use web portal of general type, such as Google Scholar.

Foreign web portals are mostly used by female participants - about 82% of female participants use it often or very often, in relation to about 66% of male participants. It is interesting to note that among foreign web portals the social networks for scientists - ResearchGate and Academia.edu - are often used, especially ResearchGate.

Finally, there are also some considerable differences in the frequency of pirate web portals use. These portals are mostly used by participants from the field of humanities - about 38% of them use these portals often or very often, in relation to about 26% of participants from the fields of social sciences and technical sciences. Pirate web portals are mostly used by younger participants - about half of them use them often or very often, in relation to about one fifth of older participants. Interesting fact is that pirate web portals are used equally frequent by male and female participants. This fact is in contrast with findings from previous research in which it was established that female faculty use these portals considerably less often [20].

All these findings about differences among the most frequent users of different types of web portals, could be summarized as follows: a) the most frequent users of Croatian web portals are participants from the field of humanities, participants of older age and female participants; b) the most frequent users of foreign web portals are participants from the field of social sciences and female participants; participants of all ages use them equally; c) the most frequent users of pirate web portals are participants from the field of humanities; participants of both genders use them equally.

The questions that could be raised in future research is: Are there certain stable characteristics related to the use of web-based literature by faculty? For example, this and previous research project have established that the most frequent users of Croatian web portals are participants from the field of humanities, participants of older age and female participants. Is this just a coincidence or is it a stable finding which could be validated by future research using different samples of participants? Also, this and previous research project have established that the most frequent users of foreign web portals are participants from the field of social sciences and female participants. These findings should also be tested by including members of different faculty in future research projects. Also, comparisons between faculty from different countries, based on the research methodology presented in this paper, could be fruitful for further advancement of

understanding information behaviour differences and similarities between various groups of university teachers and researchers.

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Mapping the Hot Topics in Library and Information Science Field in Period 2015-2018 Year

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***Abstract* - Scientometrics encompasses evaluations of science and is often called science about science. In this paper scientometrics analysis was conducted in purpose of science mapping to provide better understanding of library and information science (LIS) field. The scientometrics analysis, in period 2015-2018 year, encompassed the total of 21 of LIS journals included into the first quartile within scholarly database Web of science. The total of 460 the most cited documents were extracted and analysed. The keywords of these 460 the most cited documents were grouped quantitatively according to their frequencies and qualitatively according to their semantics into ten broader categories or so called hot topics. The following ten hot topics in LIS field were recognized: scholarly communication, social media, information security and privacy, internet of things, big data analytics, electronic/mobile health, e-government, knowledge management, information retrieval and information behaviour. The revealed hot topics within the LIS field could be used as the directions for teachers, librarians, publishers, managers, students etc.**

Keywords – hot topics; mapping; scientometrics

I. INTRODUCTION

Scientometrics is usually defined as quantitative study of science and technology [5]. Scientometrics encompasses scientific evaluations of science, measuring and analysing of science. In literature scientometrics is often named as science about science. The field of scientometrics is wider than the field of bibliometrics and encompasses quantitative aspects of science, scientific policy, scientific administration etc. In scientometrics researches the key role has the quality of bibliographical metadata sources and tracking the impact of publications [10]. Scientometrics researches could quantify scientific input data as well as scientific output data. Primary input data include workforce and financial resources and secondary input data include for example the number of working hours of each scholar. However, a very small number of scientometrics researches are focused on these input data but output data are very employed. Some of scientific output data are the number of authors, authors' geographical distribution, the number of articles per year, the number of citations per article or per author etc. [2]. According to [7] C. S. Wilson emphasized that scientometrics is not only based on measuring science and technology in regard to published literature but also on fields such as research practices of scholars, social and organizational structures, management of research and development, research of the role of science and technology in national economy, governmental policy etc. Scientometrics is a scientific field which mostly studies texts and authors. It can be distinguished two dimensions of text, dimension of documentation and social dimension. Within the dimension of documentation, text includes concepts such as journals, articles in journals, references etc. Within the social dimension, text includes classification of authors, institutions and countries [4]. According to [3], scientometrics researches can be divided in regards to the audience for whom the research is dedicated. The first group of basic scientometrics researches conduct for scientometricians and tend to improve theories and methods. The second bigger group of scientometrics researches explore scientific disciplines and enable better understanding of development and overview of condition within scientific disciplines. This group includes researches about journals, authors, institutions etc. The last group of scientometrics researches provide indicators for management of science and business. This group is the smallest one but financially the most important. Besides evaluation of authors and articles scientometrics can be used in purpose of science mapping to provide better understanding of scientific disciplines and to enhance information retrieval systems of scientific literature as well as make these systems richer [10]. Within scholarly literature impact of publications and relationships of trust and validation are present in form of citations. Citations are very important characteristics of scholarly texts. Besides standard bibliographical records on publications, scientometrics uses information about network of citations between scholarly publications. Citation databases besides bibliographical information consist of data about citations [10]. Citation index of scholarly texts is like database which besides bibliographical overview of document also provides information about network of citations between certain publications [10]. Undoubtedly, positive turnover of science about science happened when scholar Eugen Garfield introduced Science Citation Index in 1964 year. Namely, this innovation enabled statistical analysis of huge amounts of scientific literature. Many famous scholars such as Derek de Solla Price and Robert Merton recognized the value of Garfield's innovation, Price from history of science perspective and Merton from sociological perspective [8]. Citation indices enable view in the past and the future and in relationships between

articles in regard to studied literature. It enables identification of the impact of articles or authors within their scientific field. It is possible according to references which authors use in their articles [1]. Citation analysis are considered as the main instrument of scientometrics and these analyses are based upon available information within citation databases [6]. Citation databases are secondary sources of scientific and professional literature and their main purpose is to provide relevant information. Thus there is a selection mechanism for indexing the journals and other publications into citation databases [9]. The access to databases as well as databases itself are very important aspect in conduction of scientometrics analysis. According to van Leuwen there are two approaches to databases namely two different search strategies of databases, descriptive and evaluative approach [10]. Some of main disadvantages of scientometrics analyses emphasized in literature are that scientometrics analyses are mostly conducted within literature written in English and within articles in journals while other kinds of publications are excluded from analyses [10]. Nowadays, the most popular citation databases are Web of science provided by Clarivate Analytics and Scopus provided by Elsevier. The scientometrics analysis in this paper is based upon information provided within Web of science database regarding library and information science (LIS) field. Namely, library and information science (LIS) is the academic and professional study of how information and information carriers are produced, disseminated, discovered, evaluated, selected, acquired, used, organized, maintained, and managed. The mapping of hot topics is very useful for discovering emerging trends within certain field. The main research problem in this paper is to determine the hot topics within LIS field in period 2015-2018 year.

After the introduction which gives theoretical insight and literature review regarding the theme of the paper follows the description of the method used in the research. Third section of the paper consists of the overview of gained research results and related discussion. The last concluding section of the paper brings the main findings of the research and points out its possible implications.

II. METHOD

In this paper scientometrics analysis was conducted in purpose of science topics' mapping to provide better understanding of library & information science field. The time period of conducted scientometrics analysis was from 2015 year till 2018 year (excluding 2018 year). The scientometrics analysis encompassed the total of 21 of library & information science journals included into the first quartile within scholarly database Web of science according to the list in Table in Appendix.

The total of 460 the most cited documents were extracted from these 21 journals in library & information science field with the limit of 10 citations minimally per document. The keywords of these 460 the most cited documents were grouped quantitatively according to their frequencies and qualitatively according to their semantics into ten broader categories or so called hot topics. These ten categories actually the hot topics within the library & information science field were ranked in regard to the keywords' frequencies inside of each hot topic.

III. RESULTS AND DISCUSSION

The most frequent keywords of the most cited documents were grouped into ten hot topics. The first rank out of ten hot topics in library & information science field belongs to the topic of *scholarly communication.* In Table I it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *scholarly communication*. The most frequent keywords within the topic of *scholarly communication* in a descending order are *impact, evaluation, citation analysis, citations, indicators, bibliometrics, scientometrics, altmetrics, scientific collaboration, Web of Science, Mendeley, qualitative research, Google Scholar, h-index, scholarly publishing, scientific impact, informetrics, journal impact factor, webometrics* and *scholarly communication.*

TABLE I. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF SCHOLARLY COMMUNICATION

Scholarly communication	Keyword frequency
Impact	72
Evaluation	44
Analysis	29
Citation analysis	28
Citations	24
Indicators	22
Bibliometrics	17
Scientometrics	13
Metrics	12
Scopus	12
Altmetrics	11
Scientific collaboration	9
Web of Science	9
Mendeley	8
Scholarly publishing	5
H-index	5
Google Scholar	5
Qualitative research	5
Scientific impact	4
Informetrics	4
Journal impact factor	4
Webometrics	3
Scholarly communication	2

The second rank out of ten hot topics in library & information science field belongs to the topic of *social media.* In Table II it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *social media*. The most

frequent keywords within the topic of *social media* in a descending order are *communication, social media, adoption, satisfaction, commerce, Twitter, Facebook, social networking sites, e-shopping, e-commerce, technology addiction, technostress, m-banking, cyberbullying, consumers, m-commerce* and *communication overload.*

TABLE II. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF SOCIAL MEDIA

Social media	Keyword frequency
Communication	63
Social media	50
Adoption	40
Satisfaction	25
Commerce	23
Twitter	21
Facebook	17
Social networking sites	16
E-shopping	15
Technology addiction	9
E-commerce	9
Technostress	7
M-banking	2
Cyberbullying	1
Communication overload	1
Consumers	1
M-commerce	1

The third rank out of ten hot topics in library & information science field belongs to the topic of *information security and privacy*. In Table III it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *information security and privacy*. The most frequent keywords within the topic of *information security and privacy* in a descending order are *trust, information privacy, information security, accountability, protection, information security policy, software piracy, threats, security management, personal information, research and innovation policy, awareness of monitoring, unauthorized access, information systems security* and *IT security risks.*

TABLE III. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF INFORMATION SECURITY AND PRIVACY

Information security and privacy	Keyword frequency
Trust	38
Information privacy	21
Information security	12
Accountability	8
Protection	5
Information security policy	4
Software piracy	4
Threats	3
Security management	2
Research and innovation policy	1
Awareness of monitoring	1
Unauthorized access	1
Information systems security	1
IT security risks	1
Data theft	1
Privacy paradox	1
Personal information	1

The fourth rank out of ten hot topics in library & information science field belongs to the topic of *internet of things*. In Table IV it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *internet of things*. The most frequent keywords within the topic of *internet of things* in a descending order are *IT, virtual, cloud computing, digital divide, internet of things, digitization, digital platforms, digital disruption, mobilization, public cloud, hybrid cloud, private cloud, smart environments* and *internet of everything.*

TABLE IV. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF INTERNET OF THINGS

Internet of things	Keyword frequency
IT	24
Virtual	23
Cloud computing	11
Digital divide	5
Internet of things	4
Digitization	4
Digital platforms	2
Digital disruption	2
Mobilization	2
Public cloud	1
Hybrid cloud	1
Private cloud	1
Smart environments	1
Internet of everything	1

The fifth rank out of ten hot topics in library & information science field belongs to the topic of *big data analytics*. In Table V it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *big data analytics*. The most frequent keywords within the topic of *big data analytics* in a descending order are *classification, big data, data integration, mining, information extraction, online credibility, text mining, data mining, relevance, overload, big data policy, vocal data mining, big data analytics, big data definition, information dissemination, social media mining, trajectory mining, data mining platform* and *stream mining.*

TABLE V. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF BIG DATA ANALYTICS

Big data analytics	Keyword frequency
Classification	24
Big data	21
Data integration	12
Mining	12
Information extraction	10
Online credibility	9
Text mining	7
Overload	3
Relevance	3
Data mining	3
Big data policy	1
Vocal data mining	1
Big data analytics	1
Big data definition	1
Information dissemination	1
Social media mining	1
Trajectory mining	1
Data mining platform	1
Stream mining	1

The sixth rank out of ten hot topics in library & information science field belongs to the topic of *electronic/mobile health*. In Table VI it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *electronic/mobile health*. The most frequent keywords within the topic of *electronic/mobile health* in a descending order are *electronic health records, m-health, e-health, terminology quality assurance, telemedicine, health information exchange, biomedical ontology, health services, electronic medical record, virtual medical records, medical informatics, International classification of diseases, consumer health informatics* and *health care data.*

TABLE VI. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF ELECTRONIC/MOBILE HEALTH

Electronic/mobile health	Keyword frequency
Electronic health records	24
M-health	12
E-health	6
Terminology quality assurance	5
Telemedicine	4
Health information exchange	4
Consumer health informatics	1
Health care data	1
Electronic medical record	1
Virtual medical records	1
Medical informatics	1
International classification of diseases	1
Biomedical ontology	1
Health services	1

The seventh rank out of ten hot topics in library & information science field belongs to the topic of *e-government*. In Table VII it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *e-government*. The most frequent keywords within the topic of *e-government* in a descending order are *open government, e-government, citizens, government data, digital government, smart city, digital government innovation, government 2.0, collaborative democracy, reengineering open government, smart government, e-service, e-quality* and *service quality.*

TABLE VII. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF E-GOVERNMENT

E-government	Keyword frequency
Open government	21
E-Government	14
Citizens	7
Government data	7
Digital government	6
Smart city	4
Digital government innovation	3
Government 2.0	2
We-Government	1
Collaborative democracy	1
Reengineering open government	1
Smart government	1
E-service	1
E-quality	1
Service quality	1

The eight rank out of ten hot topics in library & information science field belongs to the topic of *knowledge management*. In Table VIII it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *knowledge management*. The most frequent keywords within the topic of *knowledge management* in a descending order are *collaboration, exchange, web 2.0, knowledge management, open data, business intelligence, transparency, knowledge transfer, knowledge sharing, project management, open access journals, business information architecture, open access publications, open data technology, linked open data, knowledge networks, linked references, datasets* and *open data ecosystem.*

TABLE VIII. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF KNOWLEDGE MANAGEMENT

Knowledge management	Keyword frequency
Collaboration	20

Exchange	15
Web 2.0	14
Knowledge management	13
Open data	13
Business intelligence	9
Transparency	9
Knowledge transfer	5
Knowledge sharing	3
Project management	2
Open access journals	2
Business information architecture	1
Open access publications	1
Open data technology	1
Linked open data	1
Knowledge networks	1
Linked references	1
Datasets	1
Open data ecosystem	1

The ninth rank out of ten hot topics in library & information science field belongs to the topic of *information retrieval*. In Table IX it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *information retrieval*. The most frequent keywords within the topic of *information retrieval* in a descending order are *natural language processing, culture, cross-lingual information retrieval, semantic similarity, cross-lingual text mining, cross-lingual knowledge transfer, text retrieval, information storage, information retrieval, concept similarity, semantic relatedness, social inequality, multilingual probabilistic topic models* and *media multiplicity.*

TABLE IX. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF INFORMATION RETRIEVAL

Information retrieval	Keyword frequency
Natural language processing	9
Culture	8
Cross-lingual information retrieval	3
Cross-lingual text mining	2
Semantic similarity	2
Cross-lingual knowledge transfer	1
Text retrieval	1
Information storage	1
Information retrieval	1
Concept similarity	1
Semantic relatedness	1
Social inequality	1
Multilingual probabilistic topic models	1
Media multiplicity	1

The tenth rank out of ten hot topics in library & information science field belongs to the topic of *information behaviour*. In Table X it can be seen the list of the most frequent keywords of the most cited documents encompassed by the topic of *information behaviour*. The most frequent keywords within the topic of *information behaviour* in a descending order are *planned behaviour, behavioural intention, interactivity, search engines, big five, user interface, commerce behaviour, costumer experience, knowledge sharing behaviour, seeking behaviour, information seeking, individual differences, information society, information searching, consumer behaviour, information overload, personalized search* and *database searches.*

TABLE X. KEYWORDS' FREQUENCY WITHIN THE TOPIC OF INFORMATION BEHAVIOUR

Information behaviour	Keyword frequency
Planned behaviour	8
Behavioural intention	6
Interactivity	5
Search engines	4
Big five	4
User interface	1
Commerce behaviour	1
Costumer experience	1
Knowledge sharing behaviour	1
Seeking behaviour	1
Information seeking	1
Individual differences	1
Information society	1
Information searching	1
Consumer behaviour	1
Information overload	1
Personalized search	1
Database searches	1

The research results revealed the ten hot topics in library & information science field in period 2015-2018 (excluding 2018) year. The hottest topic was the topic of *scholarly communication*. After the hottest topic of *scholarly communications* in a descending order follow the other nine recognized hot topics: *social media, information security and privacy, internet of things, big data analytics, electronic/mobile health, e-government, knowledge management, information retrieval* and *information behaviour*. The most frequent keywords (with frequency 20 and up) overall in all the analysed the most cited documents within the journals according to the list in Table 1. are: *impact, communication, social media, adoption, trust, evaluation, citations, indicators, analysis, citation analysis, commerce, satisfaction, information privacy, IT, virtual, big data, classification, electronic health records, collaboration* and *open government.* Although some of the most frequent keywords overlap

with the name of the determined hot topics, there are hot topics which name was induced semantically. Namely, in the process of recognition of hot topics it was considered not just the obtained quantitative data - keywords frequencies, but also qualitative data - semantics of extracted keywords.

IV. CONCLUSION

In this paper scientometrics analysis was conducted in purpose of science mapping to provide better understanding of library & information science field. The recognized following ten hot topics in library & information science field in period 2015-2018 (excluding 2018) year in a descending order are *scholarly communication, social media, information security and privacy, internet of things, big data analytics, electronic/mobile health, e-government, knowledge management, information retrieval* and *information behaviour*. The revealed hot topics within the library & information science field could be used as the directions for teachers, librarians, publishers, managers, students etc. Namely, teachers could focus their research projects, teaching practices or organization of scientific and professional conferences in regard to the map of the hot topics within the library & information science field. Students could also have benefit if choose some of the hot topics for the research within their seminars or final works. The librarians and publishers could adjust their services according to the map of recognized hot topics and enhance their information retrieval systems of scientific and professional literature.

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APPENDIX: TABLE. THE LIST OF LIBRARY & INFORMATION SCIENCE JOURNALS IN FIRST QARTILE IN SCHOLARLY DATABASE WEB OF SCIENCE

MIS QUARTERLY
JOURNAL OF INFORMATION TECHNOLOGY
INFORMATION SYSTEMS JOURNAL
JOURNAL OF COMPUTER-MEDIATED COMMUNICATION
GOVERNMENT INFORMATION QUARTERLY
INTERNATIONAL JOURNAL OF INFORMATION MANAGEMENT
JOURNAL OF THE AMERICAN MEDICAL INFORMATICS ASSOCIATION
JOURNAL OF STRATEGIC INFORMATION SYSTEMS
INTERNATIONAL JOURNAL OF COMPUTER –SUPPORTED COLLABORATIVE LEARNING
TELEMATICS AND INFORMATICS
INFORMATION & MANAGEMENT
JOURNAL OF INFORMETRICS
EUROPEAN JOURNAL OF INFORMATION SYSTEMS
INFORMATION SYSTEMS RESEARCH
INTERNATIONAL JOURNAL OF GEOGRAPHICAL INFORMATION SCIENCE
INFORMATION PROCESSING & MANAGEMENT
JOURNAL OF MANAGEMENT INFORMATION SYSTEMS
JOURNAL OF THE ASSOCIATION FOR INFORMATION SCIENCE AND TECHNOLOGY
RESEARCH EVALUATION
SOCIAL SCIENCE COMPUTER REVIEW
SCIENTOMETRICS

Implementation of blended learning in Computer Science

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Abstract – The main objective of this paper is to test the effectiveness of blended learning when compared to the traditional approach in teaching Computer Science. Three hypotheses were formed to measure students' knowledge levels after attending classes implementing one of the two teaching approaches. The first hypothesis predicted that teaching Computer Science without the use of ICT will meet students' educational needs and objectives (H1). The second hypothesis predicted that the use of electronic materials in Computer Science classes will enable students to reach a higher level of knowledge in Computer Science (H2), whereas the third hypothesis stated that the students who attend Computer Science classes in which the teaching method included electronic learning will be more satisfied with the acquired knowledge than other students (H3). [5]

I. INTRODUCTION

The primary concern of this paper and the conducted studies is related to the three hypotheses stated in the abstract. Before the research project was conducted it had been assumed that blended learning will be as effective as traditional learning allowing that research data might prove that blended learning increases students' knowledge level. This paper proves that the implementation of blended learning approach in education helps establish an easier connection between theoretical knowledge and its practical application. [5]

The conducted studies prove that the implementation of blended learning in teaching Computer Science increases students' knowledge level and meets their educational needs and objectives. [5]

II. THE CONCEPT OF KNOWLEDGE

Having knowledge, which is a symbol of power in the society, should provide an individual with greater ability to manage resources, and consequently, bestow the individual with power. Michel Foucault is one of the sociologists who left a significant mark in the history of sociology of knowledge. According to Foucault, knowledge is "created" under the influence of the surroundings in order to keep the control and stability in the society.

In his view, the society imposes its knowledge mechanisms, and the individual is forced to conform to the norms of the society in order to avoid being "punished". [1]

A modern man's knowledge increases on a daily basis mostly due to the development of the technology we depend on. The education system, as well as any other system developed in the modern societies, has become a part of the knowledge apparatus that in technology sees the future and power of our civilization. All of us belong to that system. Education is part of our lives, from birth to death, with the goal to become as efficient as possible in what we work on, offer and produce. [5]

Different social media, digital tools, social networks have all made an impact on the development and concept of teaching in our modern age. Learning is not oriented only on the traditional teaching method, or *face-to-face* instruction, nowadays the method of *blended learning* is used in teaching, a combination of traditional teaching methods and modern technology. The instruction can be delivered as a combination of *ICT supported teaching and learning* and *online* teaching, that is *fully online*. These teaching models are becoming increasingly widespread ways of learning among young generations across the world. [5]

A. Blended learning

Blended learning is a growing trend in many educational institutions. Teachers and students appreciate many advantages of blended learning, some of them include: flexibility of learning anywhere, at any time and individually. Blended learning is becoming the preferred learning method on a large scale, as a system that can keep pace with future. One of the papers on the quality of blended learning presented an evaluation study of the effectiveness of blended learning when compared to traditional learning styles, on the example of software engineering course. The research enabled the comparison of the results of the evaluation of the approaches implemented in the experimental and control group. The research showed that blended learning was as effective as traditional learning. [2]

In another research project focused on the application of modern technologies in teaching it was established that the process of learning was changing its focus from acquiring and adding to objective knowledge to modifying the ingrained knowledge, as well as creating and making new decisions, and creating new resources. [3]

III. RESEARCH ON THE EFFECTIVENESS OF BLENDED LEARNING

The conducted study was supposed to determine the effectiveness of blended learning when compared to traditional learning methods in Computer Science teaching. The research involved two stages, and the application of the experimental method. The research process included measuring knowledge levels of a group attending classes that implemented blended learning model and a group attending classes taught by using a traditional approach. In the first stage of the research a pilot study was conducted. Two groups, control and experimental, were formed for the purpose of both pilot and main studies. The pilot study was conducted to assess student's prior knowledge by means of a preliminary test, before introducing experimental factors. The acquired

knowledge was measured in the main study by means of a post-test after the introduction of experimental factors.

The experimental research factors included four teaching units, which are part of the lesson MS Excel Spreadsheets. The test that measured prior knowledge and acquired knowledge contained 34 questions. The same test was given to both experimental and control group of students that were included in the pilot study and the main study. [5]

The control group of students attended classes taught by using the traditional method. They were taught four units that comprise the lesson on Spreadsheets. During the experiment the students attended the classes by listening to the lectures, taking notes, and using a Computer Science textbook. The experimental group of students attended classes that covered four units that are part of the lesson on Spreadsheets in a blended learning environment. During the experiment the students attended the classes by listening to the lectures and taking notes, using an online Computer Science manual. They used the MS Excel spreadsheet program to complete exercises and tasks. The students used an *online* portal *Računalstvo-učimo zajedno* (Eng. *Computer Science – Let's learn together)* to perform the assigned tasks. [5]

A. Number or study participants

The pilot study involved 90 participants. In the control group there were 45 students, 25 students were attending a lyceum, and 20 were attending a vocational school. There were 22 male students, 9 from the lyceum, and 13 from the vocational school. 23 female students participated, 16 from the lyceum and 7 from the vocational school. The same number of students participated in the pilot study of the experimental group. There were 90 participants included in the main study. In the control group there were 45 students, 25 students were attending a lyceum, and 20 were attending a vocational school. There were 22 male students, 9 from the lyceum, and 13 from the vocational school. 23 female students participated, 16 from the lyceum and 7 from the vocational school. The same number of students participated in the main study of the experimental group. [5]

B. Sample

The average age of the students who participated in the study was 16 years, and both sexes were equally represented in the research (male participants = 48,88%, female participants = 51,11%). A sample identical to the one from the pilot study was used in the main study for both control and experimental group. The age of all participants was 15,63 ± 0,57 years (arithmetic mean ± standard deviation). *Lyceum* students were on average somewhat older than (16,00 ± 0,40) vocational school students (15,15 ± 0,36). [5]

B. Research plan

Students' knowledge was measured at the first levels of Bloom's Taxonomy, that is, students' factual, conceptual and procedural knowledge were measured. The limiting factor in the preliminary test stage was the prior knowledge of some students.

Most *lyceum* students who participated in the study had attended Computer Science as elective class in the primary school, ratio being 95% to 5% (attended – did not attend).

The number of students of the vocational school who attended the elective class Computer Science had a ratio of 50:50. Due to the stated limiting factors the students were divided in two groups, control and experimental. That way it was ensured that there is an equal number of students in both groups who did and did not attend Computer Science class in the primary school. [5]

According to the results from the pilot study this distribution of students helped reduce a greater impact of the limiting factors. Knowledge differences after the preliminary test were negligible. After introducing the experimental factors in the main study, the acquired results indicated that the knowledge of the students in the experimental group exceeded the knowledge of the students in the control group. By comparing the prior and acquired knowledge students' cognitive skills were tested. The preliminary test and the post-test examined the factual, conceptual and procedural knowledge at first levels of Bloom's taxonomy, the first and second research hypotheses. Students' attitudes regarding their satisfaction level with the acquired knowledge were also measured, for each group, to test the third research hypothesis. [5]

The following research results are described in the paper: [5]

- Pilot study based on the preliminary test taken by the control and experimental group.
- Main study based on the post-test taken by the control and experimental group.
- Histograms of obtained preliminary test results.
- Histograms of obtained post-test results.
- Research at schools during preliminary test stage.
- Research at schools during post-test stage.
- Average success results analysis.
- Analysis of acquired knowledge satisfaction level for the control group.
- Analysis of the acquired knowledge satisfaction level for the experimental group.
- Questions-based analysis.
- Group-based analysis.

The study analysis was performed via tools Statistica and MS Excel by means of the following statistical procedures: Student's T-test, Chi-square test, tools for calculation of frequency values and histogram creation. [5]

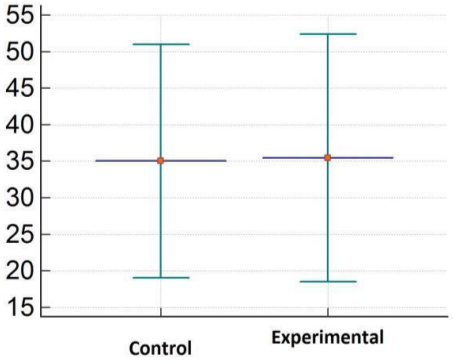
IV. BLENDED LEARNING EFFECTIVENESS ANALYSIS

This part of the paper presents the study data obtained via programs Microsoft Excel and Statistica. The study was conducted in 45 minutes, and the score range of the test used for the purpose of the study was from 0 to 82. The study data are categorized in two groups. The first group of data encompasses the results of the preliminary test, and the second group the results of the post-test. All data are presented in table form, and part of it is presented graphically. [5]

A. Study results for the control and experimental groups in the preliminary test stage

Preliminary test results represent prior knowledge of the students and are presented in table and graphical form. The study involved 90 students, 45 in the control group and 45 students in the experimental group. Control and experimental group scored similarly on the test, p=0,903 (Student's T test). The control group scored on average 35,022 ± 15,972 (arithmetic mean ± standard deviation) points, whereas the experimental group scored on average 35,444 ± 16,939 points (Figure 1).

Independent T-test was used to establish whether there are significant differences between the two groups, the control and experimental group, regarding the level of prior knowledge, and based on the analysis of points scored in the preliminary test. [5]



p=0,903; Student's T-test=0,122

Figure 1. Preliminary test score differences between the experimental and control group

The obtained values t=0,122 with significance level p=0,903 > 0,05; df=88 degrees of freedom, standard deviation=15,972 for the control group and 16,939 for the experimental group indicate that at the confidence level of 95% there is no statistically significant difference between the populations the samples come from. According to the T-test results with value of p>0,05, null hypothesis can be accepted. The obtained results show that there is no difference in prior knowledge level between the control and experimental groups.

The following calculations and data analysis confirm these results. Table 1 gives an overview of the values of T-test and p values, but also of the highest and lowest values MIN-MAX, and in the Figure 2. the data set range is displayed in lines. [5]

Table 1. Preliminary test values

PRELIMINARY TEST Groups	T-test Value	Sig. diff.	Range MIN MAX	
Control vs. Experimental	t= 0,122 p=0,903	NO	2-2	63-67

Figure 2. Y-axis shows the number of points scored, and the X-axis the number of participants for control and experimental groups in the preliminary test stage. This chart shows the results of the preliminary test for the control and experimental group, i.e. the number of points scored by each participant.

Both lines, the full and dashed, show similar values, sometimes they even overlap, which leads to conclusion that the participants in both groups had similar level of prior knowledge before the experimental factors were introduced into the research. [5]

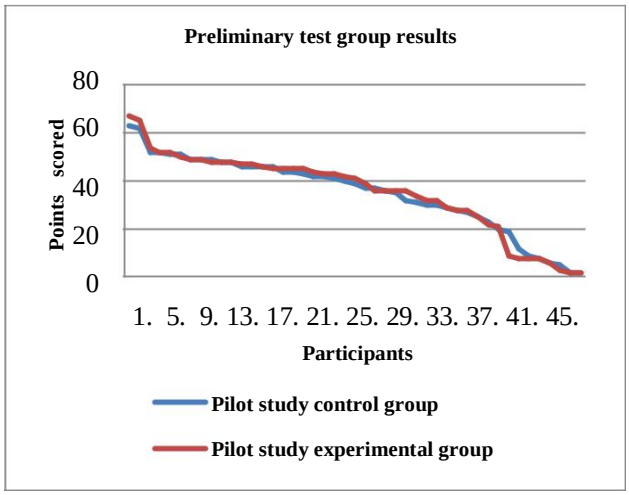


Figure 2. Participants' individual results in the pilot study for experimental and control group

The number of points scored on the preliminary test for the experimental group is within the range of 0 to 70 depending on the number of the study participants and is displayed as a dashed line. The number of points scored on the preliminary test for the control group is within the range of 0 to 70 depending on the number of the study participants and is displayed as a continuous line. Frequencies for the control and experimental group were obtained from the displayed data (Table 1. and Figure 2.). [5]

Table 2. Frequencies for the control and experimental group according to the preliminary test results

PRELIMINARY TEST		
Intervals Categories	Control group -frequencies-	Experimental Group -frequencies-
0-9	6	8
10-19	3	0
20-29	7	6
30-39	8	8
40-49	15	18
50-59	4	3
60-69	2	2
70-82	0	0

Frequencies of occurrence of scores are shown on X-axis as scores organized in categories and intervals,
whereas the Y-axis shows the number of participants in a certain category. In the category 0-9 in control group there are 6 participants, and in the same category in the experimental group there are 8 participants. In the category 60-69 there are two participants both in control and experimental groups. Both of these participants have achieved the best results in the preliminary test. (Figure 3). [5]

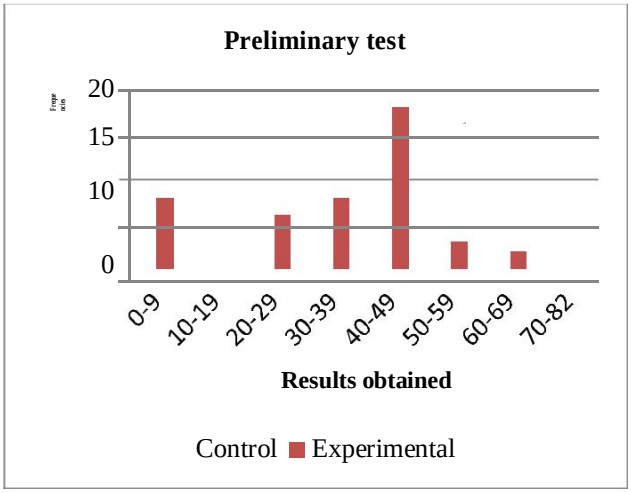


Figure 3. Frequencies for the control and experimental group in the preliminary test

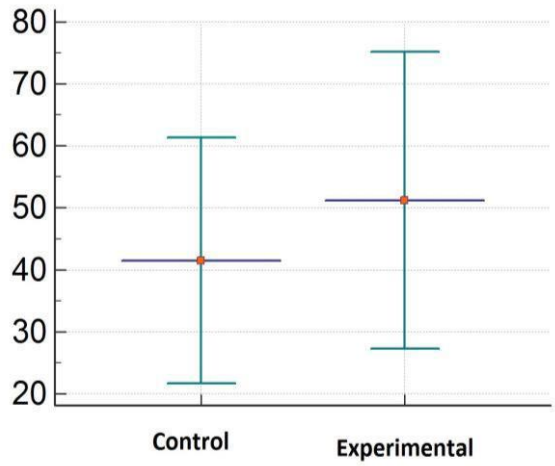
The relationship between the frequencies of the scores in the preliminary test for control and experimental groups shows that most participants belong to the category 40-49. In the control group there are around 15 participants in that category, and in the experimental around 18. The comparison of other categories and frequencies shows that the control and experimental group have an equal number of students whose test results are between 0 and 69 points. (Figure 3). [5]

B. The results of the control and experimental group in the post-test

The results of the main study show students' knowledge level after introducing experimental factors in the study. The results are displayed both in table and graphical form. 90 students were included in the study, 45 in the control and 45 in the experimental group. Table 3 shows the results achieved by each student. The table consists of two columns of data in the range from the highest value to the lowest value of points scored in the post-test. The control group of the main study received traditional instruction, whereas in the experimental group blended learning was applied.

The comparison of the scores between control and experimental groups shows that there is a statistically significant difference p=0,039 (Student's T-test). The control group had on average significantly lower score of 41,466 ± 19,836 (arithmetic mean ± standard deviation) points, whereas the experimental group had on average better score with 51,200 ± 23,939 points (Figure 4).

The independent T-test was used to establish if there are significant differences between the control and experimental groups in the levels of prior knowledge, through the analysis of points gained for the answers to the questions of the post-test. [5]



p=0,038; Student's T-test=2,100

Figure 4. The comparison of points scored by control and experimental group

The gained values t=2,100 with the significance level of p=0,038 < 0,05; df=88 degrees of freedom, standard deviation=19,836 and 23,939 for the experimental group, show that there is statistically significant difference at the confidence level of 95% between the two samples. The results of the T-test at the level p < 0,05 show that the null hypothesis of the research is rejected. The obtained results indicate that there is an increase in knowledge level in the experimental group. These results were confirmed in the following calculations and analysis. The obtained results support the second hypothesis of the research. This result proves that students learn more when blended learning method is applied in Computer Science teaching.

Table 3 shows values of T-test and p values as well as the lowest and greatest values MIN-MAX, and the lines in the Figure 5. illustrate their range. [5]

Table 3. Post-test values

Post-test Groups	T-test value	Significant differences	MIN MAX Range	
Control vs. Experimental	t=2,100 p=0,038	YES	1-3	69-80

Figure 5 below shows the number of points scored on the Y-axis and number of participants for the control and experimental groups in the post-test on the X-axis.

This chart displays the results of the test for the control and experimental group, i.e. the number of points scored by each participant. The dashed line shows more values than the continuous line. The dashed line represents the participants of the experimental group. The continuous line represents the participants of the control group. Based on the presented (Figure 5), we can conclude that the participants who used e-learning method in class have reached a greater knowledge

level than the participants in the control group. The number of points scored in the test for the experimental group is in the range of 0 to 82, depending on the number of participants. The number of points scored by the participants of the control group is in the range of 0 to 70, depending on the number of participants, and is illustrated with the continuous line. The data shown in Table 3 and Figure 5 were used to calculate the frequencies for the control and experimental group in the post-test. [5]

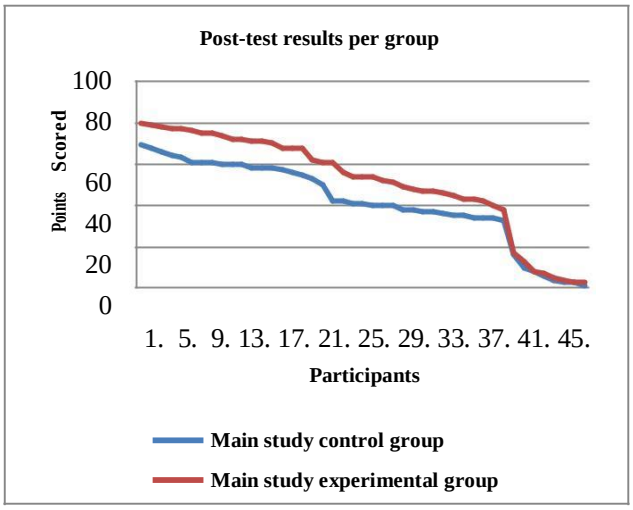


Figure 5. Post-test results achieved by the participants of the control and experimental group

From the relationship of the frequencies between the scores of the control and experimental groups it is evident that the most participants, 14, of the control group belong to category 30-39, and to the category 50-59, where there are 10 of them, and the most participants from the experimental group, 13 of them, belong to the category 70-82 (Table 4). After comparing the other scores of the main study it can be concluded that the control and experimental group have different frequency scores per category. [5]

Table 4. Frequencies of scores for the control and experimental group in the post-test

POST-TEST		
Intervals	Control group - frequencies-	Experimental group -frequencies-
0-9	7	6
10-19	1	2
20-29	0	0
30-39	14	2
40-49	5	9
50-59	10	6
60-69	8	7
70-82	0	13

The frequencies on the x-axis represent points scored per category in stated intervals and the frequencies on the y-axis show the number of participants in each category. It is noticeable that there were 7 participants in the category 0-9 in the control group, and 6 participants in the experimental group. There were no participants in the category 70-82 from the control group, whereas 13 participants from the experimental group belong to this group. Therefore, it can be concluded that the students from the experimental group achieved better results in the post-test of knowledge in Computer Science than the control group students (Figure 6). [5]

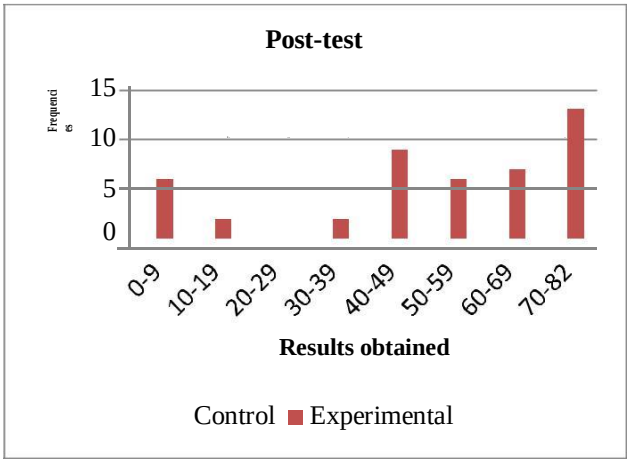


Figure 6. Frequencies of scores of the control and experimental group in post-tes

Figure 7 shows the results of the preliminary test and the post-test for the control and experimental groups. Study results are shown in the line chart. The highest value has the thicker line that represents the results of the experimental group in the post-test. The dashed line and the continuous thin line display almost equal values, as expected since they represent the pilot study results of the control and experimental group. The post-test values of the control group that the dotted line represents are visibly higher than the values displayed by the preliminary test lines, and closer to the values of the continuous thicker line, however they are 10 points lower on the Y-axis in comparison to the values displayed by the line that represents the experimental group for the post-test. Based on the results of the tests in both studies and groups we can conclude the following: the main study participants in the experimental group achieved the best result. These participants used modern media for e-learning in classroom. The obtained results confirm the second research hypothesis. [5]

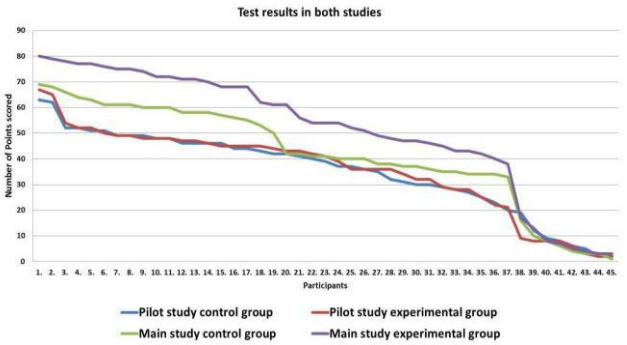
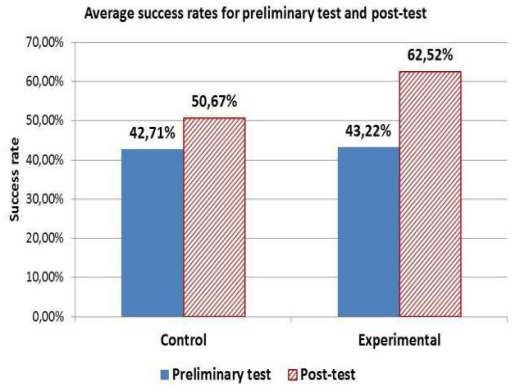


Figure 7. Results of the control and experimental groups in the preliminary test and post-tes

C. *Preliminary test and post-test results*

The comparison of the results of the preliminary test and the post-test in the control and experimental group (Figure 8) yielded the average test success rates for both tests. The average success test rate for the control group for the preliminary test is 42,71%, and for the experimental group 43,22%. The average success rate for the post-test for the control group is 50,67%, which is statistically significantly less than the average values obtained in the experimental group, 62,52% (p<0,001; Chi-square test = 17,405 and df=1). [5]



(p<0,001; Chi-square test)

Figure 8. Average success rates for preliminary test and post-test

The control group improved its knowledge level by 7,96 percentage points, which is statistically significantly less than the experimental group, which improved its knowledge level by 19,30 percentage points (p<0,001; Chi-square test =17,405; df=1), which is well illustrated in Figure 8. This result refutes the first research hypothesis

(Hypothesis 1: Computer Science instruction without the use of ICT satisfies student's educational possibilities and aims.) [5]

D. *Results of measurements of students' satisfaction levels with the acquired knowledge*

At the end of the study sessions students filled out a questionnaire designed to check their satisfaction level with the acquired knowledge and following results were obtained. The students in the experimental group are more satisfied with the acquired knowledge and mostly because blended learning method was applied in the teaching process. There were 48,89% students satisfied with the attained knowledge, 22,22% partially satisfied, and 28,89% of the students were not satisfied with the knowledge they acquired (Figure 9.). [5]



Figure 9. Post-test results regarding the satisfaction level with the acquired knowledge for the experimental group

The students of the control group were not satisfied with the acquired knowledge, 37,77% of them, 26,67%, were partially satisfied, and 35,56% were fully satisfied (Figure 10.). [5]

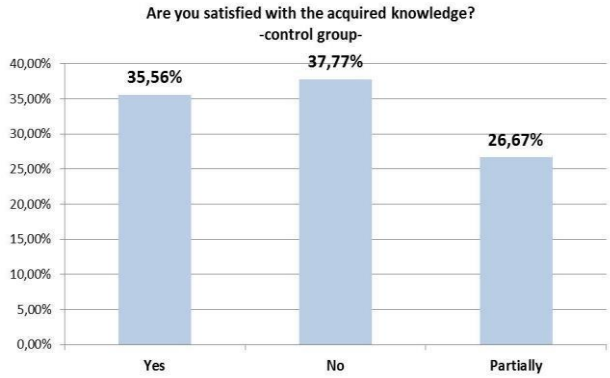


Figure 10. Post-test results regarding the satisfaction level with the acquired knowledge for the control group

The questionnaire the students were asked to complete consisted of two questions. The first question was related to the satisfaction level with the acquired knowledge (three answer choices provided), and in the second question students were asked why they were satisfied with the acquired knowledge. By comparing the charts (Figure 9. and Figure 10.) it can be concluded that the students from experimental group are considerably more satisfied with the acquired knowledge, even though there is no statistically significant difference. (Table 5), i.e. p=0,436 (Chi-square test =1,663; df=2). A number of students wrote that they are satisfied with their acquired knowledge because the blended learning method was used in class. The control group students were less satisfied than the experimental group students because they consider that learning Computer Science without the use of computers makes no sense. In their view learning theory is useless because it will not help them improve their computer skills. [5]

Table 5. Comparison between control and experimental group regarding their satisfaction level with the acquired knowledge

	Control group /n(%)	Experimental group /n(%)	p
Yes	16 (36%)	22 (49%)	0,436
No	17 (38%)	13 (29%)	
Partial	12 (27%)	10 (22%)	
TOTAL	45 (100%)	45 (100%)	

*Chi-square test=1,663; df=2

The third research hypothesis was not statistically proven, the analysis results, however, show that there is a great difference in satisfaction levels between the control and experimental groups. [5]

V. CONCLUSION

According to the research results it can be concluded that blended learning encourages young generations to be creative and explore. The main reason obviously lies in the multimediality of the e-content that in an interactive way provides feedback to the student and offers greater opportunities for practical application. The analysis results refuted the first hypothesis. The second hypothesis, which is the main hypothesis of this research was confirmed and supported by results of the statistical analysis. The third hypothesis was not statistically confirmed, but higher values are observable in the experimental group in which the students were more satisfied with the acquired knowledge. In similar studies in the field of e-learning that might be conducted in future, it should be taken into consideration that a greater sample would ensure better statistical validity of the data. Smaller samples are of less statistical value when compared to the whole population which can lead to statistical deviation from the real life situation. [5]

Nowadays, education is a lifelong process of key importance for the labor market. People involved in the process of education are faced with a challenging, demanding and arduous aim. A society that wants to succeed and survive as modern, technologically developed, knowledge society has to be capable to recognize the skills needed for the progress of its community. It needs to be able to connect the theoretical knowledge with its practical application and direct people towards progress. In order to adjust the education to the real needs of the society, clear development guidelines need to be defined. It may be assumed that the technology, which is increasingly taking over power over the individuals will become the strongest link in the system that constantly aspires to new achievements guided by the desire for improvement. [5]

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Creating student's profile using blockchain technology

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Blockchain technology offers advantages such as integrity, anonymity, credibility and independence of the institution and time because of its decentralized nature. One of the current areas for tackling challenges and potential application of blockchain technology is education. Higher education is a complex system with various challenges that could be potentially improved by introducing this technology. This paper shows a brief overview of current systems, their current state and a direction of their development, but also proposes specific guidelines and upgrades for current systems, that would enhance them and, consequently, the area of education. It also proposes blockchain integration levels in higher education that, combined with data extraction, can expand and deepen the area of education for the benefit of institutions, employers and students.

Keywords - blockchain; data extraction; education; student's profile

I. INTRODUCTION

Blockchain is an emerging technology that is based on decentralized and anonymous architecture which confronts current technological systems and the usual network topologies. It is based on a distributed ledger, i.e. a database on a peer-to-peer protocol [11]. Blockchain technology records a series of transactions between nodes in the network, grouping data into blocks and using special cryptographic methods to create an infinite array of blocks. The technology is anonymous and protects its user's identity, unchangeable and trustworthy due to its decentralized architecture.

Network anonymity is achieved due to lack of exposure of private data in the network and by using encryption to identify and authenticate users. The network of trust marks blockchain technology as the unmistakable true source of information. Cryptographic methods involved in block creation as well as in linking blocks make each blockchain transaction stable and immutable. The consensus algorithms presented in the blockchain maintain functionality and truthfulness of the network by rewarding their users who contribute and validate transactions. Decentralization is a great advantage of blockchain technology compared to current systems, because it removes a central unit or central node in a network that maintains, monitors, and most frequently charges network usage services. Centralized systems generally control all streams of information within the network and user data, and the stability and functionality of the entire system depends on the main central node. Blockchain works on a series of equally important nodes that maintain the network and in a case of a failed node, the network is not compromised. Copies of the database, i.e. ledger, are distributed to all nodes of the network and can be accessed at any time to see the last state of the database.

Many states, institutions and organizations have launched blockchain initiatives and are developing their own technology that will potentially improve the current one [1]. Although blockchain technology is mostly connected of cryptocurrencies, it can be applied to a lot of different areas.

II. BLOCKCHAIN SYSTEMS IN EDUCATION

As a very promising technology, blockchain has found high-quality applications in the field of education. Today's systems and networks in the field of education have largely been centralized, have full control over their students' knowledge and are largely bureaucratized and nonautomated. Blockchain systems applied in the field of education offer a turn of ownership. Due to its characteristic of equality in the network nodes and the exclusion off a central node, students would have full independence of their personal data. It will allow total independence of the students towards the institution and with complete control over their data. Data stored on the blockchain is permanently recorded and encrypted using cryptographic methods to ensure integrity, immutability through hash functions, authenticity and anonymity.

The blockchain's potential in education goes much further, opening the student's opportunity of anonymity over their personal data, independence of institution, immutability of records of official documents and certificates with a complete confidence in the truthfulness and infallibility due to networks architecture. With the emphasis that the student manages all his data. Blockchain opens up a new approach to education. Using this technology, it is possible to reduce the administrative costs and the cost of the study since most of administrative work would be automatized. It also opens an opportunity for a different approach in paying tuition and gives opportunities for more customized and online studies. [22][25]

Although it is currently in its experimental beginnings, the potential of the distributed education system does not remain unnoticed. Many universities, organizations and companies are launching their own blockchain initiatives and exploring the benefits and applications in the field of education [14][18]. There are numerous publications addressing the potential applications and a large number of projects and co-operations in the field of education.

The most up to date university project is Blockcert, an open-source software developed by Media Lab at MIT university and the Learning Machine company [2][21]. The project seeks to expand existing systems and create a universal software that is applicable to all educational institutions which issue certificates. The Blockcert system allows educational institutions to issue academic certificates and give users full control of their own official documents and personal data. Such system offers the sovereignty and independence of a third party after the issuance of the certificate since all data is written on a blockchain. User data as well as all other documents are the exclusive property of the user and the user can make decisions about sharing his personal data. Without questioning absolute truthfulness of the data provided by the systems such as Blockcert, the user does not need to provide insight into a range of other private data to support the integrity of the certificate. Since every transaction on a blockchain has two anonymous parties who are participating in transaction, personal identity does not need to be revealed since it is connected with the participants public key.

Blockert is currently based on Bitcoin blockchain, using unique identifiers to store the hash of a certificate, or to be more precisely bash of certificates. This allows systems to store any kind of certificate or any kind of data to the blockchain because it is not storing document, but only its hash. Previously Blockcert delivered certificates to all attendees of a workshop by hashing document content and then hashing the group of documents which is known as the Merkle root. The institution issues a certificate through its own system which, upon issuance, records the evidence on the blockchain about the specific certificate, data about the person to whom the certificate was issued and the time it was issued. After the issuance, the user and all the third parties with whom the user wishes to share the obtained certificate can verify the certificate through the Blockcert verification system. Blockcert allows users to control and retrieve certificates through a mobile application. Blockcert creates an opportunity for institutions to deliver and safely store all official documents in an easy way without the risk of forgery or document loss, all while not exposing private user data.

Currently, only the Massachusetts Institute of Technology, the University of Nicosia and the University of Birmingham research center develop their own systems based on the Blockcert specifications. The University of Nicosia is the first university based on blockchain architecture [9]. Besides offering a degree program on cryptocurrencies and providing students with tuition fees in cryptocurrencies, they offer a free online course and issue academic certificates on the blockchain. For the students who successfully complete the course, the faculty issues a digital certificate that is recorded on the blockchain. Every certificate is separately hashed and then included in the index document. Afterwards, the index document is hashed and its hash is placed on the blockchain.

Sony Corporation and Sony Global Education have developed a certification education system using blockchain technology. The system is used to authenticate, share and store documents generated through education [10]. Woolf University is the first university completely based on blockchain technology [19].

The technical capabilities of each system differ depending on various factors such as selecting platforms, tokens, etc.

III. IMPROVEMENT PROPOSAL

The current development of blockchain technology in education is mostly focused towards issuing academic certificates to ensure integrity, trust and availability regardless of institution or time. Furthermore, in combination with a variety of available services, issuing certification can be further improved.

Systems that offer biometric identification, protect copyrights, archive documents [15][16][17], etc. surely open question just how broad and applicable area in which technology together with education comes in, and to the which extent we can apply blockchain technology and the all benefits it can bring.

In the case of issuing official records on a blockchain, current systems can expand their functionality and in combination with other technologies could enable much more features. There are three main processes involved in issuing a certificate: institution issuing a document by recording it on a blockchain, verification of a document, and sharing the document with all interested parties.

A diagram of components and their interconnections in an educational environment in Blockcert system is shown in figure 1.

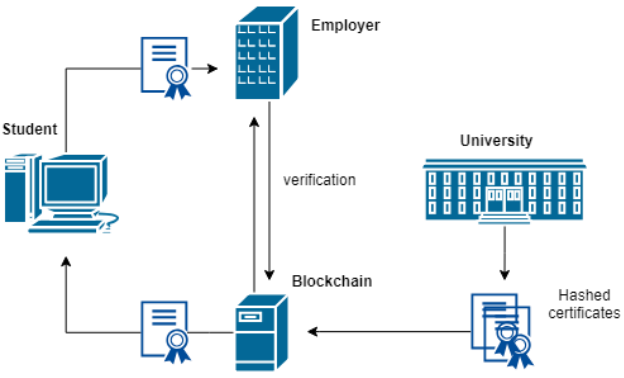

Figure 1. Components of a blockchain in an educational environment

Figure 1 shows a blockchain that is used by certain university, its students and employers. The university issues students' diplomas, uses hashed certificates and then adds them to the blockchain. Employers, who also

have access to this blockchain, can use it to search and verify students' diplomas.

But blockchain technology offers much more than just easier verification of diplomas. Technology is regularly new, but its benefits are proved in many fields, although it requires certain adjustments, not just in technical aspects but also in management and organizational aspects. Our proposal for improvements in educational institutions is based on multiple various dimensions and each is discussed in a separate section.

A. Division to courses

In most educational systems the only proof of fulfillment is the final diploma. However, during the years of studying, students acquire different key performance indicators which in sum result in a degree and the aforementioned document representing it, the diploma. In order to allow students a more modular approach to education, the diploma may be deconstructed down to a smaller collection of key performance indicators, i.e. grades and ECTS points. If the diploma is deconstructed and students have the ability to retrieve only aspects of it, it would allow a more flexible educational system.

One of the problems in the mentioned approach is the increase of issued documents which the faculty must handle. However, by introducing modern blockchain systems the problem would be solved through automation, all while keeping the integrity of certificates.

To reiterate, the certificate is an evidence of individual's learning. The first, almost logical, upgrade to current systems could be the dissection of a degree down to individual courses. The courses are constituent units of the curriculum whose successful graduation results in a diploma. By using blockchain technology or systems such as Blockcert, the process can be improved by recording and grouping certificates of all successfully passed courses instead of delivering a single diploma. Systems that function on the principle of saving hash to blockchain can generate any form of certificate because the blockchain does not record the contents of the document, but only their hash and thus is primarily used for verification.

For each course, the system would generate a new certificate that would be recorded on the blockchain and sent to the student. The user interface would consist of a series of passed certifications, i.e. courses. Certificates would be generated similar to the current system, bashed or in the index document, but with additional data that could be grouped.

B. Employer benefits

By recording the courses, it is possible to gain a deeper insight into the knowledge gained during the course of the study and create a student profile by listing all the courses and grouping them into categories. The course categories can refer to semesters, years or levels of study, and issuing a certificate for each course would open a possibility for the validation of a specific subject. Another possibility would be grouping the course as a defined set of knowledge that the student has acquired through the study and as a factor in assessing the knowledge of the particular area. With the extension of the system, employers would receive, apart from the diploma itself, information on the passed courses.

In this way, the employment process could be more improved. Adding a course to a student profile would allow the search of required courses, i.e. the required courses or category of courses for the required position, and thus the better filtering of potential employees. In addition, students who are in the process of acquiring a diploma or have not completed a degree, but have a number of passed courses, this would allow qualification on positions based on acquired knowledge, despite the lack of a diploma. It could also be a potential motivation for more active students. Such an approach would yield a more just system.

Furthermore, splitting diplomas into smaller objects can go much further and the student profile can be elaborated in more detail. Courses are comprised of conditions and activities that the student must successfully pass in order to pass the course. Courses can thus be divided by the formal obligations that the student performs through the semester. A number of smaller units such as presence, assignments, performance ratings, home works can bring a much wider picture of the quality of the acquired knowledge. All of the above-mentioned conditions in the course represent the total of knowledge gained through the study. Although these course units are already defined as a set of obligations and requirements in the course, they can be always be reevaluated, reused on other courses and further dissected.

C. Data ownership

In a system without a central authority, students are becoming rightful owners of their data. Applying blockchain technology in a field of education is a step to a more privacy-oriented system. Private data is no longer collected and contained and there is no central point where data can be exposed. All the data in the blockchain is associated with user's public key and only way it can be accessed is through a linked private key. Private key is in a exclusive ownership/property of a student and without its private data remains encrypted to all third parties. Current systems [2][9] are not recording student's personal data on a blockchain but only hash values of a certificate. Due to this one-way function it is impossible to retrieve original information. In blockchain terminology public key stands for public address which is linked to a student's identity. Once a certificate has been issued and recorded on a blockchain, the student holds all means of controlling the certificate. The university no longer has to hold any information about the student. Once a hash value is stored on a blockchain and student has received his certificate, university could crease to exist but the student will still be able to verify his acquired knowledge. The right to be forgotten is the most difficult part regarding blockchain technology since once the data has been hashed and stored on the blockchain, it cannot be removed. However, the student is the sole owner of the private key needed to unlock and access the data, therefore all private and personal data covered via the GDPR directive is truly and solely owned by the individual.

D. Introducing smart contracts

One of the most important features of blockchain architecture are smart contracts, which enable an extension of its functionality. Smart contract is an executable program that is triggered when system's state satisfies contract's conditions or requirements [12]. Although they are not so present in the most of current education systems, their implementation greatly shortens administrative tasks and increases level of trust in the entire education system. Along with the current proposals, by introducing smart contracts, it is possible to deliver all the previous items by fulfilling the conditions. Specifically, the diploma could be delivered to the student after the passing of all courses or by obtaining the required ETCS score. The smart contracts in education could be triggered after the fulfillment of all conditions required from the course, without any need for manual revision. As an example, students would automatically receive a certificate upon acquiring a positive grade in the final exam, attending 80% of lectures and completing 25 exercises defined by the course.

Employers would also have many benefits. Such an approach would allow them to search and verify candidates on a lower level, with precise criteria, including students who have only passed a certain course, regardless of their other knowledge or their diploma.

The question is not to what extent it is necessary to analyze studies and courses and divide them to smaller units, because technically this is entirely possible. The question is to determine an ideal level of granularity, in order to achieve the maximum effectiveness for students and potential employers.

E. Extraction of skills from courses

The next proposal relates to the extraction of features or skills that students acquire through the course of studying. By using machine learning algorithms and clustering techniques, it would be possible to extract knowledge and achievements [3] from a particular course and improve the student profile. Profiles would be much more individualized by combining the list of formally acquired skills predefined from the course syllabus, and the extracted skills from the course syllabus using machine learning. By combining these factors, it would be possible to gain insight into the entire student's study and the competences it has acquired. The process and result could be further extended by including additional information dissected from the final grade, such as percentage of attendance and other performance indicators defined by the course.

From a perspective of an employer, it would be possible not only to filter potential employees by courses, but to search by defining specific sets of knowledge. This would ease the process of hiring by allowing the search queries to be more flexible due to the extracted informal features generated by machine learning algorithms.

The next step in development of technology could lead in the direction of cognitive skills especially in the direction of modern cognitive abilities. The current educational system is rigid and non-adaptive to the everyday needs defined by potential employers. The current system within its course syllabus define formal skills such as mathematical competency, logical reasoning, etc., while potential employers search for a combination of skills which also include collaboration and teamwork efforts, creative thinking, public speaking, adaptiveness to new situations, etc. [4][5]

The required skills could be extracted by the aforementioned machine learning algorithms by extending the data observed in them, specifically by inserting job descriptions and intersecting them with previous results. Skills could provide an insight into a different perspective on access to education, creating a focus not only on adopted knowledge but on ways of acquiring knowledge. They could show student skills beyond the courses, and profiles would gain breadth and individuality in describing the student.

Blockchain student cognitive profiling, along with all the features of blockchains such as anonymity, integrity, independence, offers a different approach to employment and employee selection, and offer the fullest and widest approach to education.

F. Extending student's profiles with different sources

The traditional education system presumes that all needed competencies and skills may be acquired through the defined curriculum. However, in practice this proves wrong in many cases due to many factors, from bureaucratic problems of changing the curriculum to the inability to support all the new skills presented. As a result, students nowadays refer to multiple locations in order to achieve the most out of their professional education. Additional sources include extracurricular studies, private schools and courses and online free courses which include certification, e.g. the popular online learning platforms.

By allowing the students to be full owners of their own data, in this case certificates and diplomas, if all of the certificates are registered on the blockchain and implement the same process as mentioned in previous sections, the final product would be an extensive profile of students' skills, courses and education located and owned by the student and verifiable from the same source - the blockchain.

Benefits for the employers in such scenarios are obvious and extend the previously mentioned. A single source of truth presenting all of the competencies which a potential employee has presented, a combination of traditional course outcomes and modern soft skills, would allow the student to be fully showcased and would greatly benefit the end-employer in its searching and selection process.

IV. CONCLUSION

The blockchain technology opens a new to approach to education widening the possibilities of user protection data ensuring authenticity and security to various academic records, transcripts and certificates. With decentralized access to that kind of valuable information it becomes truly independent as its issuers and allows open secured access to it.

The number of projects and ideas is growing as well as the number of members and organizations involved and their mutual co-operation. It is difficult to predict in what direction and how far technology will be faced with everyday new implementation and adaptation proposals, but also on many challenges in terms of scalability, security, application of different consensus algorithms and different platforms. Although for the most part the system of crediting students through blockchain is in the test phase, the potential for applying this technology in the field of higher education is limitless considering value of secured data. Blockchain technology allows students more flexible education and creates a different approach to employment and employee selection.

Possibilities of blockchain technology has not yet reached it's full potential but it's decentralized nature, security and independence are becoming more valued in various industries and institutions that stress most value on the authenticity and credibility of certified data.

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Education in science literacy outside the classroom: the case of libraries

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Abstract – **Education in science usually is related to diverse science activities undertaken in schools and at universities. School and university students have mostly unobstructed access to scientific knowledge and instruction in scientific methods as part of their daily educational activities, while citizens outside the domain of formal education are in less favorable position. As a result, they seek scientific content and activities online or in libraries, including public libraries, which are by their definition accessible to all citizens regardless of their age, education, gender, religion etc. and offer diverse learning opportunities to their users. Public libraries in Croatia have been helping citizens to become familiar with recent developments in science and to become informed individuals who will be able to make important decisions in their lives based on their knowledge about the world that surrounds them. This paper aims to introduce public libraries in Croatia as places at which science education is not only possible but it is already done rather intensive and widely accepted by the different generations of library users.**

Key words – science education, public libraries, Croatia

I. INTRODUCTION

Science is one of the most prominent and most favored human endeavors in society. During the development of the human civilization, people have developed many interconnected ideas about the physical, biological, psychological, and social worlds they investigated [1]. They tested their ideas mainly by applying different scientific methods, and these scientific methods helped them prove their ideas true (or false). Today, after centuries of successful scientific research resulting in many important discoveries and their application in education, medicine, engineering, space exploration, business etc., there are still individuals who have doubts in science and outcomes of its activities. This happens because of the lack of knowledge about the world we live in, but also because science is sometimes applied in very closed communities which occasionally tend to be elitist and do not communicate enough or communicate at all with the wider public. We have now entered a new era of development of science – open science. Open science is here to enable better and open cooperation between scientists, better insight into scientific activities to science funders but also to enable better insight into the world of science to all individuals in schools and universities and those who are enthusiastically interested in sciences but their education was completed recently or long time ago so now they seek additional scientific knowledge outside the classroom and formal education to understand changes and phenomena happening in today's world. This paper aims to explain what open science is and how important it is for an individual to have access to results of scientific research without obstacles (for instance, in public libraries) in order to become scientifically literate and to understand effects of science on everyday life.

II. OPEN SCIENCE

"Open Science represents a new approach to the scientific process based on cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools. The idea captures "a systemic change to the way science and research have been carried out for the last fifty years: shifting from the standard practices of publishing research results in scientific publications towards sharing and using all available knowledge at an earlier stage in the research process" [2]. The OECD defines Open Science as making "the primary outputs of publicly funded research results – publications and the research data – publicly accessible in digital format with no or minimal restriction" [3]. The EU sees open science as an important developmental driving force. The EU/EC suggested the five points of potential policy actions [4]: "1. fostering and creating incentives for open science, by fostering open science in education programmes, promoting best practices and increasing the input of knowledge producers into a more open science environment (citizen science). This area is also concerned with guaranteeing the quality, impact and research integrity of (open) science; 2. removing barriers to open science: this implies, among other issues, a review of researchers' careers so as to create incentives and rewards for engaging in open science; 3. mainstreaming and further promoting open access policies as regards both research data and research publications; 4. developing research infrastructures for open Science, to improve data hosting, access and governance, with the development of a common framework for research data and creation of a European Open Science Cloud, a major initiative to build the necessary open science infrastructure in Europe; and, 5. embedding open science in society as a socioeconomic driver, whereby open science becomes instrumental in making science more responsive to societal and economic

expectations, in particular by addressing major challenges faced by society".

What is most important both to scientific professionals (researchers) and to scientific nonprofessionals (enthusiasts and students) is to acquire access to results of scientific endeavor without obstacles. Open science enables public insight into results of work of professional scientists and, what is also important, it enables civic engagement in science. To be able to understand results of scientific research, a person must be scientifically literate.

III. SCIENTIFIC LITERACY

Science is the driving force of the development of society, so those who are professionally involved in science as well as citizens should possess knowledge about world that surrounds them and understand how science is changing that world. Of course, the quantity of knowledge about scientific methods and facts based on scientific research differs between professional, citizens enthusiasts and layman. Main problem in case of citizens enthusiasts and layman is that they are not all educated enough or educated at all in science or are able to keep up with the latest scientific developments.

In contrast to citizens enthusiasts whose knowledge about a certain world phenomenon does not need to be detailed (but it could be, and sometimes is), the professional researcher should possess a number of competencies such as "knowledge, skills, attitude, and characteristics which are conducive to research, must have an ability in critical thinking, synthesis, capable of criticism, well predicted an answer, knowledgeable in the use of the scientific method and logic, able to criticize with logic, good interpersonal contact with others, as well as using the information as a basis for decision making" [5].

In addition to enthusiast, school and university students should develop such skills to a degree which will prepare them to become at least informed citizens and to answer challenges at their future workplace. The world itself is changing fast and old knowledge and skills are not good enough for future world.

Science does not happen in vacuum, but it is integral part of the 21st century society. The 21st century requires new set of skills, which include basic, scientific, economic, and technological literacies; visual and information literacies; multicultural literacy and global awareness [6].

Aita, Rannikmäec, Soobardc, Reiskab and Holbrookd [7] made a step further and suggested that new standards related to expected student capabilities in the 21st century necessary to replace the existing basic skills and knowledge expectations of the past and to succeed in this six major criteria areas: "1.) transformation of schools through science education, students need to develop an understanding of big ideas about objects, phenomena, materials and relationships in the natural world 3.) individuals need to be nurtured who are able to appreciate diversity of values and culture sensitivities surrounding issues, to have compassion for others, collaboratively construct values for the larger welfare, and ultimately take action 4.) an increasing urgency needs to be recognized for skills such as analyzing the credibility and utility of information, evaluating its appropriateness and intelligently applying it 5.) skills are needed to infer meaning from science texts which relates to the ability to recognize the standard genres of science, their appropriate use, and, in the case of argument, to evaluate the claims and evidence advanced 6.) metacognitive knowledge is also an important need for science learning which is related to positive attitudes and knowledge gains".

To become an active and a responsible citizen, one should possess "necessary knowledge and understanding of the problems faced by mankind" [8]. In case of science, knowledge and understanding are usually perceived as science literacy.

In the past several decades, the goal of science education globally has been achievement of scientific literacy [9]. However, the term scientific literacy is understood differently in different environments, and it is not equally accepted in all educational institutions. "Scientific literacy represents the ability to use evidence and data to evaluate the quality of the information and arguments presented by the scientists and, in mass media" [8]. It also means "knowledge and understanding of the scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" [10]. Scientific literacy can be divided into four categories: "1.) cultural scientific literacy - means understanding the science by a person with average intelligence and education of a culture; 2.) civic scientific literacy- represents the level of scientific understanding necessary a person to make informed decisions with regard to legislation and public policy; 3.) scientific literacy practice - refers to scientific knowledge that a person needs to solve practical problems (expl. determining the most efficient way to heat home); 4.) aesthetic literacy and consumer science - indicates to what extent the understanding of scientific laws" [8].

As a result of being educated or acquainted with science, a scientifically literate person would require competencies to: "1.) explain phenomena scientifically: recognize, offer and evaluate explanations for a range of natural and technological phenomena; 2.) evaluate and design scientific enquiry: describe and appraise scientific investigations and propose ways of addressing questions scientifically; 3.) interpret data and evidence scientifically: analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions" [11].

IV. EDUCATION IN SCIENCE

Generally speaking, education in science starts at an early age and it continues throughout the entire life of a person. "Education contributes to the development of the ability of understanding of the most effective way to use science in daily life and social responsibility" [8]. The PISA report from 2015 indicates that the Croatian students fell behind the OECD average in science related performance [12]. To improve this situation the current educational system in Croatia must change to introduce newly discovered science related knowledge, skills and

teaching methods in schools and at universities in such a manner, which would benefit students. During their education in schools and at universities, students develop their research competencies by participating in scientific curricula which includes the logic, critical thinking and integration, creating description and argument, the communication, and the use of mathematics [5]. While many of these skills are included in academic curricula at all levels of education, formal education must end at some point in time and after that moment individuals are left on their own to continue their science education in years to come. Currently, Croatia does not have developed system of life-long learning, which would facilitate and guarantee continuing education to every individual interested in it. So, students should learn two things during their formal education. First, they should acquire as much knowledge about science as possible during their formal education. The opportunities for this are enormous as students have many ways in which they can access scientifically related knowledge offline in academic libraries or online in many other information resources available to them. Second, their knowledge and experience in finding scientifically related knowledge should be applied once their formal education finishes to continue their education in science which progresses perpetually. As the access to university information resources ceases to exist, former students should focus their search to other institutions, which offer insight into current scientific knowledge to the wider public.

Luckily, such institutions exist as schools and universities are not the only places where science education happens. According to Rennie, informal science education can happen in various non-school environments and they remain catch-all term "for science-related activities that are not part of a formal, assessable curriculum offered by educational institution" [13]. One such environment is library in general and public library in particular.

V. EDUCATION IN SCIENCE IN LIBRARIES

Public libraries in Croatia are very busy places offering a variety of activities including science related activities. It is now a common knowledge that libraries (in general) have been closely related with education in general for centuries. Their positive involvement in education include referral services, information and teaching resources, individual tutoring programs and educational classes, outreach to specific people's groups with educational handicaps, distribution of resource materials to institutions, including hospitals, prisons, homes for the disabled and aged, rehabilitation centers and groups with education related problems and adolescents involved in crime, unemployment and the like [14]. Public libraries play "the role of a nodal point in assimilating informal or formal information of local learning content and co-relating it to knowledge and information from global resources" [14]. During their activities in education in science, public libraries in Croatia cooperate with individual scientists and scientific institutions to acquire new information about the latest scientific discoveries and also to acquire new knowledge for themselves as "librarians don't always have all the skills needed in order to satisfy the digital learning needs of all groups, but they have the ability to connect people" [15]. The result of this cooperation is quality science related library programs and cooperation in scientific projects.

No matter how good public libraries are in helping people to get informal education in science, they are often neglected or even invisible when media search for scientific activities outside schools and universities. To improve this situation, public libraries use Web pages and social media to promote their science related activities.

The following part of the paper presents selected examples of science related activities in public libraries in Croatia. This list could be longer, however, information about science related activities are not systematically archived on the Web pages of public libraries so it is sometimes difficult to find such information after the completion of such activities.

Zagreb City libraries presented a series of lectures for public called "Eppur si muove." [16]. The first lecture was held on March 26 2014. Lecturers were scientists in different fields of science, philosophers, sociologists, theoreticians and journalists.



Figure 1. Eppur si muove

The lectures covered a wide spectrum of topics presented by dozens of scientists and journalists. There is no entrance fee to the lectures, which take place in the attic of the Zagreb City library – a place well chosen as an open forum for exchange of knowledge and ideas.

"Bogdan Ogrizović" library introduced the public round table on different topics including scientific topics and this round table is broadcast on the Croatian national radio every time it takes place, which helps in even wider availability of the content of the round table [17]. Due to the limited capacity of the library facilities, the listeners sometimes stand on their feet instead of sitting on chairs.



Figure 2. Public round table

In 2017. the library at the University of Rijeka [18] was part of the national Festival of science during which dozens of institution like schools, universities, libraries and museum participate in popularization of science. Although it is not a public library, the library at the University of Rijeka participated by organizing a series of lectures in different scientific topics. By participating in the lectures, audience was acquainted with selected scientific topics.



U Sveučilišnoj knjižnici održan program povodom „Festivala znanosti“

Ažurirano 24.5.2017.

U ponedjeljak, 24. travnja, održan je program pod nazivom „390. godišnjica dolaska isusovaca u Rijeku (sjećanje na prošlost – odrednica sadašnjosti)“, kojim je Sveučilišna knjižnica sudjelovala u „Festivalu znanosti“ čija je ovogodišnja tema Vrijeme.

Dr. sc. Maja Ćutić Gorup održala je predavanje pod nazivom „St. Veit am Flaum: od kapetana zaštitnika reformacije Francesca Barba do dolaska Družbe Isusove“, koje je obuhvatilo razdoblje od protestantske djelatnosti riječkog kapetana Francesca Barba u vrijeme djelovanja tiskare u Urachu (1561. – 1565.) do dolaska vjerskih redova s protureformatorskim ciljevima u Rijeku početkom 17. stoljeća.

U predavanju mr. sc. Ivice Musa SJ „Isusovci i kolegij u Rijeci: pretpovijest i dinamika nastanka isusovačkog školstva i dolaska u Rijeku“ bilo je riječi o osnivaču Družbe Isusove Ignaciju Loyoli i osnivanju i djelovanju isusovačkih zavoda po Europi i svijetu, uključujući i Rijeku.

Otvorena je i izložba kiparice i slikarice Margarete Krstić pod nazivom „Odjeća Rijeke i okolice od 16. do 19. stoljeća“, koja se može pogledati do 28. travnja prema prethodnoj najavi.

Figure 3. Science festival at the Library at University of Rijeka

Zadar city library also organized a number of science related public lectures, which enabled audience to become acquainted with the relevant discoveries in science [19].

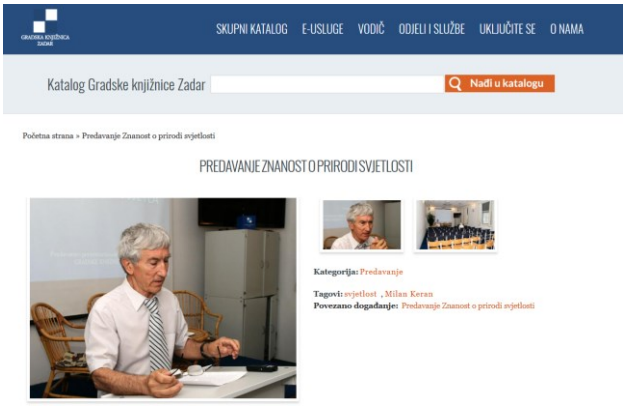

Figure 4. Zadar city library

Another science related event in Zagreb City Libraries are workshops for children in the library department for children and youth [20]. Children will be introduced to topics in biology, ecology, environment protection, health, nutrition and other similar topics which promote science fight ingorance and help in cooperation with scientists.



Figure 5. Small scientific workshop

Zagreb City Libraries offer science related programs even for pre-school children [21]. They organized the smallest scientific workshop in which pre-school children are acquainted with topics related to exploration of Universe.



Figure 6. Smallest scientific workshop

City library in the Croatian town Đurđevac organized scientific workshop for children [22]. The activities included use of magnifying glass to observe one's hair and skin, collecting material for inspection under the microscope and design of a volcano.



Figure 7. Scientific workshop for children

The City library in the town of Metković organized a workshop for children as a part of the project "Scientific magic" [23]. The project was original idea of the Croatian chemical society with aim to popularize science among children of pre-school and school age. The aim of the workshop is to present natural laws and phenomena to children.



Figure 8. Scientific workshop as part of the project "Scientific magic"

The city library Sisak organizes a series of lectures and workshops as part of the project "Jump into science". Aim is to attract children of pre-school and school age as well as children with needs. The lecturers will be experts, university and school students.



Figure 9. Project "Jump into Science"

All these examples demonstrate active involvement of public libraries in Croatia in education in science outside the classroom (of a school or of an university). Education outside the classroom generally comprises of three domains: knowledge, attitude and skill. These three domains have the following objectives: "first, to reinforce student understanding of concepts taught in class; second, to provide learning experiences in real-life situations; third, to make learning more meaningful and enjoyable; fourth, to enable students to think and master knowledge though contextualised experiences; fifth, to increase student interest and attitudes to learn; sixth, to expand teamwork and social skills; seventh, to develop skills in the collection, processing and analysis of data and information; and eighth, to cultivate wholesome values among the students themselves" [25]. All three domains could be acquired in schools, at universities and in libraries.

While this paper mentioned school and university students in some of its parts, it must be noted that the

content of the science related activities are intended for wide variety of library user groups and individuals like special age groups like pre-school children, but also schoolchildren, university students and adults of all ages. This makes library activities truly universally accessible to different users, which is the original idea of existence of every library.

VI. CONCLUSION

Science helps our society develop better and faster. Scientific activities can most frequently be found in educational institutions and commercial companies which plan their development on research and development. However, science is not carried out exclusively in educational institutions, but they can also be found in other environments and institutions like libraries. Libraries have central role in society of information supplier and facilitator of different educational and cultural activities. As such, they have enough experience in organizing science related activities that otherwise immanent to educational institutions. Their role is extremely important in the changing environment and in time when pressure is put on libraries to change their role in society: "New business infrastructures, healthcare, academic research, economic development and social interaction have sprung from the arrival of networking, data storage, new innovative software and microprocessors, thus providing for direct access to all information, eliminating the legendary intermediary, and thus gaining on space and time" [14]. However, libraries, and especially public libraries are regaining space and time taken by technology offering unique personal and group approach to support the learning process especially in learning about science. The proof that they are doing this job well is the number of interested library users who attend science related activities in public libraries (as presented in Figure 2.). Unfortunately, so far there hasn't been no special evaluation of the outcome of these activities and their influence on students and other categories of library users but that is something that remains to be done in future. Until then, the number of science related activities in public libraries will continue to depend on financial means, number of librarians who can participate in organizing such activities, space capacity in library etc. Because of that, some library activities are carried out less frequently and in more modest environment. However, public libraries will not give up on education in science for user groups who are seeking such activities in their premises.

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Implementation of Electronic Design Automation software tool in the learning process

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Abstract - Design of analog and digital electronic circuits is an integral part of the electrical engineering curriculum. Software tools, which enable design, simulation, measuring and circuit analysis as well as PCB (Printed Circuit Board) design, are called EDA (Electronic Design Automation). The paper describes the introduction of EDA software in the first semester of the professional study of electrical engineering at the Zagreb University of Applied Sciences within course *Personal Computers in Electrical Engineering*. Examples of laboratory exercises related to electrical circuit diagrams, use of component libraries, work in standard laboratory environment (power supplies, function generators, voltmeters, ammeters, oscilloscopes, etc.), circuit analysis in a DC and AC mode as well as in time and frequency domain are described. Focus is on the optimal implementation of EDA tool *NI Multisim* and its integration with the existing learning management system *Moodle* as a platform for exercise learning and knowledge assessment.

Keywords: Electronic Design Automation, EDA, Multisim, circuit analysis, LMS, learning and knowledge assessment

I. INTRODUCTION

The design of analog and digital electronic circuits, the manufacture of a prototype, testing and after that device production are common tasks of electrical engineering. Design automation of electronic systems is the engineering science that derives software and hardware tools for the design of integrated circuits and systems based on abstraction, design methodologies, and software implementations of sophisticated algorithms for verification and synthesis [1]. Software tools that enable the design of electronic circuits, circuit analysis and measurements as well as preparation for printed circuit boards (PCB) are generally referred to as EDA (Electronic Design Automation) software. In addition, EDA has the ability to simulate and work with programmable digital components such as microcontrollers. Circuit analysis in the design phase is important for emulation of circumstances that may affect the functionality, layout and final dimensions of the product (e.g. the width of the printed circuit, component spacing, parasitic capacitance and frequency range, thermal stresses and cooling, total power consumption) [2].

EDA tools have enabled the integrated circuit industry to sustain exponentially increasing product complexity growth to the present day, while maintaining consistent product development timeline and costs. EDA started as a field in the 1960s when researchers of some leading academic and industrial labs conceived the first computer-aided design (CAD) tools for supporting engineers in the analysis and layout of circuits and boards whose complexity was growing dramatically. State-of-the-art EDA includes features from simulation to physical design, from formal verification to logic optimization as well as of its evolution into system level design, nanotechnology, and synthetic biology [1]. Significant features of EDA are [2]:

- Wide component library including real manufacturers' components;
- Ability to create new virtual components by user;
- Circuit analysis (DC and AC mode, transient analysis, transfer function analysis, temperature analysis, etc.);
- Creating parts of the technical documentation (parts list, electrical scheme, PCB (Printed Circuit Board) layout, connection plans, etc.);
- Netlist creating (standard data set for external PCB module or other modules).

Introduction to EDA software is curriculum of *Personal Computers in Electrical Engineering* (PCEE) course. PCEE is being held in the first semester of the professional study of electrical engineering at the Zagreb University of Applied Sciences. Laboratory practicum for PCEE is held on personal computers only [3]. Due to this fact as well as the intention to bring closer work in standard laboratory environment as soon as possible to students of the first semester, it is decided to introduce EDA software tool in PCEE curriculum.

The software used is National Instruments Multisim. For learning process and EDA knowledge/skill assessment, the LMS (Learning Management System) Moodle is used as a platform for all laboratory exercises. Circuit analysis using Multisim allows the user to: Observe the circuit behavior before the actual manufacturing; Use ideal components to isolate design and circuit limitations; Make measurements that are hard to make in the real circuit (because they might damage the circuit, they are affected by electric noise; not possible because of a lack of proper measurement equipment); Perform repeated simulations with parametric values for a component; Observe temperature dependence of the circuit behavior and Observe circuit behavior under parasitic elements due to real components [4].

The following section (Section II) describes the introduction of EDA software with examples of laboratory exercises related to electrical circuit diagrams and circuit analysis. Section III describes the implementation of LMS Moodle platform for exercise learning and knowledge assessment for EDA software tool as well as benefits of its integration.

II. EXAMPLES OF LABORATORY EXERCISES FOR EDA

Design process of an electrical device in the EDA begins with drawing the circuit schematic diagram on the EDA working surface and then follows the circuit analysis. Therefore, laboratory exercises are designed to gradually cover required knowledge needed for successful use of EDA tools: *Introduction in Multisim workspace, Measuring instruments usage, Circuit DC analysis, Circuit AC analysis at single frequency, Time domain and Transient analysis and Frequency domain analysis* [2].

It is worth to mention that above-stated PCEE laboratory exercises rely on topics of *Fundamentals of Electrical Engineering* course, which is held in the first semester, too. This enables students to examine acquired knowledge in a simulated environment.

A. *Exercise: Introduction in Multisim workspace*

Aim of this exercise is to familiarize students with the software tool interface, organization of toolbars, component libraries and their use, to draw a simple circuit diagram as well as to start simulation process. Steps are as follows:

- Understanding the interface, menu, toolbars and workspace;
- Understanding the component library, to differentiate real from virtual components, properly selecting and adjusting component values;
- Understanding the component and measuring instruments placing and wiring on the workspace;
- Clarifying the role of the GND common point (GrouND terminal);
- Starting the simulation process to obtain results.

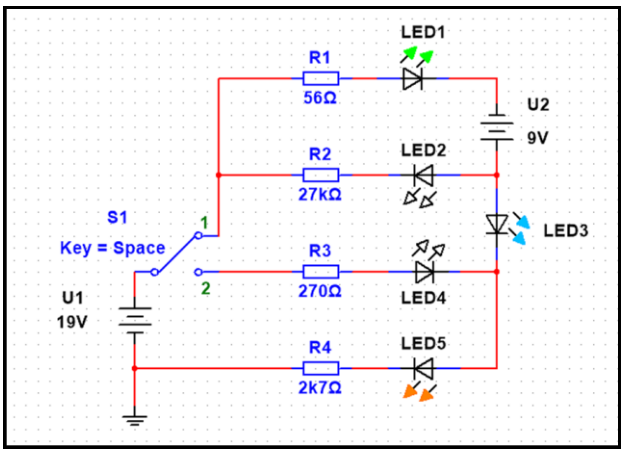

Fig. 1 Schematic diagram in Exercise A: Introduction in Multisim workspace [2]

Circuit chosen for the exercise has LED (Light Emitting Diode) lights and a switch as simple animated components convenient for the first student work in Multisim (students can immediately see when the circuit is working or not working) – Fig. 1.

B. *Measuring instruments usage*

The aim of the following exercise is to learn how to work with standard laboratory equipment, such as power supplies, voltmeters, ammeters and oscilloscope. Virtual instruments or simulation of real instruments (Fig. 2) can be selected. All measurements are done in *Interactive simulation* mode.



Figure 2. Simulation of real oscilloscope in Multisim used in Exercise B

Circuit in Fig. 3 is used as the first example in this exercise. DC power source is used to make easy understandable initial use of the virtual (simulated) laboratory instruments, particularly to clarify the multimeter input impedance.

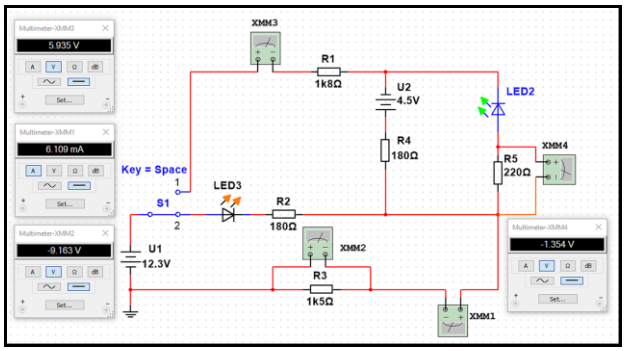

Figure 3. Circuit used in Exercise B

In the second example in this exercise, AC power source is used in rectifier circuit. As measurement instruments, an oscilloscope together with ammeters and voltmeters are used (Fig. 4).

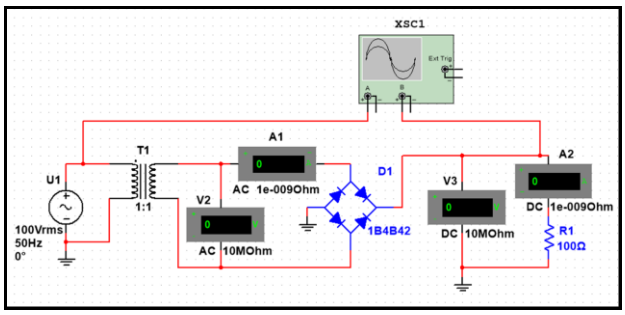

Figure 4. Rectifier circuit used in Exercise B [2]

C. *Circuit DC analysis*

DC Operating point simulation is used for static analysis of circuits suitable for circuits with nonlinear

components (such as s diodes and transistors). Results of this simulation is given in form of table (Fig. 5) consisted of chosen loop current and node voltages regarding to the reference point GND. This simulation interactively illustrate students all voltage and current values as well as their polarity / direction at all elements of circuit, which is useful for getting the practical understandings before work in laboratory practicum with real circuits.

Circuit used in Exercise C is presented in Fig. 6. The LED lights are use as indicators for proper operation of the circuit. Multimeters are used for comparison with results of *DC operating point* simulation. In this simulation, voltage or current probes can be used (see results indicated with *"PR"* suffix in Fig. 5 and their position on schematic diagram in Fig. 6).

Personal computers in electrical engineering
DC Operating Point Analysis

	Variable	Operating point value
1	-I(LED1:K) | I(PR2)	6.28848 m
2	-I(R1:1) | I(PR3)	1.31568 m
3	V(7) | V(PR1)	-6.23540
4	V(1)	-12.40000

Figure 5. Results of DC Operating point simulation for circuit used in Exercise C

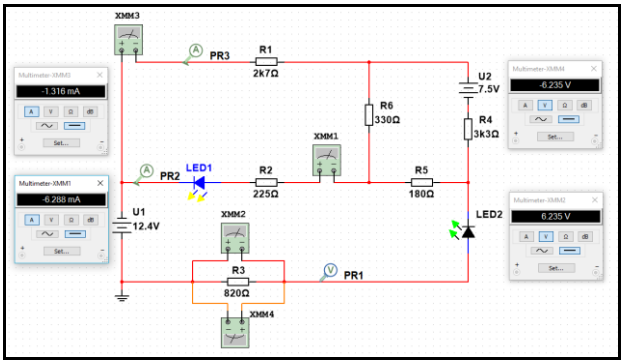

Figure 6. Circuit used in Exercise C

D. *Circuit AC analysis at single frequency*

AC analysis were performed on circuits with alternating current power sources. Types of probes used for the analysis are current probe, voltage probe and differential voltage probe. Output of AC analysis at single frequency can be in complex number form or in phasor form with magnitude and phase (Fig. 7).

Personal Computers in Electrical Engineering
Single Frequency AC Analysis @ 50 Hz

	Variable	Frequency (Hz)	Magnitude	Phase (deg)
1	-I(U1:1) | I(PR1)	50	36.86035 m	-61.02329
2	I(R1:2) | I(PR2)	50	17.85714 m	0.00000e+000
3	I(C1:2) | I(PR3)	50	31.41593 m	90.00000
4	I(L1:1) | I(PR4)	50	63.66198 m	-90.00000
5	V(1) | V(PR5)	50	10.00000	0.00000e+000

Figure 7. Results of AC analysis at single frequency

Circuit used in Exercise D is presented in Fig. 8. The capacitor and inductor are introduced. Power supply has sine wave shape one with constant frequency.

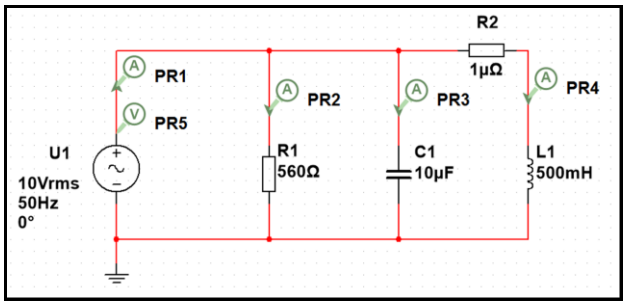

Figure 8. Circuit used in Exercise D [2]

Through this exercise, students are introduced to the differences in working with real and virtual components in EDA, too. Namely, the resistor R2 (with resistance of 1µΩ) has to be added in serial connection with inductor L1 (see Fig. 8) to make the simulation work properly. Otherwise, simulation will stop and worn the user that inductance is connected in parallel to the voltage source.

E. *Time domain and Transient analysis*

In this exercise, the current and voltage transient phenomena in time domain are analyzed for a RC circuit shown in Fig. 9. The function generator is used to generate a symmetric bipolar rectangular voltage at selected frequency. Resulting transient analysis is shown in Fig. 10.

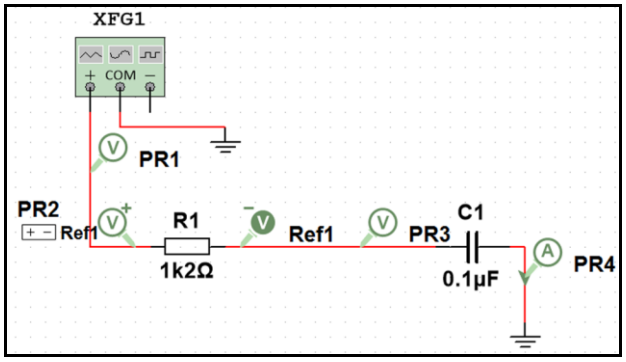

Figure 9. Circuit used in Exercise E [2]

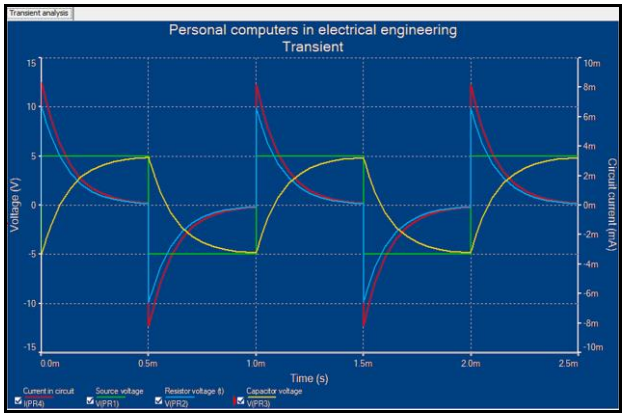

Figure 10. Transient analysis in time domain in Exercise E

F. *Frequency domain analysis*

The frequency domain analysis is performed on circuit from Exercise E (Fig. 9). The function generator is used to generate a sine wave in range of frequencies (AC sweep).

Resulting frequency domain analysis for RC circuit is shown in Fig. 11.

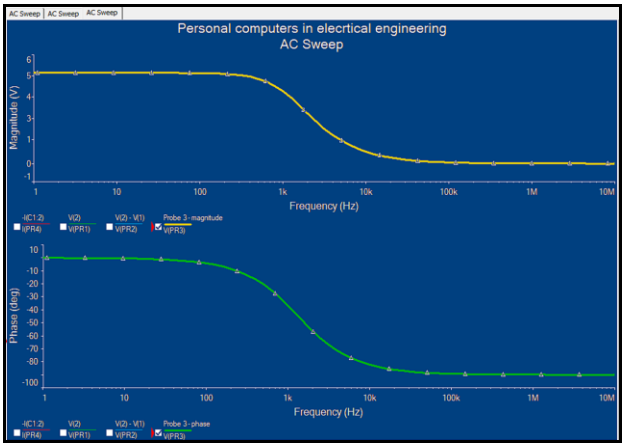

Figure 11. Frequency domain analysis shows magnitude and phase results depending on frequency

III. INTEGRATION WITH LMS MOODLE AND ITS BENEFITS

The integration of EDA with the existing LMS, where all the other exercises and knowledge/skill assessment are conducted, was realized through the following aspects:

- Exercise attendance record;
- Step-by-step instructions for exercise (circuit diagrams and textual instructions with relevant explanations) and expected result of simulations;
- Tasks for homework exercise, deliberately without detailed instructions but with the expected results;
- Assessment system, which consists of acceptance of numerical measurement results of exam in input forms (shown in Fig.12), comparison with the correct solution with accepted tolerance, automatic grade of student responses and administration of overall student achievement. In addition, backup for subsequent analysis are enabled via upload of student Multisim (.ms14) files.

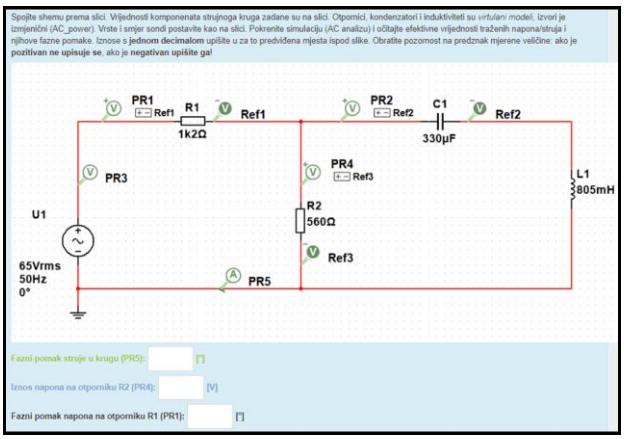

Figure 12. Example of test task for knowledge/skill assessment

The test is time-limited. Overall duration is set in LMS, so after the expiration of the time the test automatically closes [5].

The statistical analysis of the LMS assessment records can be used to track students' success and their most common mistakes. Two colloquia are prepared: Test EDA-1 and Test EDA-2. Each of them consists of three tasks covering different simulations of electrical circuits.

To check the correctness of the solution, reading of certain values from EDA analysis and multimeters from the set positions are required. Obtained values in the EDA need to be entered by the students in the LMS exam form. Afterwards, the LMS conduct an automatic assessment and administration of the exam [6]. In the first year of implementation, the Test EDA-1 was attended by 201 students, of whom 72% solved all 3 tasks correctly. Test EDA-2 was attended by 150 students of whom 62% answered all 3 tasks correctly. For the first and second test, approximately 2.3 correct assignments was average per student. An overview of the most common mistakes is given in Fig 13. Note: the typos refers to numeric digit substitution (e.g. 63 instead of 36).

Subsequent analysis of submitted solutions uploaded by students (i.e. Multisim files) found that the incorrect wired circuits, not properly adjusted component values and wrongly conducted measurements were source for *Significantly wrong values* (See Fig. 13). The percentage drop of *Empty Answer* and *Wrong Polarity* in Test EDA-2 indicate that students got better prepared for the test that was held a month after the first.

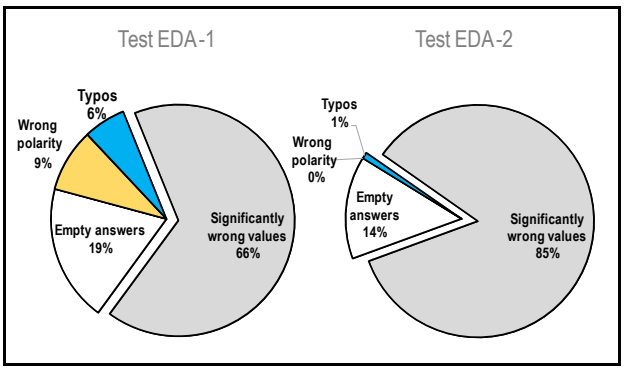

Figure 13. Overview of the most common mistakes based on statistical analysis of the LMS assessment records

IV. CONCLUSION

The introduction of EDA software in the learning process of the professional study of electrical engineering at the Zagreb University of Applied Sciences through laboratory exercises is described. Laboratory exercises present complex form of class delivery because students are not only required to be familiar with the theory behind the particular exercise subject, but they also have to handle with software tool and understand laboratory equipment characteristics and their usage limitations. Therefore, sequence of exercise topics is designed to gradually cover required knowledge needed for successful use of EDA tools: *Introduction in Multisim workspace, Measuring instruments usage, Circuit DC analysis, Circuit AC analysis at single frequency, Time domain and Transient analysis and Frequency domain analysis*. For each exercise, appropriate circuits are designed and step-by-step learning instructions for their design are implemented in LMS. Acquired knowledge and skill assessment with automatic grade of student responses is implemented via LMS, too. It is shown that EDA-LMS integration enables detection of most frequent student

errors, which gives guidelines for improving teaching process. Developed exercises are initial steps of EDA Multisim usage. More advanced options, such as working with digital circuits, microcontrollers and PCB design, are out of the scope of PCEE course and represent curriculum for higher semester courses.

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Crowdsourcing image descriptions using gamification: a comparison between game-generated labels and professional descriptors

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***Abstract* – The traditional approach to achieve high metadata quality in image description is to use subject experts. However, cultural heritage institutions often lack the human resources to handle the amount of material that is in need of description. One of the possible solutions to this problem is applying the gamification approach in the process of description. Many studies have shown that applying game design features outside traditional game environments can increase the motivation and productivity, and that those games can be particularly effective in invoking intrinsic motivations and overall enjoyment. However, there is a need to explore the quality of such game-generated tags in comparison with using controlled vocabularies and traditional approaches. In this paper, we compare game-generated image labels and professional descriptors. First, a subject expert using controlled vocabulary added descriptors for each image. Then, by using a gamified platform for collecting semantic annotations of digitized images, game-generated tags were collected. In the final stage, game-generated labels were evaluated by the subject expert in the context of appropriateness of using them as descriptors within a standardized system. Results have shown that game-generated labels can serve as a basis for high quality labels suitable for including a standardized description in order to enhance description and retrieval.**

Keywords - gamification; image labelling; photographs; subject acess

I. INTRODUCTION

While the technology to search text is widely available and familiar, the technology to effectively search images and video without any descriptive metadata is still in its early stages. Most web search engines find images by indexing the text that surrounds any image and matching it with the given query. Naturally, this means that someone has to add annotations to every single image in order for the image to be retrieved. Any such process of manually adding descriptive metadata to a large image archive would entail large expenses and a large amount of time. Since algorithmic solutions for image retrieval are currently not on par with human performance, there is a need to investigate how the process of adding descriptive annotations could potentially be transformed from a tedious and labour-intensive task into an enjoyable experience. In this paper, we discuss different game-based approaches in harnessing collective efforts of online communities, with a special emphasis on the development of solutions aimed at image labelling and descriptive metadata.

II. THE RISE OF GAMIFICATION

With the development of different digital technologies in the Web 2.0 era, people have moved from a passive position to a more participative role and now have the spare time to use their *cognitive surplus* (spare processing power of the brain) to engage in different online activities harnessing collective intelligence [1]. One such activity that has become a main source of using that cognitive surplus is gaming, not only for children or teenagers, but for the entire age spectrum. The latest Entertainment Software Association [2] annual report on the essential facts about gaming habits in America states that 60 percent of Americans play video games daily, with an average of two gamers in each game-playing US household. According to the report, adult women represent a greater portion of the video game-playing population (33%) than boys under 18 (17%) and the average female video game player is 36, whereas the average male video game player is 32. According to the research, today, the average gamer is a woman of 36 years who plays casual games on her mobile phone as a favourite leisure activity [2].

Following the popularity of games as a leisure activity among all age groups, organisations across the globe began exploring games as a way to outsource various tasks related to their products and services to the crowds gathered under the notion of gamification [3]. A seminal paper on the topic of gamification [4] defined gamification as “the use of game design elements in non-game contexts.” In a later paper [5], authors differentiate between gamification and gameful design, stating that gamification is the application of gameful design:

gameful design is defined by the end of affording ludic qualities or gamefulness (the experiential qualities characteristic for gameplay) in non-game contexts. In contrast, gamification describes the means of using game design elements in non-game contexts, typically for the end of gameful design [5]. One of the most commonly used frameworks for game design is the MDA framework consisting of *mechanics, dynamics, and aesthetics*, and it is used as a tool to help designers, researchers and scholars achieve gamified design [6]. *Mechanics* describes the particular components of a game, at the level of data representation and algorithms. It includes various actions, behaviours and control mechanisms afforded to the player within a game context. Together with the game's content (levels, assets, etc.), mechanics support the overall gameplay dynamics. *Aesthetics* describes the desirable emotional responses evoked in the player when he interacts with the game system [6].

There is a different number of terms emerging in literature when these types of games that have some greater purpose or goal are discussed, using the collective participation of human players to support computational activities [7]. Games that focus on scientific problems have been called "citizen science games", while others have more broadly used the terms "games with a purpose," (GWAP) or "human computation games." Reference [7] also adds a new term, "knowledge games," defining them as: "…games that seek to invent, create, and synthesize new understandings of the world, solve real-world problems big and small, and help us reconsider, reframe, and reflect on humanity and our universe. "[7].

Various empirical studies indicate that gamification is an effective approach to increase user motivations [8], participation and long-term engagement [9]. Thus, the use of gamification in crowdsourcing is drawing an increasing attention, in both academia [10] and practice [11].

III. GAMIFYING IMAGE LABELLING

A large amount of research has been carried out on image retrieval (IR) in the last two decades. Image retrieval systems can be broadly categorized into two main categories: context-based and content-based. Context-based image retrieval systems use text to describe the image, whereas content-based image retrieval (CBIR) systems employ visual features such as colour, shape, texture and object position for image description [12]. Context-based image retrieval systems have been used since the late 1970s and are still the predominant method used for image search. They are known to be more efficient and accurate, and are based on assigning metadata to images. The metadata could be a title, natural language description, author, date and time of creation, and assigned keywords, either with the help of controlled vocabulary, professional natural language description, or through social tagging [12].

Within the content-based image retrieval systems, there are two main approaches: one that focuses on automatic methods and one that focuses on human-oriented image metadata creation. Automatic approaches aim to identify semantics relevant to the content of static images via the identification of visual features. Various approaches that use machine learning for image or image region categorization can perform well, but are limited to a small number of categories and the lack of training sets to be used effectively for the acquisition of more specific metadata [13]. Generally, automated approaches introduce certain inaccuracy, which makes them difficult to apply to heterogeneous resources. More or less, they also need large training sets of already annotated images, which stress the initial requirement of human labour needed to create them [13]. The traditional approach to achieve high metadata quality is carried out by using dedicated experts, who are aware of the purpose of their activity and who annotate resources as their primary job. However, such experts must be properly paid for their work, and cultural heritage institutions often lack the resources to handle the amount of material that is in need of cataloguing. Therefore, in the image domain, image annotation cannot yet be effectively performed via automated approaches and it requires manual image annotation, which does provide quality metadata, but does not scale due to the lack of time, resources and motivation of humans to do it [14].

One of the possible solutions to this problem is applying the gamification approach in the process of annotation. First significant developments in this area came from the field of human computation with the works of Luis von Ahn [15] and the related papers which explored how using the collective intelligence can solve problems that are hard or still impossible to do by using computer programs or algorithms [16], especially interested in the field of image labelling [17]. In order to address this problem, he introduces the term *human algorithm games* as a "paradigm for utilizing the human processing power to solve problems that computers cannot yet solve" (von Ahn, 2005). Von Ahn applied this idea by developing one of the first, as he called it "game with a purpose", the *ESP Game* [16]. The general idea was to gamify the process of image labelling in the online environment. From the player's perspective, the goal of the *ESP Game* is to guess what their partner is typing for each image. Once both players have typed the same string, they move on to the next image. The game does not ask the players to describe the image: all they are told is that they have to

"think like each other" and type the same string (thus the name "ESP"). The game was very successful, and almost 1.3 million labels were collected with only 13 630 players, some of whom spent over 50 hours playing the game. Manual evaluation of the added labels showed that more than 85% of labels were relevant, thus providing the evidence that this game-based approach produces high-quality labels [17]. However, despite its influence and novelty, there were some shortcomings in the way people labelled images in the *ESP Game*. Firstly, there was a lot of redundancy in the tag sets with a number of synonyms appearing as labels, secondly, there was a tendency to match based on colours and thirdly, players tended to add more generic labels [18].

Another development in the field of metadata crowdsourcing games aimed at describing different digitized collections was the development of the Metadata Games [19] project, a free and open source software system that uses computer games to collect information on archival images. Metadata Games is designed to be a free, open source, customizable software package available to a wide range of cultural heritage institutions without expensive licensing fees or contracts, helping cultural heritage institutions gain useful data for their collections, assisting scholars in learning how to interact and utilize collections in new and possibly unexpected ways, and providing a host of opportunities for the public to interact with cultural heritage institutions [20]. The project currently offers two mobile and four online games aimed at collecting metadata, and is used with over 45 collections worldwide.

The usability testing of the Metadata Games platform compared crowdsourced metadata generated by the users of the Metadata Games platform against the traditional metadata provided by the staff of the Boston Public Library. The findings of the study demonstrated that crowdsourced metadata, when used in tandem with traditional metadata, increases findability, corrects preventable search failures, and is by and large accurate [21]. It was concluded that games can be particularly effective in invoking intrinsic motivations and overall enjoyment, and that given the same tagging conditions, librarians and non-librarians produce a surprisingly similar distribution of useful metadata [21]. Other studies have also shown that applying game design features outside the traditional game environments can increase motivation and positively influence the behaviour of individuals [10].

In order to examine game-generated tags and their usefulness for subject description, a comparison of game-generated labels and professional descriptors was undertaken. The research question examined whether game-generated image labels can produce useful semantic annotations for visual resources in comparison with the traditional approach carried out by using dedicated experts.

IV. GAME-BASED LABELS VS. PROFESSIONAL DESCRIPTORS: A CASE STUDY

The research was structured into three complimentary stages. In the first stage, 20 digitized photographs were thematically selected by a subject expert in charge of the collection of the photographs used in the "Croatian Homeland War" exhibition authored by the Croatian Historical Museum. After the process of selection, the subject expert added his professional descriptors to each item, following relevant standards for assigning subject metadata**.** The subject expert assigned a total of 117 descriptors on 20 photographs with an average number of six descriptors assigned to one item. (Table 1). After that, a game-based application was developed and used for gathering image labels on the same 20 items. The application was based on the tools developed by the Metadata Games (metadatagames.org) project, a free and open source software system that uses computer games to collect information on archival images (Figure 1).



FIGURE I. APPLICATION INTERFACE FOR GAME-BASED LABEL COLLECTING

By using this platform and customizing it in local language, we had the tool to compare game-generated metadata against the traditional metadata assigned by the subject expert. The application was active during a period of 30 days and it attracted a total of 147 active players contributing a total of 1811 different tags describing a total of 20 different images. (Table 1)

TABLE I. GAME-GENERATED VS SUBJECT EXPERT DESCRIPTORS

	Game-generated labels	Subject expert descriptors
No. of labels	1811	117
Max. no. of tags assigned	129	9
Min. no. of tags assigned	56	4
Avg no. of tags assigned	90.5	5.85

After this first stage of data collection, each item in the collection was now described with two types of data: (1) descriptors assigned by the subject expert and (2) game-generated labels.

The second stage was aimed at analysing the collected corpora. By comparing these two sets of labels on a syntactical level, there was an overlap of 52.87%, meaning that little less than half of all game-generated labels was not present as a descriptor assigned by the subject expert. This left us with 850 game-generated labels for which we wanted to know their potential as possible index terms. When this set was analysed on a linguistic level, it was shown that a typical game-generated label consists from either one or two words (91%), is a noun (82%), in singular (78%) and in its nominative form (99%). In that sense, the analysis showed that a typical game-generated label does not differ from the linguistic characteristics of standard descriptors used for subject indexing. This has led us to believe that such game-generated labels can provide a basis for including the user warrant criteria in the description as a basic prerequisite for any subject indexing process, and that these labels could be useful as additional indexing terms.

For this reason, the final part of the research analysed the usefulness of game-generated labels for subject description from the point of view of the subject expert who assigned the professional descriptors in the first stage.

In order to make the set manageable for the subject expert, a frequency threshold for each label was introduced. It was decided that any label that has a frequency of three or higher would be subjected to subject expert evaluation. Since other game-based collection platforms such as the ESP game considered the label validated only if two players agreed on the same label, it was considered that if three independent players entered the same label describing one image, this label should be considered relevant within the system. By using this approach, the initial set of 850 game-generated labels was reduced to a manageable 178 labels subjected to expert evaluation. This meant that on average, for each item, the expert would evaluate eight or nine game-generated tags for each image. The research idea was to examine what percentage of these game-generated labels (with a frequency of three or more) would the subject expert include in the standard description within a controlled environment such as a library or a museum catalogue. The expert used a 5-point Likert scale ranging from 1 (would not include the label in any form), across 3 (would include the label with some normalization added) to 5 (would include the label as it is). Figure II shows the grades for each of the 20 images.

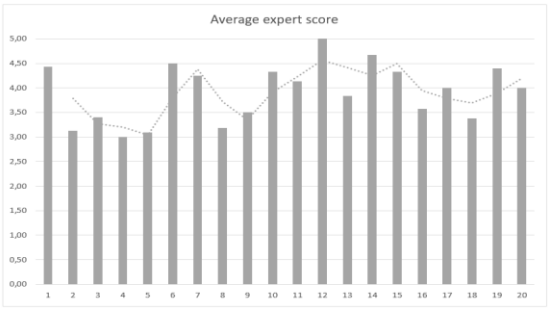

FIGURE II. AVERAGE EXPERT SCORE OF GAME-GENERATED LABELS

As we can see, the expert valued the game-generated tags very high with an average score of 3.91, and no tags scored lower than 3. This effectively shows that game-generated tags, from an expert point of view, provide high quality labels suitable for inclusion in a standardised description, such as museum or library catalogues.

V. CONCLUSION

The right use of gamification in crowdsourcing can significantly increase enjoyment and participation, and can transform tedious and time-consuming activities into fun and exciting experiences.

Gamification is not just a method of getting things done by the user, but an approach that can engage them to contribute, collaborate and co-create. Many successful projects in the heritage sector, often gathered under the notion of citizen science or crowdsourcing, have shown that gamification can be a viable solution to a number of tasks, and many projects started to explore the potential of that kind of gamification approaches in order to make different tasks more appealing, fun and productive.

When applied to the field of image description, gamification has also shown many benefits. Since image annotation cannot yet be effectively performed via automated approaches and since it requires manual image annotation, cultural heritage institutions often lack the resources to handle the amount of digitized material in

need of indexing. Many studies have shown that applying the gamification approach in the process of annotation can increase motivation and positively influence the behaviour of individuals. Furthermore, it has been deduced that games can be particularly effective in invoking intrinsic motivations and overall enjoyment. The key issue when gathering crowdsourced image descriptions lies in the achievement of the semantic richness of labels in terms of search and retrieval.

This paper has presented a case study for the potential of including game-generated image labels into standard description, comparing them with standard descriptors assigned by a subject expert. It was shown that a typical game-generated label does not differ from the linguistic characteristics of standard descriptors used for subject indexing. Furthermore, when game-generated labels (with a frequency of three or higher) were subjected to evaluation by a dedicated subject expert, it was shown that game-generated tags provide high quality labels suitable for inclusion in a standardised description, such as museum or library catalogues.

Following this results, we can conclude that this research confirms the earlier results [21], and that game-generated image labels can serve as a basis of including the user warrant perspective into the standardized description in order to enhance description and retrieval.

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Puzzle-like programming languages in teaching programming

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***Abstract* - This paper examines use of puzzle-like programming languages in teaching programming. It analyzes a variety of puzzle-like programming languages and their availability in Croatian elementary and high schools and textbooks. Also, it compares available puzzle-like programming languages by criteria that should be satisfied to be recognized as programming language that is suitable for teaching programming.**

Keywords – teaching; programming; puzzle-like

I. INTRODUCTION

Computers play a large role in our everyday lives and familiarity with computers and programming is becoming essential. Methods to introduce computer programming to children are being explored by researchers and teachers. It is shown that learning how to program computers can have a positive effect on children's achievement in math and science, but also in language skills, creativity and social-emotional interaction [1].

Learning to program is similar to learning a new spoken language. The content of a first programming course should focus upon syntactic and mechanical learning to certain extent. Without knowing syntactic rules of a language, programs cannot be written. Mathematics and foreign languages have traditionally been taught through practice and drill. Repetitive drill learning can be appropriate technique for teaching syntactic rules in a first programming course [2]. But drill way of teaching is boring for students and it is difficult to motivate them. It is important for students to be motivated intrinsically when learning so they can achieve better results that way.

Nowadays, there are at least three different types of programming languages: image or picture languages, block or bubble or puzzle-like languages and "real" programming languages [3]. Image programming languages use images and other visual methods to bring the basic ideas of programming closer to students. Block programming languages use blocks with parts of code written on them to solve a problem. Block programming languages represent a transition from image programming languages to traditional programming languages. The "real" (traditional) programming languages are actually textual programming languages but, if explained step by step, they can also be used as teaching programming languages.

In this paper we describe puzzle-like programming languages used to teach children hot to code. Puzzle-like programming languages look like a set of drag-and-drop code fragments.

II. PUZZLE-LIKE PROGRAMMING LANGUAGES

Puzzle-like programming languages (visual programming languages, block-based programming languages) are programming languages that let users create programs by manipulating with elements graphically rather than by writing textual commands. These programming languages may be classified according to the type and extent of visual expression used, into icon-based languages, form-based languages, and diagram languages. They provide graphical or iconic elements which can be manipulated by users in an interactive way according to some specific spatial grammar for program construction.

The general goal of puzzle-like programming languages is to make programming more accessible to novice, mostly children, and to support programmers at three levels: syntax, semantics and pragmatics [4].

A. Popular puzzle-like programming languages

Puzzle-like programming languages are becoming more and more popular in education. They differ in their characteristics, features and possibilities. This paper analyses the characteristics and features of five most popular of puzzle-like programming languages: Alice, Kodu, mBlock, Scratch and MakeCode. Those languages are then compared following 17 criteria and checked if they meet the required criteria.

B. Criteria

Creators of programming languages for teaching programming, Saymour Papert (creator of Logo), Niklaus Wirth (creator of Pascal), Guido can Rossum (creator of Python) and Bertrand Meyer (creator of Eiffel) suggested criteria that programming languages for teaching programming should satisfy. [5] There are 17 criteria that are grouped into related sections.

Learning:

- The language is suitable for teaching. That means that the language should have simple syntax and natural semantics, and abbreviations should be avoided.
- The language can be used to apply physical analogies. To meet this criterion, language should

provide multimedia capabilities without extension.

- The language offers a general framework. In other words, the language should let beginners learn fundamentals that will serve as basis for learning other programming languages.
- The language promotes a new approach for teaching software. That means language should cover many aspects of software development process, not only implementations. The language for teaching programming should be designed to cover entire methodology for constructing software, both language and principles, tools and libraries.

Design and environment:

- The language is interactive and facilitates rapid code development. Environment that support use of the language should allow beginners to implement new ideas. Also, it should give students feedback on their progress in an interactive way.
- The language promotes writing correct programs. It is important to avoid "trial and error" approach to writing code. Students should be taught to write correct code without bugs.
- The language allows problems to be solved in "bite-sized chunks". In other words, it should allow students to focus on one part of the problem without moving on the next one. The language should support problem decomposition using procedures, functions etc.
- The language provides a seamless development environment. The code writing environment should have an intuitive GUI. It should make features and libraries easily accessible for beginners and for advanced programmers.

Support and availability:

- The language has a supportive user community. There should be support for all users, students and everybody interested in learning that programming language. Support can be in form of course books, tutorials, web pages, documentation or some other form.
- The language is open source, so anyone can contribute to its development. The language should be product of group of people that does not want to profit from the creation of the language but let anyone be part of the process of making a programming language suitable for teaching programming.
- The language is consistently supported across environments. It should be accessible from different platforms.
- The language is freely and easily available. It should be available worldwide, and should not be charged for using.
- The language is supported with good teaching material. That means there should be textbooks and other teaching/learning materials that follow the selected programming language.

Beyond introductory programming:

- The language is not only used in education. It should be suitable for developing real world applications. In other words, it should be applicable in various areas, not only in education.
- The language is extensible. It should let programmers access advanced functions.
- The language is reliable and efficient. It should be useful also in creating bigger applications. It is not very important from pedagogical perspective but programming instructors feel it is an important criterion.
- The language is not an example of the QWERTY phenomena. It means the language should be useful nowadays but it should also work well in teaching programming fundamentals that do not change in time.

III. PUZZLE-LIKE LANGUAGES COMPARISON

In this chapter, five programming languages will be described and compared. There will also be shown how does the programming code for calculating the sum of the first ten even integers look like.

A. Alice

"Alice is used by teachers at all levels from middle schools (and sometimes even younger) to universities, in school classrooms and in after school and out of school programming, and in subjects ranging from visual arts and language arts to the fundamentals of programming and introduction to java courses [6]." It is a programming language used mostly for teaching programming with offers students a full transition to the Java programming language. There are four versions of Alice and one should choose a version according to their knowledge and interests.

Alice programming language is definitely a language suitable for teaching and specially teaching younger students, although it is said that Alice is used as teaching language also at universities. It is applicable between operating systems. Alice offers a general framework and helps teach software in new, modern way.

Also, Alice is an example of interactive programming languages that helps students learn how to write correct codes, although it sometimes relies on "trial and error" principle, which is often the way younger students learn everything, so it is also a way of learning how to program for the youngest students. The language has an intuitive GUI, but it does not allow programmers to solve problems by cropping the problem onto smaller parts.

Alice has sufficient support for students and teachers, it has many teaching materials on their web-site and it also has forum that is often updated. The language is partly open source, but it is available under different platforms.

It is free and easily available worldwide. Unfortunately, it is not available on many languages, so it is mostly downloaded in English.

Alice, as a programming language, is used mostly in education. It has a Java in background so student can see how would the code they wrote look like if they wrote it in Java programming language. That is why Alice represents a good transitional programming language in teaching programming. Alice will help students understand the concept of programming. On the other hand, it is not useful in creating high speed applications nor is it helpful in writing more complicated programming codes.

B. Kodu

"Kodu lets kids create games on the PC and Xbox via a simple visual programming language. Kodu can be used to teach creativity, problem solving, storytelling, as well as programming [7]." It is a programming language that is created for teaching youngest students because of environment and features. It is suitable for teaching and it represents a new way of teaching programming. On the other hand, it is not applicable in different operating systems and does not offer a general framework because it, almost in general, relies on creating games for the youngest students.

Kodu is interactive programming language and encourages students to split the problems they need to solve in smaller parts but it mostly does work as an "trial and error" way of writing codes. The GUI is designed for basic programming. There is support for both students and teachers, there are even competitions that motivate students to write their first codes. It is available under different platforms and is free from subscription.

Although students can create games in Kodu, those are simple games. That is why Kodu is used only in education. It helps beginners understand the basic concepts of programming but it not useful for solving some more complicated problems.

C. Scratch

"Scratch is a programming software tool that is designed by MIT and is one of the most popular programming languages for children. It makes programming as easy as building blocks [8]." Scratch is a real example of puzzle-like programming languages. Parts of code are written on blocks that are shaped and colored differently, but intuitively demonstrate beginners which part fits next to each other.

Scratch is suitable for teaching and works across different environments. The language offers a general framework and is a good example of the modern approach for teaching software. It is interactive and promotes writing correct programs, but still mostly relies on "trial and error" method. Fig. 1 shows how does the programming code that calculates the sum of the first ten integers look like.

Scratch supports modularization and has an intuitive GUI for both design and implementation. It has a very supportive user community with lots of teaching materials

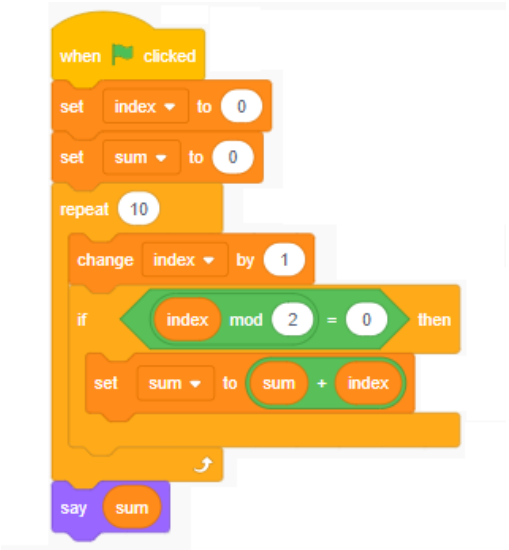

Figure 1. Code written in Scratch programming language

and tutorials, forum etc. It is open source and supported across environments.

There are different versions of Scratch in different languages. Also, Scratch gives a possibility to write code online. It is used only in education but in the background of Scratch there is C++ programming language. In that way students can see how their code would look like written in C++. It helps students to transit from puzzle-like to textual programming languages. Scratch gives students good introduction in programming and helps them learn how to think logically.

D. mBlock

"mBlock is a STEAM programming software tool designed for programming for kids. It is developed based on Scratch and Arduino code. Fig. 2 shows programming code that calculates the sum of the first ten integers. It can be seen that the code looks almost the same as the code written in Scratch programming language. It supports block-based and text-based programming languages. With mBlock 5, children can not only create games and animations by dragging blocks or using Python code, but can also code robots or boards to do anything they can imagine [9]." mBlock is a programming language that meets the same criteria as Scratch but also represents a

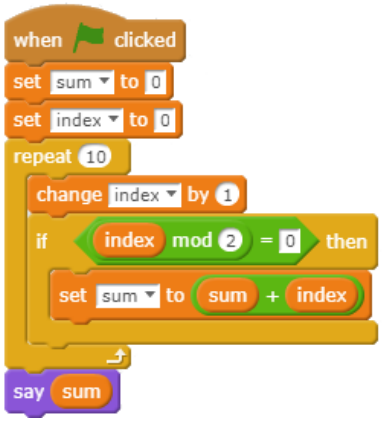

Figure 2. Code written in mBlock programming language

programming language that is used in programming physical objects. That is why it demonstrates students what is the real effect of their code.

E. MakeCode

"The MakeCode editor provided by Microsoft makes it easy to program your micro:bit with blocks and JavaScript [10]." MakeCode editor is, just like Scratch and mBlock, a real example of puzzle-like editor. Fig. 3 shows the code for the sum of the first ten integers. It looks similar to code written in Scratch and m Block, but it the parts of the puzzle needed to build the code has some tiny differences.

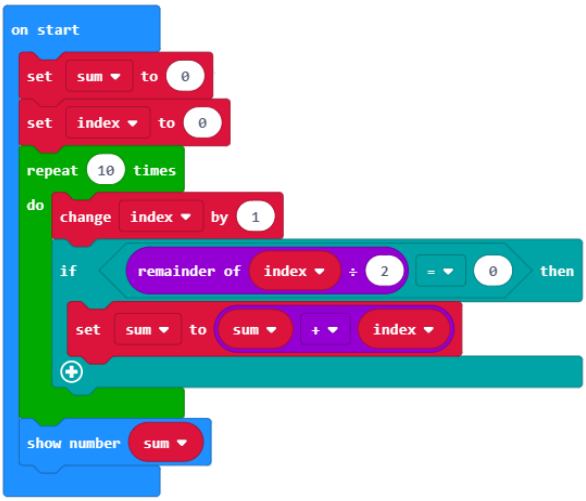

Figure 3. Code written in MakeCode programming language

It is used mostly for educational purposes. It helps students understand the basic concepts of programming and algorithmic way of thinking. It is a good way for students to go from puzzle-like to textual programming languages because MakeCode editor gives them opportunity to see how the code they wrote looks in Python. As MakeCode is used in writing code for micro:bit, it also allows students to get the real feel of what their code does as it effects on what happens with their micro:bit.

F. Additional comparison

There are some other features that can be observed when evaluating programming languages for teaching. The features of programming languages analyzed in this paper are listed in Table 1. that shows a year when each programming language was first and last released (First version, Last version), operating systems they can be installed on (Operating systems), how many users worldwide do they have (Users) and what kind of user support (Support). It can be seen that Alice was released 20 years ago, while mBlock and Make Code are relatively new. Scratch was publicly launched in 2007., but its first prototype was made in 2002. All programming languages have their last release in 2018. or even in 2019., and that proves their active community and development.

TABLE I. ADDITIONAL COMPARISON OF PROGRAMMING LANGUAGES

	Alice	Kodu	mBlock	Scratch	Make Code
First vesion	1998.	2009.	2013.	2007.	2016.
Last version	2018.	2018.	2018.	2018.	2019.
OS	Windows, macOS, Linux	Windows	Windows, macOS, Linux	Windows, macOS, Linux	Windows, macOS, Linux
Users	-	-	6 million	30 million	100 million
Support	Online Com., Forum, Events, Textbooks	Online Comm., Events	Online Comm., Events, Contests	Online Comm., Scratch Wiki, Events	Online Comm., Events, Contests
Approx. age	10-14	3-14	3-14	3-9	10-14
Exp. level	None or little	None or little	None	None	Little to some
Physical objects	No	No	Yes	No	Yes

All languages can be installed on Windows operating system, and all languages except Kodu support macOS and Linux operating systems. mBlock, MakeCode and Scratch have well-built community support. Forums and websites give relevant information, and teaching materials are available and free. There are also events and competitions that specially motivate students.

It is shown for which age groups these programming languages are suggested for (Approximate age). Most languages are suitable for teaching youngest students. Kodu, mBlock and Scratch are suitable for teaching children who did not even enroll in elementary school.

Table 1. also shows how much experience students should have to start programming in each programming language (Experience level). As the languages are suitable for teaching the youngest students, they do not need to have any experience. It is desirable that students have little or some experience in programming when writing code in MakeCode editor.

mBlock and MakeCode programming languages are suitable even for programming physical objects, for example, simple robots (Physical objects). That gives students better understanding of algorithms and basic concepts of programming. The possibility of programming physical objects is one of the biggest advantages of mBlock and MakeCode.

Kodu gives students opportunity to create their own games and that makes it easier for teacher to motivate students to start writing their first codes. That is the biggest advantage of Kodu programming language. The biggest advantage of Alice is existence of many official textbooks for teaching programming using Alice. Both Alice and Kodu do not have as good support as MBlock, Scratch and MakeCode have. On the other hand, mBlock, Scratch, Kodu and MakeCode are not that present in schools all over the world as Alice is.

G. *Puzzle-like programming languages in Croatian schools*

In schools in Croatia there are few programming languages used to teach programming: Logo, Python, QBasic. While taking part in programming competitions, students also use Basic, C, C++ and Pascal. In some schools, students write their first programs in Scratch, MakeCode and mBlock programming language [11].

Puzzle-like programming languages are not common in Croatian education. They are used for teaching programming as extracurricular activity, but not in schools. Some teachers in elementary schools teach their students to write code in Scratch, MakeCode or mBlock. There are no official teaching materials (textbooks or digital materials). Teachers can find materials on official websites or education forums. Also, there are plenty of examples that are good as motivation for beginners. The main problem is language. Most of the materials are in English so teachers need to be fluent in English and able to translate all the materials in Croatian.

IV. CONLUSION

As computers and programming are becoming par of everyday life, children are taught to write their first codes at early age. For youngest students, writing code in traditional textual programming languages can be a problem because of lack of basic knowledge. Puzzle-like programming languages let children start programming even before enrolling elementary school. Most popular puzzle-like programming languages meet the criteria written by creators of programming languages for teaching programming. Some of the puzzle-like programming languages are suitable only for educational purposes but they help teachers motivate students and teach them basics. MakeCode programming language could be the most suitable for teaching programming in elementary school as it has simple sintax and students can see the output on the little screen. For secondary school students, mBlock is great programming language for teaching since more complex codes can be written and they can also see the product of their work by the moves of the physical object.

In Croatian schools, puzzle-like programming languages are not used very often and there are almost no teaching materials. However, some teachers manage to use puzzle-like programming languages in classrooms and in that way introduce programming to their students in modern way.

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Methodology for using games as an educational tool

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***Abstract* - To motivate today's students that have access to various learning online platforms and use computers and different mobile devices every day, as a teacher I am forced to constantly change and use a variety of teaching methods. This paper will describe the methodology for the following types of games: guessing games, conclusion games, competition games, memory games, knowledge and validating resources games, games played in pairs. These games are intended primarily for teaching computer science subjects. Activities listed in this paper can help create an active learning environment and encourage teachers to look further for the better solutions of their application.**

Keywords* - *guessing games, conclusion games, competition games, memory games, knowledge and validating resources games, games played in pairs

I. INTRODUCTION

A game is a structured form of play, usually undertaken for enjoyment and sometimes used as an educational tool. [1]

Playing games shouldn't be just one of the side-effects of teaching work, it should be part of the student's reality. The purpose of this article is to help teachers find a game that will best suit their group of students at a certain point in time. Some of the games are shown in several variations; I hope that this can inspire teachers to explore further ways of changing and adapting the proposed games to the specific requirements of a particular group of students. Regardless of their age, a group of students differ in their likes and dislikes of a certain activity, and the teacher's attitude towards games has an impact on students.

This paper will describe the methodology and the examples for the following types of games: guessing games, conclusion games, competition games, memory games, knowledge and validating resources games, games played in pairs. An objective for each game is described in the Table I. The game division and the ideas for the games came after reading a book intended for teaching foreign languages: "A game is a game is a game [2]".

These games are intended primarily for teaching computer science subjects. They were designed and implemented during several years of teaching different ICT subjects in the 4-year programme: Computer engineering technician in the Electrical Engineering Vocational School Zagreb.

TABLE I. GAME AND OBJECTIVE

Game	***Objective***
Guessing game	Guessing a concept (term) on the basis of very little or no data or information.
Conclusion game	Based on the data and various information that they need to collect and evaluate students solving a specific problem.
Competition game	Strengthening the psychological stability of an individual.
Memory game	Improving memory skills.
Knowledge and validating resources games	Finding the right question, answer or description of a given task in the shortest possible time, relying on your own knowledge and skills (researching data and validating resources).
Games played in pairs	Strengthening the feeling of independence and responsibility.

Games described in this article showed the best results in motivating students to achieve their learning outcomes. Examples described for each game were used during teaching different computer science subjects. The methodology for each game was used in more than one subject.

This paper is a practical result of years of inventing and testing different games and approaches to motivate students to participate more in the classroom.

A. A Good Detective

Students gather around the table that has different printed cards; there is one card more than the number of students. [2] The teacher explains the rules of the game: all characters are suspected to have participated in a cyber-attack, but only one character has committed the attack, and that character has no alibi. Also, the teacher explains the nature of this cyber-attack. For example, a cyber-attack in which a hacker accessed Google's corporate servers and gained access to a database

containing classified information. The teacher can also leave a short description of the cyber-attack on the table so students can see it while asking questions and giving alibies.

Students have some time to memorize the cards with the characters (about two or three minutes). The teacher takes away the cards and shuffles them, then gives each student one card. Students mustn't see the cards held by other students.

The teacher has that one, extra card for the character that has committed the cyber-attack. The teacher then places that card on the table, face down. Nobody knows what character is that because the card is placed face down. Only the teacher knows that all students are innocent and that the card placed on the table is the criminal.

Students now accuse for the crime each character that they can remember. A student who has that character needs to explain his/her alibi. Alibi is an explanation for the character's vocation. If the student gives a valid alibi, he/she places the card back on the table placing it face up.

For example:

Student number one: I accuse the AutoCAD designer!

Student number two: (the student who has the card with a picture of the AutoCAD designer) No, the cyber-crime that was committed has no connection to that field. AutoCAD designers are drafters that specialize in the use of computer-aided design software to create digital technical drawings.

The game is over when each character is mentioned, and all alibies are given. Then the card that was left on the table face down is turned over. Each student needs to give a reason why this character has committed the cyber-attack.

This game can be played in two groups. The first group is playing while the second group is monitoring their activities, then they switch roles.

To prepare for this game, the teacher needs to print the cards with characters and their vocations and a description of the cyber-attack. The estimated time for a group of students (5 to 7 students) is 15 to 20 minutes.

B. What Is It?

The teacher has up to 20 cards that have pictures of different objects. For example: learning about networking devices, equipment needed to create and maintain a computer network, learned about computer hardware, etc.

The teacher has all the cards (and only the teacher can see the cards); he/she takes a card with one object and gives information about it, for example: the category of the object. Students ask yes/no types of questions. The teacher's answer to the students' questions can be only yes or no. The game is over when students guess the object.

Also, instead of objects, concepts from programming can be used.

To prepare for this game, the teacher needs to print the cards with the objects. The estimated time for smaller group of students (up to 14 students) is 20 to 30 minutes.

C. What Does the Word Mean?

The teacher writes one word on the board. Students need to explain what that word means. To answer, they can only ask the teacher questions that can be answered with yes or no. [3] For example, this game can be used in repeating learned concepts from various programming languages.

For an advanced level of this game, the teacher can use pieces of code, and students need to guess the function of that code segment. Also, the teacher can give a list of specific sets of commands and students need to guess what they are used for (e.g. configuring a wireless router, creating a database, etc.).

To prepare for this game, the teacher needs to prepare terms, pieces of codes, sets of commands used in the game. Materials for the game can be printed, shown as a PowerPoint presentation or written on the board. The estimated time for up to 10 terms and for a group of students (up to 14 students) is 20 to 30 minutes.

II. CONCLUSION GAMES

A. Problem Solver

The teacher gives each student his own problem to solve. In doing so, the teacher can write down guidelines on how to find the answer to the given problem, what needs to be researched and taken into consideration.

For example: "A friend of yours is a painter and wants to open a web shop so he can sell his paintings. Create a concept for that web shop.", "You have an apartment rental agency and need to create a web page to promote it. Create a concept for that web page", "Your sister and her friend have a small office. They want you to create an office network for them. Create a basic concept of that network", "Build a concept of the weather station for one flower plantation", etc.

To do the necessary research and solve the problem, students can use books, other written materials and Internet resources. Each student has 30 do 45 minutes for doing the research. Each student needs to present the solution for the specific problem to the rest of the class.

A simpler version of this game is to put one problem and guidelines on the board for all students. Students can do the research in pairs or groups. At the end, each group can present their solution to the rest of the class.

To prepare for this game, the teacher needs to print the problems and guidelines, prepare books or other written material. Each student must have access to a computer and the Internet. The estimated time for a group of students (up to 14 students) is up to 90 minutes.

B. What Category Is It?

The teacher has up to 20 cards that have pictures of different objects. The teacher puts pictures of the objects on the board. Students need to group the pictures into

categories, such as networking devices or computer hardware. There can be two or more categories.

To prepare for this activity, the teacher needs to print out pictures with objects.

The estimated time for a smaller group of students (up to 14 students) is up to 10 minutes. If this game is played with the whole class up to 25 students or more, students can be divided into groups and each group can have its own category. After they sort the objects into categories, students need to present their category to the rest of the class. The estimated time for a larger group of students (whole class divided into groups) is up to 45 minutes.

III. COMPETITION GAMES

Guessing and conclusion games can be modified to become a competition game. Competition games give students an opportunity to prove their competences under pressure, to learn to win and to lose. The main objective for implementing these types of games is strengthening the psychological stability of an individual.

A. What Is It? No Questions Asked!

The teacher prepares up to 20 different terms (or, for example, problems). The teacher explains the term or the problem to students and they need to guess the term or figure out the solution to the problem. Students aren't allowed to ask the teacher any questions. They can discuss among themselves or use learning materials.

The student with the most correct answers wins the game.

To prepare for this game, the teacher needs to prepare terms or specific problems. Each student must have access to a computer and the Internet. The estimated time for a group of students (up to 14 students) is up to 20 minutes.

B. Programmer

The teacher gives each student the same task. To solve the task, each student needs to write a code in a specific programming language (or, for example, to fix errors in the code and make the program functional).

Students have 30 minutes to do the given task. Assignments are submitted and the teacher evaluates the best solution. After all the students have submitted their assignments, the teacher can show one of the probable solutions.

The winner is the student who finishes the assignment first, and then he/she explains the solution to the rest of the class.

To prepare for the game. the teacher needs to print the programming task and guidelines or other necessary written materials. Each student must have access to a computer and the Internet. The estimated time for a group of students (up to 14 students) is up to 45 minutes.

IV. MEMORY GAMES

A. Match Pairs Memory Game

Students need to match a term or a concept with its definition or explanation. For example, the term can be "IP address", and an explanation would be "A unique string of numbers separated by full stops that identifies each computer using the Internet Protocol to communicate over a network". In teaching programming, students can match parts of the code with the explanation what that part of the code does in a specific program. Also, students can match commands with an explanation for that command.

The teacher can use an online tool to create the matching pairs game, so each student can play for himself/herself. If students don't have access to computers, the teacher can print the term or concept and its definition or explanation, divide students into pairs and let them play the match pairs memory game in pairs.

To prepare for this game, the teacher needs to prepare an online game or print out the necessary materials keeping in mind the number of students in the classroom. The estimated time for this activity is up to 15 minutes.

V. KNOWLEDGE AND VALIDATING RESOURCES GAMES

A. A Quiz

A quiz consists of various types of questions such as Multiple Choice, Yes or No, Fill in the Blank, Matching, Definitions, Open-ended, etc. It can have a time limitation implemented on the whole quiz (for example: a quiz with 10 questions can last 20 minutes) or each question can have its own time limit (for example: multiple choice-1 or 2 minutes, writing the answer-5 minutes).

Questions can be created in a way that students need to research a specific topic and validate found information to write an answer.

To prepare for this game, the teacher needs to prepare a quiz (using various online platforms such as Moodle, Edmodo, Schoology, etc.). Each student must have access to a computer and the Internet. The estimated time for a quiz activity depends on the level of difficulty. Quizzes can be used as a method for repeating learned outcomes, testing the level of achieved learning outcomes, researching a specific topic or problem, or as an introduction to the learning outcome.

The estimated time for the quiz activity depends on the number of questions asked and their difficulty.

B. A Quiz - Without an Online Platform

The teacher reads a question and students answer. Also, the teacher can give a more difficult question that requires from students to go through the written materials and evaluate researched data and then give an adequate answer.

To prepare for this type of a quiz, the teacher needs to prepare and print out questions, written materials (books, technology magazines). The estimated time depends on the number of questions and level of quiz difficulty. The

estimated time for a group of students (up to 14 students) is from 10 to 20 minutes. If the whole class is involved in this activity, students can be divided into groups and the activity can last for 45 minutes.

C. An Empty Nutshell

The teacher divides the class into teams (four or five teams, depending on the number of students in the class). Each student gets a picture or a term that only he/she can see. Then each student needs to write several sentences (a description) about that picture or topic. Each group reads the explanation for their topics and students from other groups try to guess what the answer is. [4]

This game is over after all students have presented their object, terms or topics. The point of this game is not to guess the answer. The winner is the group that has written the best descriptions in the sense that others couldn't guess the correct term.

It is not necessary to divide students into groups; descriptions can be read in front of the whole class. All students can try to guess the answer.

To prepare for this activity, the teacher needs to print out objects, topics or terms for each student. The teacher can also prepare additional questions to help students write down the necessary descriptions. The estimated time for the whole class (up to 22 students) is up to 45 minutes.

VI. GAMES PLAYED IN PAIRS

Most of the games mentioned in this article can be modified to be played in pairs. In that case, the teacher needs to prepare a larger quantity of written materials for the students.

A. Describe and Arrange

Students are divided into pairs. Each pair gets their own set of pictures and articles. The teacher writes several categories on the blackboard. Students must read the material first and organize pictures under each article. Then, each pair of students needs to put their articles and pictures under a specific category on the blackboard explaining why they chose that category.

For example, when learning about computer hardware, the teacher can use different technology magazines (such as Bug or PC Chip in Croatia) to prepare the necessary pictures and articles. The categories in that case can be Input Devices, Processing Devices, Output Devices, Memory/Storage Devices, etc.

For students that have basic or advanced knowledge of different programming languages, they can first match a command with its description (basic level) or part of the code with its function in the program (advanced level). Then, after doing so, they organize given commands or parts of the code under the programming language category.

While each pair is sorting their materials under the category written on the blackboard, other students are listening and stating their opinion on the chosen category.

To prepare for this activity, the teacher needs to prepare the necessary written materials, pictures and articles for each pair. The estimated time for a smaller group of students (up to 14 students) is up to 45 minutes.

B. The Empty Office

Students are divided into pairs; each pair has a different assignment. The main task is to equip an open office space for a small company (for example: architect's office, programming office, etc.). Depending on the number of pairs, a different task is given to each pair. For example: the first pair needs to order the necessary equipment from the computer store, the second pair needs to recommend the number of computers and a minimum computer configuration needed, the third pair needs to recommend and order additional equipment (such as printers, scanners, plotters, projectors, etc.), the fourth pair needs to configure a network and order the required equipment from the store, the fifth pair needs to recommend all the necessary software for that company and the cost for each software (such as operating system, Office, AutoCAD, programs for editing pictures, videos and sound, etc.)

At the end, each pair presents their work to the rest of the class. Students can write down their answers and post them on the blackboard, or the game can become a project where each pair will create a poster with all the necessary steps they had to take and the pictures for the hardware ordered from the store. If students have access to a computer classroom, the game can be played in a way that they put their solutions on Google Drive (the teacher can create a folder and share it with students) and then present their work to the rest of the class as a presentation.

To prepare for this activity, the teacher needs to prepare written materials and questions that can help each pair come to the solutions for the given task. If the students have access to a computer classroom, the teacher can prepare guidelines for searching the Internet to find the required information for completing the task. The estimated time for this activity is up to 90 minutes; also this activity can become a project assignment.

VII. CONCLUSION

As a teacher I am forced to constantly change and use a variety of teaching methods to motivate today's students. Games are one of the easiest ways to encourage them to start mastering learning outcomes more effectively. Playing games shouldn't be just one of the side-effects of teaching work, it should be part of the student's reality. The attitude of the teacher towards games plays a major role in their implementation.

I have applied the described methodology in my personal work with students during the period of several years. As a teacher I have noticed that applying these games made my work easier. Students were more motivated and have shown better results in achieving the learning outcomes.

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Measuring Eye Movements in Learning Research: A Useful Window to Cognition

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Abstract **- Analyzing the eye movements made while inspecting a visual environment can be of valuable help to get insight in the involved cognitive processes. With the help of state-of-the-art eye-tracking systems and using various paradigms, researchers are able to measure and interpret different eye movement parameters such as fixations, saccades, pupil size and scan paths when evaluating visual surfaces (e.g. in consumer research or user interface design). These analyses allow to widen the knowledge on complex processes, such as decision-making, or to investigate e.g. learning strategies. The current article aims at giving an overview of how eye-tracking and the analysis of eye movements, respectively, might be useful in the emerging and changing field of Learning Research: Firstly, the physiological and anatomical basics of eye movements are reflected, then the concept of eye-tracking and different technological systems for that purpose are introduced. Moreover, we will summarize eye movement parameters and finally end with a reflection of eye-tracking in Learning Research.**

Keywords: Eye Movements, Eye-Tracking, Cognition, Learning Research.

I. Physiological and Anatomical Basics of Eye Movements

Whenever we look at a scene in order to search for something, when we read a book or a newspaper or just enjoy the view on the top of a mountain, our eyes make continuous eye movements, so-called saccadic eye movements or saccades [1] (see Figure 1). Saccades are fast, jump-like (ballistic) eye movements [2]. With peak velocities of up to 500 ° per second [1], they are the fastest movement our body can generate [3]. Typically, we make about 3-4 saccades per second, most of the time unconsciously, even though they can also be made voluntarily [2]. Saccades help in overcoming our eyes' limitations of visual acuity: The retina of an eye consists of the fovea (located in the centre of the retina which subtends about 2° visual angle [4]), whereas in the parafovea (extending 4-5 ° visual angle around the centre of the retina) and the periphery around it, visual acuity drops increasingly [4] with distance to fovea. Hence, when making saccades, the movement directs the fovea to the point of interest and then this point can be seen in a very clear and acute way.

The size of saccades varies from about 1 ° visual angle in silent reading to about 4 ° visual angle in scene perception [1] (for comparison, the size of a thumbnail seen over the length of an outstretched arm covers about 1.5 – 2.0 ° visual angle [4]). To perform saccades, a certain time (about 150-175 ms) is needed to plan and execute them [1]. During a saccade, we are not able to process input from our surrounding environment [2]. In other words, participants in studies typically do not notice changes made in the visual field during a saccade, a phenomenon which is called saccadic suppression and often used in experimental research in order to investigate perceptual and attentional processes [5-6]. Besides saccades, there are three other types of eye movements: 'Pursuit' eye movements, when the eyes follow a moving object; vergence ("inward") eye movements, when fixating close objects; and vestibular eye movements, when compensating for head and body movements [1]. Moreover, there are three sorts of small eye movements that typically occur during fixations [4]: Nystagmus (constant tremor of the eyes), drifts, and microsaccades (both drifts and microsaccades are slightly larger than nystagmus [1]).



Figure 1. Example of a fixation path (scan path) by a single subject when inspecting a visual environment: Fixations are highlighted in blue and saccades are highlighted in yellow.

In the time between two saccades our eyes stand still for about 200-300 ms: This is called fixation [1] (see Figure 1). During this time, visual information is processed, and the next saccade is planned. Although fixations are described as being stationary, the eye never fully stands still: As stated already above, small movements can be seen during this period [2].

When examining eye movements in a scientific context, saccades and fixations are typically of major interest. The picture in Figure 1, for example, shows a seagull sitting on a fence, and in the background we see some trees. Observers inspecting this picture make certain fixations and saccades in order to acquire the most important information from it (this corresponds to real-world seeing). The sequence of fixations and saccades made during inspection of a certain scene is called scan path. Using eye-tracking, researchers can define the scan path, but also detect in what specific way participants scanned the scene.

Generally, the question of which areas or objects in a visual scene are likely to be inspected or not, and for how long they will be inspected, is challenging to answer: It depends on various factors of attention and also on a variety of additional factors. Recently, five factors were defined for guiding visual attention [7]: 1) Bottom-up saliency (i.e., how strongly something in the picture catches the viewer's attention); 2) Top-down orientation of features (where viewers consciously decide what to view); 3) Scene structure and meaning (depending on certain items in the scene that guide attention); 4) History of visual search in certain scenes (sum of information on a certain scene we have accumulated over a period of time, from milliseconds to years); and 5) Relative value of certain objects in a scene (related to reward). Along these lines, also the expertise of an observer changes eye movement behavior. For instance, in a meta-analysis, researchers could show that experts needed a shorter time to fixate relevant areas the first time, fixated more task-relevant areas than task-irrelevant areas, and had shorter fixation durations but longer saccades, compared to novices [8].

Furthermore, analysis of eye movements can also help investigating clinical cases. For instance, eye movements differ across developmental stages [1] or regarding specific diseases: Dyslectic readers show a higher number of fixations and longer fixation durations compared to healthy controls when reading a list of words [9]. In a review of scientific literature concerning the use of eye-tracking in early autism research, it was proposed that a reduced time of looking at people and faces, as well as attentional problems, are among the earliest signs of Autism Spectrum Disorder; also, they emerge during the first year of life [10]. In combination with attentional tasks, vergence (i.e., eye movements inwards to fixate close objects, see above) can be a potential marker for Attention Deficit Hyperactivity Disorder (ADHD) [11]. Other researchers have aimed at comparing the eye movement behaviour of women with spider phobia, when viewing spider pictures and neutral pictures, with and without usage of placebo medication [12]. In the placebo-treated group, the number of fixations and the dwell time on spider pictures increased, compared to the group without placebo treatment; this suggests that a placebo was helpful in decreasing avoidance of spider pictures in women with spider phobia. As can be seen, eye-tracking was valuable in coming to this conclusion.

Generally, eye-tracking is a useful tool in science and is used in a broad array of fields, from Scientific Research to Commercial Applications and Marketing [13], as well as Usability Research [14]. It is useful in evaluating therapies [15], Multimedia Learning [16-18] and as a reliable method in promising scientific projects for future research, e.g., Human-Computer Interface [19-20]. Eye-tracking is also an important tool in the validation and evaluation of Automatic Question Creation: Some years ago, we validated automatically-created questions from the Enhanced Automatic Question Creator (EAQC) [21], comparing these automatically-extracted concepts to participants' eye movements [22]. Another field of usage for eye-tracking systems is research with Virtual Realities [23].

II. Concept of Eye-Tracking and Different Technological Systems of Eye-Tracking

As stated above, eye movements and gaze directions can be enormously important for a variety of cognitive research. A common way to investigate eye movements is eye-tracking, an advanced technology with a long history of many decades. The largest group using eye-tracking nowadays are researchers; another large and recently emerging group of users are in advertisement and marketing [3]. Eye-tracking systems comprise typically not only the hardware, but also stimulus and presentation tools [3]. There are many ways to measure eye movements and the following overview should be a brief introduction:

Electro-Oculography (EOG): Some decades ago, electro-oculography was the most common way to perform eye-tracking and it is still used in present times [4]. For EOG, electrodes are attached close to the eye, measuring the skin's electric potential differences [4]. This method is used to detect movements of the eye in relation to the position of the head of a participant: However, it is not the best choice for detecting participants' points of regard (i.e., at what position a person looks at).

Scleral Contact Lenses: Here, special contact lenses are attached to a small wire coil [4]. Through the coil, the position of the pupil moving through an electromagnetic field can be detected. Although it is the most precise method to detect eye movements, the usage can cause great discomfort with participants and hence, this technique is considered to be invasive.

Video-based eye-tracking with pupil-and-corneal-reflection method: This eye-tracking technology detects the location of the eye with a sampling rate of up to 2000 times per second (i.e., 2000 Hz) and gives precise information about where the individual is looking at [24]. Usually, these video-based systems of

eye-tracking make use of a corneal reflection of the eye caused by a light source (e.g., infra-red) and measure this reflection in relation to the pupil centre. Eye-tracking with infrared video recording is relatively non-invasive [4].

Besides the way of how the measurement of eye movements is carried out, there are also different ways of how to classify eye-tracking systems (from laboratory use, to use in applied settings). All these systems have their advantages and disadvantages and the decision as to which system to use usually depends on the question one intends to address, and on individual availability of different systems. Here we aim to give an (at least partial) overview of some of these eye-tracking systems:

Head-mounted systems are mounted directly onto the participant's head and resemble helmets. An advantage of these systems is that participants do not have to get their head fixated, although they should avoid larger head movements [4].

Tower-mounted systems are eye-tracking systems with a chin rest and front head coil, resembling the equipment of ophthalmologists (see Figure 2). Generally, these systems are easy to apply; however, participants are not allowed to move their head while testing.

Desktop-mounted systems are equipped with small eye-tracking cameras mounted on the table in front of participants, e.g., at or beneath a computer monitor. These systems require a relatively stable head position; however, again some degree of head movement is tolerated [25]. Generally, these systems are less expensive than head-mounted or tower-mounted eye-tracking systems [25].

Eye-tracking glasses are special glasses that allow for maximum natural gazing behaviour, as the head of the participant is completely free to move. These eye-tracking systems are often used in applied settings such as clinical settings or marketing/advertising. They are typically less expensive compared to other eye-tracking systems.

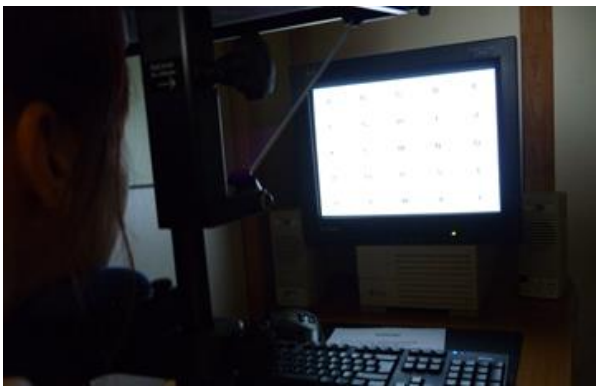

Figure 2. Eye-tracking with the usage of a tower-mounted eye-tracking system.

III. EYE-TRACKING PARAMETERS

Table 1 shows an overview of eye-tracking parameters (summarized and partly adjusted according to [19]). Regarding fixations, interesting parameters can include, e.g., the number of fixations overall, the number of fixations per area of interest or within a time interval, the fixation duration, possible refixations, and the overall dwell time on a certain scene. Regarding saccades, typically, one can rely on the number of saccades or saccade amplitudes, but additionally, parameters such as saccade direction or saccade velocity can be useful in solving certain questions. Regarding the overall scan path, it can be interesting to investigate, for instance, how much time participants need to perform the search, how long their scan path is and which directions they use in performing their eye movements when regarding a certain scene. Moreover, there are related parameters such as the blinking rate or the pupil size during fixation; these can also be interesting for certain questions. This list is a summary; there are many more eye-movement-related parameters available.

TABLE 1. EYE-TRACKING PARAMETERS (according to [19]).

Fixations: • Number of fixations overall • Number of fixations on a certain area of interest or within a time interval • Fixation duration • Refixation • Dwell time • Etc.
Saccades: • Number of saccades • Saccade amplitudes • Saccade direction • Saccade velocity • Etc.
Scan Path: • Scan path duration • Scan path length • Scan path direction • Etc.
Related Parameters: • Blinking Rate • Pupil Size during fixation

IV. A VARIETY OF EXAMPLES FOR EYE-TRACKING IN LEARNING RESEARCH

As discussed above, eye-tracking offers a reliable way to measure cognitive data and is a very well-established research tool. Typically, it enables drawing conclusions on questions that would not be possible to answer without eye-tracking. Regarding Learning Research, eye-tracking can open new doors and help to gain new insights into a very broad field of research, and further, has various practical applications. We would like to summarize and illuminate some of the studies which have used eye-tracking within Learning Research.

In an eye-tracking experiment, English speaking second year college students learning different languages (Russian, Arabic, Chinese, Spanish) were compared while watching films in their target learning language, with written captions [26]. Participants watched two animal videos (one of them included familiar language, one unfamiliar language) in their target learning language and researchers studied how often foreign language learners read the captions, if the target language learned impacts the time of caption reading and if there is an influence of how familiar the film is on reading of captions. The results showed that Arabic Learners spent more time reading the film-related captions than learners of Russian or Spanish [26]. Learners of Chinese spent more time on captions of unfamiliar films than familiar films, whereas learners of all the other three languages spent an equal amount of time on both (familiar films and unfamiliar films) [26]. To summarise: In that experiment, the usage of eye-tracking helped to find out more about specific usage of written captions when watching films within a group of learners of different languages, opening doors to new pedagogical insights and questions.

In another experiment, eye-tracking was used to see how different ways of representing something mathematically (formula, graph, plain text) would influence how students work [27]. The authors defined three conversions (formula-text, graph-text, text-formula) and participants had to find the matching answer out of four alternatives in a variety of items [27]. The authors reported that there is a difference in the way one perceives formulas (longer fixations) and graphs (shorter fixations): Generally, graphs show an overall longer dwell time compared to formulas [27]. Here the usage of eye-tracking allowed the researchers to detect cognitive insight in direct comparison of different methods of mathematical teaching.

Finally, a group of researchers aimed to implement the usage of eye-tracking in Computing Education Research and gain insight into the connection between eye movements and comprehension in programming [28]. They organized a workshop on "Eye Movements in Programming" and analyzed two cases of eye-tracking while professional programmers were reading and trying to understand short Java programs [28]. The researchers report that they learned many lessons and they gave tips on how to organize programming education to get the best learning outcome possible [28].

V. CONCLUSION

Generally, eye-tracking is a very interesting and promising way of collecting physiological data as a reliable predictor (e.g., for attention) for research and other fields such as marketing. State-of-the-art eye-tracking systems offer a rather uncomplicated and non-invasive way to collect data, validate theoretical approaches and open new doors of thinking and imagination in different fields of our lives. Regarding Learning Research specifically, eye-tracking can be used to investigate different pedagogical approaches over the wide and heterogeneous field of learning, and also to evaluate and validate different ways of teaching.

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Distinguishing the Themes Emerging from Masses of Open Student Feedback

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***Abstract*—Student feedback is one of the key methods for assessing the quality of teaching in higher education. Feedback is often collected using both Likert-type scales and open-ended questions. However, open-ended text answers are a difficult resource to utilize because of the manual work involved in qualitative analysis, and it is a challenge to gain insight of the underlying themes or issues behind the feedback. This paper presents a study in which we create and analyze topic models from open-ended student feedback. First, 6087 individual student evaluations were collected from university courses between two academic years, from 2016 to 2018. Then, topic models from the feedback texts were created using the Latent Dirichlet Allocation method with the R programming language and environment for statistical computing. After analyzing the resulting topic models, six categories of feedback were distinguished: 1) Positive comments about arrangements, 2) dissatisfaction in the teaching, 3) comments about course arrangements and deadlines, 4) lack of student motivation, 5) interest in the topic and understanding the material, and 6) comments about interesting, rewarding but challenging courses. Finally, this paper discusses the topic modelling results to provide an insight into the automatic analysis of student feedback.**

I. Introduction

Student evaluations of teaching are an integral part of quality control in higher education, as they have been commonly used to evaluate both teaching material and teachers themselves [1], [2]. Student evaluations are often collected using Likert-type scales, from which numeric data is easy to collect, process, analyze, and present as an indicator of quality. Unfortunately, not only are student evaluations a hard resource to use to their full potential, the validity of evaluations as a measurement of quality is questionable [3], and evaluations do not necessarily reflect about students learning [4]. In addition to numeric data feedback, forms often contain open-ended questions prompting the students to leave free-form feedback. However, these open text feedbacks are more challenging to analyze in large numbers, as they would require work-intensive qualitative analysis.

This paper presents a study on the use of open-ended student evaluations collected in large quantities. Specifically, the objective of this study is to apply a topic modelling method as a systematic, automated way to analyze open text feedbacks in the masses. The main research question this paper addresses is, **what can be learned from topic models of open student feedback**? The main research question is further divided into sub-questions, which are listed as follows.

- What themes can be recognized from the topic model, and how can the emerging topics be described?
- How do the discovered themes relate to course arrangements, course topics, student motivation, teaching methods, and the teachers competence?
- Which themes or topics can be addressed by course staff and how?

The working hypothesis is that particular themes and development agendas can be distinguished from masses of open-text feedback by using statistical analysis methods, such as topic modelling. This would benefit the oversight of higher level education on an institution-wide level or a study programme wide level.

Rest of the paper is structured as follows. Section 2 presents related research on the text-mining and analysis of student feedback. Section 3 presents the research method and the data collection procedure. In section 4 the results from the Latent Dirichlet Allocation (LDA) [5] analysis are presented. Finally, section 5 discusses the results, and section 6 concludes.

II. Related Work

Analyzing the open texts in student evaluations of teaching is by no means a novel concept. Alhija & Fresko [6] investigated what can be learned from students written comments by performing a manual content analysis for 3067 collected feedbacks. The study distinguished three major domains of feedback (the course, the instructor, and context of instruction), in addition to individual content areas within the domains (such as course content, assignments, teaching style, scheduling and student composition). The study also concluded that comments tend to be more positive than negative and general in their nature. In a similar vein, Brockx et al. [7] also analysed comments left in 2029 student feedback surveys by using manual inspection and coding. The authors conclude that positive comments deal with the combination between theory and practice, whereas negative comments focus on the evaluation and context of the course.

TABLE I
CORRELATION MATRIX OF THE TOPIC PROBABILITIES (N = 6087)

	Topic 1	Topic 2	Topic 3	Topic4	Topic 5	Topic 6
Topic 1	1					
Topic 2	-0.3071*	1				
Topic 3	-0.3164*	-0.1009*	1			
Topic 4	-0.1586*	-0.1088*	-0.2192*	1		
Topic 5	-0.0810*	-0.2573*	-0.2451*	-0.1311*	1	
Topic 6	-0.0458*	-0.3314*	-0.1779*	-0.3339*	-0.1698*	1

* $p<0.05$

Grebennikov & Shah [8] analysed 78800 comments from study programme feedback surveys from 2001 to 2011 using a text analysis tool. The analysis yielded 26 different comment categories, which could be broadly grouped into five main domains. The use of text analytics tools for analysing student feedback has previously been explored in several studies with smaller sample sizes, for example by Kabanoff et al. [9], as Santhanam et al. [10], and Stupans et al. [11].

III. METHODS

The student feedback data used in this study come from the feedback surveys collected at LUT University during the academic years 2016-17 and 2017-18. In the university in question, a development project of the feedback questionnaire started in 2015. Therefore, the questionnaire has been subject to a number of revisions during the last few years. The first questionnaire (2016-17) had one broad open-ended question: "*Other feedback about the course (for example, ways to enhance learning during the course)*". The second questionnaire (2017-18) had five more focused open-ended questions: "*What factors affected my level of motivation?*", "*What factors affected how much I invested in my learning?*", "*What factors affected the workload?*", "*My feedback regarding the teaching methods:*", and "*What factors promoted my learning and how could learning be supported better?*" In addition, both questionnaires included several 5-point Likert-scale questions about, for example, students motivation, teaching methods, workload, and perceived learning. The link to the surveys was distributed via email to all enrolled students of all courses approximately half a week after the course had ended. Responding to the surveys was voluntary and anonymous.

The total number of student feedback questionnaires collected was 9148 in 2016-17 and 8092 in 2017-18. For the topic modelling, we restricted the sample to the responses that contained at least one answer to the open-ended questions written in Finnish. The resulting sample size for topic modelling was 6087 including 2445 surveys collected in 2016-17 and 3642 surveys collected in 2017-18.

We used the LDA topic modelling [5] as a statistical text mining method [12] to distinguish recurring themes from student feedback. The underlying mechanism in LDA is a probabilistic Bayesian network model, in which each document is characterized by certain topics, and each topic is defined by a specific set of words, which co-occur with a certain probability. To summarize, the topics of each document are defined by a set of words that often appear together. The algorithm is further explored by their inventors in [12]. A summary of the algorithm's process is presented as follows from a list originally published by Chaney et al. in [13].

1) For K topics, choose each topic distribution β_k. (Each β_k is a distribution over the vocabulary.)
2) For each document in the collection:
   (a) Choose a topic assignment z_n from ϕ_d.(Each z_n is a number from 1 to K.)
   (b) For each word in the document
   i. Choose a topic assignment z_n from ϕ_d. (Each z_n is a number from 1 to K.)"
   ii. Choose a word w_n from the topic distribution $\beta_z n$. (Notation $\beta_z n$ selects the z_nth topic from step 1.)

For the analysis, we used a modified version of the NAILS script [14], which utilizes the topicmodels R package [15] and visualized with the LDAvis library [16]. Semantic coherence, a quality value for deciding the number of topic models [17], was calculated using the R stm library [18]. LDA-based topic modeling is a commonly used method for text analysis and equivalent methods have been used to statistically analyze scientific texts in earlier studies [19], [20], [21]. Our analysis process is as follows.

1) Download student feedback data.
2) Sort the feedback by metadata such as course type and language.
3) Select the subset to be analyzed; in this case Finnish language responses.
4) Preprocessing:
   i) Use the R textmining [22] library's Finnish stopwords list
   ii) Stem the words using the snowball stemmer library [23]
5) i) Assign each row of feedback into a single document unit.
   ii) Break the word content of document into unigrams.
6) Run the NAILS script[1] [14] on the data, which performs the following:

[1] Available in GitHub at https://github.com/aknutas/nails

TABLE II
DESCRIPTION OF THE TOPICS

Topic	Name	Keywords
1	Positive comments about arrangements	Exam, good, exercises, lectures, moodle, material, better, homework
2	Dissatisfaction in the teaching	Student, teacher, every, return, some, questions, own, even, entire, point, help, get, done
3	Comments about course arrangements and deadlines	Practical assignment, time, group, same, period, workload, weekly assignment, instruction, other
4	Lack of motivation and support	Task/assignment, doing, always, exercises, weekly, right
5	Interest in the topic, understanding the material	Topic, more, little, less, pass/through, part, time, example, felt
6	Comments about interesting, rewarding but challenging courses	Topic, good, learning, lecturer, interesting, fitting, motivation

i) Calculates the optimal number of topics with R stm library [18].
ii) Performs LDA topic modeling with R topicmodels package [15].
iii) Visualizes the topicmodel with the R LDAvis library [16].

7) Naming the themes:
i) Manual inspection of results, and
ii) Assigning theme names based on the topic models' keywords.

IV. RESULTS

Initially the LDA algorithm was run multiple times with different parameters in order to discover most suitable models for the analysis. In total we created a series of 26 models with a range of 4 to 30 topics, which were then evaluated with the semantic coherence quality measure. Several local quality value maximums were selected for qualitative evaluation and after final evaluation a six topic model was chosen. A map of the topics and the relative distances between them are visualized in Figure 1. The inter-distance map shows that topics in the chosen model are relatively well distinct, even though some topics are more close to each other.

In addition to the inter-topic distances using the Jensen-Shannon divergence method (see Figure 1), we assessed topic similarities using Pearson correlation coefficients (see Table I). As shown the correlations are quite low ($|r|$= 0.0458 - 0.3339) indicating that the topics in the model are not strongly correlated with each other (the probability of a topic belonging in a certain topic is not too dependant on other topics). LDA is a probabilistic model and we used the probabilities returned by the algorithm to assign each observation to its most likely topic. The number of feedbacks assigned to one topic varies between 13% and 21% (see Table III): Topic 1 has the most number of observations (20.8% of the total). Topic 6 (19.25%), Topic 3 (17.1%) and Topic 2 (15.62%) are the next largest categories. Topic 5 (13.91%) and Topic 4 (13.31%) contained a similar number of observations.

The topic modeling results and the themes we discovered are summarized in Table II. Next we present the descriptions of the topics, based on the keywords and the authors' quick assessment of the most central texts within a topic: Because LDA is a probabilistic method, the texts with the highest probability to belong in one topic can be treated as canonical examples of what themes the topic contains.

As depicted in Figure 1, the words occurring in Topics 1, 3, and 4 are close to each other. The common theme for these topics were course arrangements. Common keywords for these topics were all related to course arrangements and organization, such as "assignment," "exercises," or "homework."

However, during a manual inspection of the most central feedback texts, we found that the Topics 1 and 3 contained mostly positive or neutral feedback, while Topic 4 contained negative feedback regarding the course arrangements. Topic 1 was generally the most positive feedback category, while Topic 3 contained discussion about stress or hurry, and Topic 4 discussed poor course support or lack of motivation. All topics acknowledged positive things about the studied subject.

Topic 2 contained very specific keywords, from which it was hard to categorize the topic as positive or negative. Again, upon further analysis of the texts, manual inspection revealed that Topic 2 mostly discussed the dissatisfaction with teaching and the students professional relationship with the teacher. Also, the Topic 2 was most concentrated on what the student might have needed, but did not receive.

Topics 5 and 6 discussed the subject of the course or the material. Again, these topics were similar in their keywords, so further manual inspection was required. Generally both topics acknowledged that the subject or material was interesting or beneficial, but Topic 6 also contained discussion about challenging topic or positive stress.

TABLE III
FREQUENCIES AND PERCENTAGES OF THE TOPICS

Topic	f	%
1	1266	20.80
2	951	15.62
3	1041	17.10
4	810	13.31
5	847	13.91
6	1172	19.25
Total	6087	100

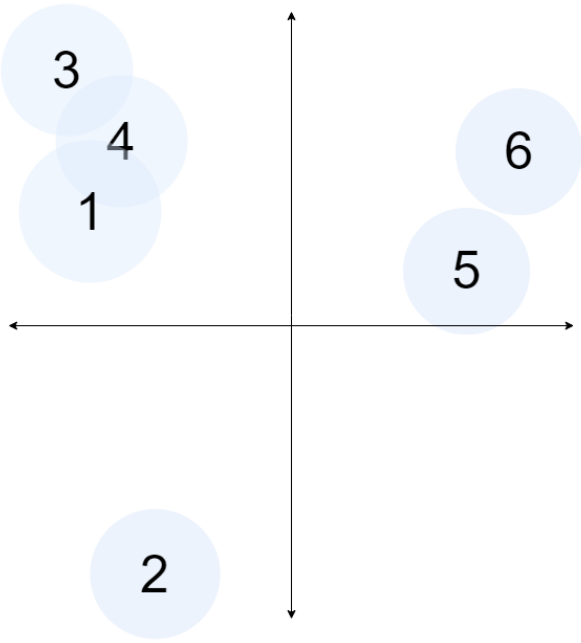

Fig. 1. The intertopic distance map visualizing the topic-term relationships using the LDAvis library [16]

V. Discussion

Our study demonstrates that this kind of analysis can be used to supplement quantitative student feedback evaluations. We identified several themes relevant to analyzing and improving teaching and learning outcomes, such as themes related to materials, course arrangements, student motivation, and course schedules. These themes can be used to give more context and pinpoint issues that need improvement.

The themes distinguished in this study are in line with the types of feedback presented by Alhija & Fresko [6], with the key difference that we could not see any disposition towards positive comments being in the majority in our results. In contrast to Brockx et al. [7], whose study suggests negative comments focus on course evaluation and context, we could distinguish one topic of positive comments within these themes and course arrangements.

Next, we address the individual research questions. To answer the first research question *what themes can be recognized from the topic model, and how can the emerging topics be described*, we can state that several different themes could be identified, from motivating subjects to student critique of course arrangements.

For the second research question *how do the discovered themes relate to course arrangements, course topics, student motivation, teaching methods, and the teachers competence?* We found several topics, each of which is a theme connected to one aspect of teaching, including motivation, teaching arrangements and professionalism.

Finally, for the third research question *which themes or topics can be addressed by course staff and how?* Each of the discovered topics provide actionable feedback for the teaching staff, or for the use in curriculum design. The themes are important as a single student feedback text alone might not be useful but if, for example, several students give feedback about the lack of support, this can indicate that some course arrangements should be altered or communicated better to the students.

All in all, to answer our main research question guiding the process of this study *what can be learned from topic models of open student feedback*, we conclude that analyzing open text feedback using statistical or machine learning methods can be used to as a source for course (or program) wide qualitative information. However, the interpretation of this automated analysis may be difficult: Even though some emergent themes behind the feedback can be distinguished, some topics are harder to utilize in practice.

The main contribution of this study is the constructed topic model which distinguishes themes arising from open student feedback. The used data set is similar in size in comparison to previous work, such as [6] and [7]. Some themes were related to the student's perception of the quality of teaching, similarly to the study by Kabanoff et al. [9]. The study also adopted the practice of using manual analysis to some degree to ensure the results are meaningful and contextually relevant, as suggested by Santhanam et al. [10].

VI. Conclusion

Our research goal was to examine which kind of themes emerge from large datasets of free-form text student feedback. We accomplished this by processing 6078 observations of unique student feedbacks using the LDA algorithm with the R programming language and environment for statistical computing. With this method, we discovered six topics discussing different aspects of teaching and learning. The generalized results contribute to existing knowledge about the types of feedback students leave in their course evaluations.

There are, of course, limitations concerning this study which need to be addressed. The topic model with six themes was chosen using the semantic coherence measure, which is a statistical method for determining the quality of the model. A more thorough approach would have required a qualitative evaluation of alternative models. However, we did choose a relatively low number of topics which suggests that the resulting themes can be generalized. In addition, we calculated the Pearson correlation coefficients to verify that the topics are distinct from each other.

Furthermore, the analysis of the resulting topic model was mainly based on the descriptive keywords (produced by the LDA algorithm) and an informal inspection by the researchers. For this reason, there is a possibility that some topics description may be misrepresented in our presentation of the results. We, therefore, must acknowledge the risk of researcher bias, even though we try to limit it by working in a group of researchers, and the fact that the analysis is based on the results of a statistical method. In order to properly dismiss this risk, we propose

a thematic analysis approach that enables a systematic, qualitative evaluation of the topic modelling results to be carried out in future work. Additionally, the robustness and generalizability of using the topic modeling method on student feedback requires further study.

Other future research avenues could include the automatic processing of open feedback, or longitudinal studies with feedback collected from several successive years. The dataset in this study was also limited to one language only (Finnish), meaning that there is more work to be done in analyzing the responses which were left out here.

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Electronic Commerce Entrepreneurship Education using Virtual Laboratory

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***Abstract* - The information and communication technologies (ICT) allow educators to transform education still more and more. Education in the area of entrepreneurship might be supported by the usage of a virtual laboratory of electronic entrepreneurship as in the case of our faculty. Future entrepreneurs get the opportunity to try out the establishment and operation of their own businesses in the form of virtual companies as part of their studies. The aim of this paper is to present how the virtual lab of electronic entrepreneurship might serve for educational purposes. Entrepreneurship education is supported by the virtual laboratory of electronic entrepreneurship at our faculty for several years already and our students gain practical experience of establishing and managing a small virtual business. These students' businesses operate in the field of e-commerce and their functioning is supported by the virtual bank, electronic registry, virtual certification authority, virtual e-shops and learning management system. The experience from each year is further incorporated into the educational process of the subject and our results show that virtual lab of electronic entrepreneurship is a useful tool for entrepreneurial skills development.**

Keywords – eCommerce; virtual laboratory; entrepreneurship education.

I. INTRODUCTION

Information and communication technologies (ICT) changed the economic activity in many ways. Entrepreneurs often use ICT to set up businesses, to promote and distribute their products, to make use of banking services or to communicate with authorities. ICT enabled the emergence of electronic commerce (or e-commerce) as a still growing distribution and marketing channel. Electronic commerce represents the provision of services or products using ICT resources and is often interconnected with e-marketing, electronic payment systems, electronic data interchange or business intelligence systems. E-commerce activities might be oriented as business-to-customer, business-to-businesses or customer-to-customer relations [1].

Entrepreneurs in the field of electronic commerce (as all businesses) have to communicate with the authorities of public administration to meet legal obligations (e.g. business registration, applications for licenses, tax registrations and declarations, etc.). This communication is often provided using digital channels and represents the government-to-business layer of e-government [2].

E-commerce primarily supports also electronic payments or various forms of electronic banking services. The main advantage of electronic banking is continual access to the payment services for both customers and businesses. It allows making transactions almost anytime from anywhere in the world with the use of electronic data interchange. This fact allows e-commerce retailers to ensure cash flow without need of brick-and-mortar shops and thus gain the cost- and time-saving benefits. It is therefore desirable, to take into account these aspects of e-commerce so that students can gain experience with the operating of this type of entrepreneurship in the education process of future e-commerce entrepreneurs. The educational process at our faculty is intensively supported by information and communication technologies. ICTs help to develop knowledge and skills of students not only in computer science (or informatics) but also in many other subjects [3]. For example, e-learning as a very frequent distant learning form of education emerges thanks to information technologies [4]. ICT within the context of e-commerce entrepreneurship education have dominant role based on the very principle of e-commerce [5].

II. VIRTUAL LABORATORY

Information and communication technologies might be integrated into the education process in various ranges, extent, and forms. The mastery and utilization of ICT are now one of the decisive factors of success for an entrepreneur in electronic commerce. It lies in the ability of entrepreneurs to orient themselves in a variety of information in their business area. This fact suggests the usage of ICT in the education process of future electronic commerce entrepreneurs. At our faculty, the education form of the virtual laboratory of electronic entrepreneurship was selected to provide training to potential entrepreneurs in e-commerce. A virtual laboratory is one of the possibilities of intensive ICT involvement in teaching. The concept of a virtual laboratory is an environment of multiple ICT systems that enables simulation of some kind of activity. Klamma et al. (2015) suggested the use of virtual laboratories for the purposes of entrepreneurial education [6]. Our virtual lab includes an electronic registry, certification authority, virtual bank, and virtual e-shops.

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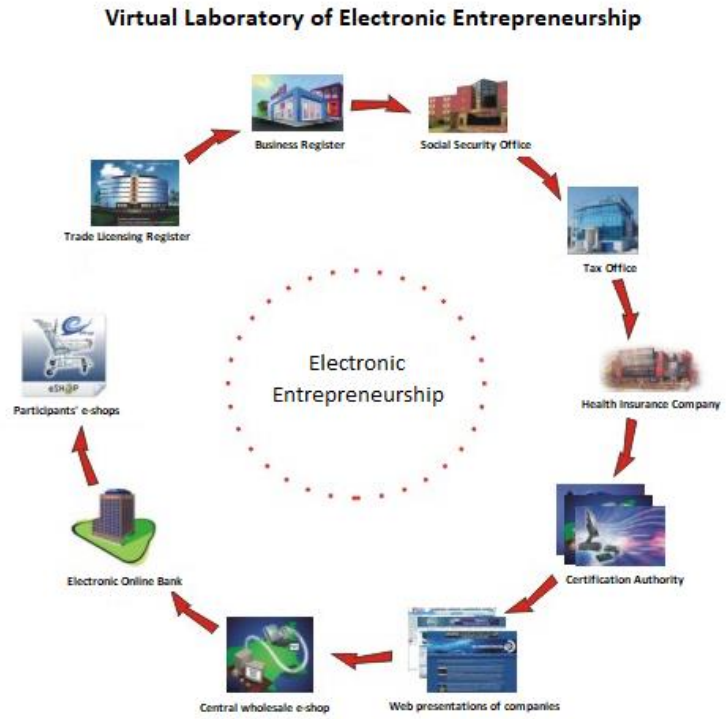

Figure 1. Virtual Laboratory of Electronic Entrepreneurship

Figure 1 schematically illustrates parts of the virtual laboratory of electronic entrepreneurship. Operations of our virtual laboratory are supported also by learning management system (LMS) Moodle.

E-commerce entrepreneurial education at our faculty using Virtual laboratory of electronic entrepreneurship is provided in the course named Economic Information Systems (EIS). Any perfectly prepared discourse, video lectures or multimedia textbook will not replace the personal experience of participants. Therefore, in the EIS course, the methods of problem-oriented learning, learning by doing and e-learning are used. This course aims to teach course participants to operate a small virtual business from its establishment to first annual closure of accounts using information and communication technologies. The participants should build on knowledge of accounting, marketing, law and tax systems, basic computer skills, website creation and its publication on the Internet.

The subject of study named Economic Information Systems (EIS) is provided as an e-learning course based on the platform of LMS Moodle [7]. This learning management system is used standardly for e-learning of the majority of study subjects at our faculty. LMS Moodle also supports basic communication with the course participants. All study materials for a given subject of study are published in Moodle. All tasks within the course and its schedule are posted there, so participants have the overview if they meet deadlines. Multiple tasks (e.g. strategic plan, business plan, accounting reports) are uploaded into the LMS Moodle by participants and evaluated by lecturers.

The EIS course is provided in the form of distant learning. The advantage of the distant form of learning is that the trainees are not strictly bound to the exact time of the lesson or lecture. They can consult the lecturer at any time via emails, live chat and via the learning management system. Their tasks can be elaborated flexibly at work, at home or virtually at any place with internet connection.

The course is supported by components of our virtual laboratory of electronic entrepreneurship:

- virtual wholesale e-shop operated by lecturers,
- virtual business registration authorities (licensing register, tax office, business register, social insurance, and health insurance),
- virtual electronic bank,
- e-shops and other entities necessary for the implementation of assigned tasks.

The course also provides a web domain, which contains links to web presentations of the participants' firms stored on a server. The course is oriented on the conditions of e-commerce in the Slovak economy. Course participants are engaged in the retail sector (purchase and sale of goods). They establish their firms according to legislation conditions of Slovak Republic. Virtual electronic registry operated by lecturers is used to emulate public authorities (business register, tax office, licensing register, social insurance office, healthcare insurance authority). During the preparation of the establishment of

the company business plan is developed and all the necessary documents (deed of foundation, registrations, licenses, etc.) are completed.

After all legislative conditions for the founding of the company have been met, participants prepare their websites as a presentation of their e-commerce firms. Furthermore, provided e-shop solutions are integrated into their websites. The source of their products is central wholesale e-shop operated by lecturers, through which they buy goods for further trading. Their clients are simulated by other students, who are buying goods sold in other students' e-shops. In this case, they act as private persons to generate some demand for goods. Lecturers also generate another portion of demand by buying in students' e-shops. All payments in e-shops are transferred using the virtual bank, which also provides starting loans to all students' businesses.

All participants' firms have to keep their accounting of the current business period in electronic form. After the simulated end of the first business period, participants prepare the financial statements and evaluate their business within a strategic study. This study contains intentions for the future development of their business. At the end of the course, students also analyze some of the information systems used during the course and also give feedback regarding the course.

The EIS course uses a virtual laboratory of electronic entrepreneurship to support the operation of students' virtual firms. The laboratory contains the following electronic systems:

A. Electronic registry

Electronic registry serves as a virtual representation of public administration authorities within the EIS course. While setting up their virtual businesses, participants have to communicate with these virtual public administration authorities using electronic communication. This communication is adapted according to the valid Slovak legislation. Participants are obliged to register their businesses with the Trade Licensing Register and Business Register. Furthermore, they have to register their newly created firms at virtual Tax Office, Social Security Office and Healthcare Insurance Company. All necessary forms are available in electronic form. After filling those forms, the pdf files are generated to be sent through the electronic registry. The application forms have to be signed using a digital signature.

Electronic communication using digital signature is an important part of the EIS course and deals with the following terms and principles:

- digital signature and electronic signature,
- symmetric and asymmetric encryption,
- electronic signature legislation,
- Public Key Infrastructure (PKI),
- certification and registration authority,
- electronic data interchange.

Guidelines on the usage of a digital signature for communication are available on the web site of the faculty's certification authority. This certification authority allows the course participants to get private certificates of digital signatures for the purposes of the EIS course. It is based on open source PKI certification authority – EJBCA [8].

The digital singing of prepared pdf files is performed in Adobe Acrobat Reader DC. Website of the certification authority contents also information on the usage of a digital signature in communication and authentication in general. Possible usage of a digital signature in the whole field of e-government is described. The term of Public Key Infrastructure (PKI) is introduced to course participants [2]. They also gain some practical experience with PKI in the process of generating their digital signature certificates at the faculty's certification authority. Digitally singing all necessary documents in electronic form (and sending them to corresponding virtual authorities) allows participants of EIS course to gain practical experience with a digital signature. The content of the EIS course reflects the real options of communication with public administration authorities in Slovakia at a basic level [8].

B. E-shop

E-shop solution is another key part of the virtual laboratory of electronic entrepreneurship. The main e-commerce activity of students in the EIS course is establishing and managing e-shop linked to their website. All goods of participants' virtual firms are merchandised here, but the source of the goods is in the central wholesale e-shop of faculty managed by lecturers. The goods are of a virtual character and are inserted into the inventory of wholesale e-shop with no production costs.

Participants may buy goods from central wholesale e-shop (for further trading in their e-shops) from the product group (computer equipment, office equipment or office furniture) of their interest. Lecturers create some demand by purchasing in students' e-shops. Participants should buy goods from the e-shops of other participants (selling products from two other groups of goods) with the aim to simulate demand in participants e-shops. The course participants also represent their businesses by a website. It is the main tool of the firm's marketing activities and it should attract potential customers to buy goods from the firm's e-shop. The registration in e-shop is needed to buy some product from a given firm. Participants in this part of the course have the opportunity to experience both sides of the purchase process in an e-shop using the virtual laboratory. [4].

C. Electronic payments

The virtual laboratory of electronic entrepreneurship contains also virtual bank supporting electronic payments. The purchases in e-shops invoke necessity to administer electronic payments for the goods purchased. Those payments are conducted via internet banking system of faculty's virtual bank. This virtual bank is called Electronic Online Bank (or EOB) and was provided to faculty for free as outdated banking software by its developing company UNICOM. The electronic payment

functionalities of EOB are satisfactory for the educational purposes of the EIS course. Participants get virtual euros at their newly generated bank accounts in the form of a loan to support the payment processes within the course. Any electronic payment in e-shop will redirect a buyer to the virtual bank's internet banking form prefilled with the parameters of this particular payment. A digital signature is used as the authorization element in EOB. Furthermore, the identification process of bank users is realized using digital signature [9].

All participants get practical and theoretical knowledge about the security of the payment process during electronic purchase. Most often, the security of electronic payments usage is a question of users' safety behavior. The participants of our course will learn safety rules while using online payments and try to follow them in praxis. Various methods for authentication and authorization of electronic payments are available in EOB (One-Time Password generator, SMS code, and digital signature), but for the EIS course, only the most secure one – the digital signature is supported [10]. The biggest technological challenge when building the virtual laboratory of electronic entrepreneurship was an interconnection of e-shop with the payment system of the virtual bank to allow automatic transfer of payment data.

III. SURVEY RESULTS

During recent years, surveys on participants' experience with e-commerce, electronic payments, and electronic communication were conducted to gather feedback on Electronic Information Systems course. Each year, the survey is performed before and after the course completion. Participants' experience and knowledge about electronic business, electronic commerce, electronic payments and electronic communication with public administration were examined in the survey. The results bring also relevant suggestions for improvement of the education process within the EIS course. The respondents of the survey were all participants of EIS course in the year 2018 (last finished course to date) and they were addressed by a link in LMS Moodle. Participation in the survey was mandatory for all course participants. Following table contains demographic data of the EIS course survey.

TABLE I. DEMOGRAPHIC DATA OF EIS COURSE PARTICIPANTS

Age	**Count**	**Percentage**
19 – 24	94	80.34
25 – 29	18	15.38
30 and over	5	4.28
Gender		
Men	44	37.61
Women	73	62.39
Residence		
Large-sized city (over 100 000 citizens)	68	58.12
Medium-sized city (40 000 to 100 000 citizens)	13	11.11
Small town (5 000 to 40 000 citizens)	7	5.98
Village (under 5 000 citizens)	29	24.79

Source: authors

The survey was executed in digital form using the web questionnaire. It was gathered 117 completed questionnaires (in both times: pre- and post-course). Most of the respondents (94 representing above 80 percent of participants) were in the age range between 19 and 24 years as it is the usual age of the most students of the internal form of study. Between 25 and 29 years of age were 18 respondents (15 percent of students) and 30 and more years had only 5 respondents (slightly above 4 percent of participants) of the survey. Participants of 25 and more years of age were mostly the students of the external form of study mostly studying part-time alongside their jobs.

The majority of course participants (over 62 percent) were women, which reflects also the gender composition of students at our faculty. The rest of the survey sample (almost 38 percent) created male respondents. The area of residence in Slovak conditions may affect the availability of high-speed broadband internet services. In larger cities in average higher speeds of connections are available. The most of respondents (over 58 percent) are residing in large-sized cities (above 100 000 citizens) and 13 respondents (11 percent) were from medium-sized cities, where the availability of high-speed internet is good. The rest of the respondents were from towns with less than 40 000 citizens or villages, where the availability of high-speed broadband internet is lower.

Survey data were gathered before the course and after its completion. Following results were gathered before the start of EIS course.

Theoretical experience with the establishment of the company and with business legislation, in general, had all participants thanks to the fact, that they already attended the courses of business legislation in previous years of study. Only 3 percent of participants adduced some practical experience with the establishing or managing firm, while the rest of the respondents did not indicate any experience with entrepreneurship at all. All students indicated experience with preparing the business plan, what was caused by the content of their previous studies at our faculty. Just 4 percent of respondents adduced some experience with using a digital signature in e-government applications. Compared to the past, this is a tiny shift in the area of the digital signature usage, but it is still low. Almost 22 percent of respondents indicated some experience with electronic communication with public administration authorities, but only as individuals and not as entrepreneurs or company representatives. This result suggests a low level of e-government usage in Slovakia [11].

The majority of respondents (94 percent) had experience with creation of the simple website, again mostly because of their previous studies at our faculty. None of the participants had experience with establishing and managing an e-shop or linking it with a website. Over 80 percent of respondents adduced experience with purchases in real e-shops. Even 96 percent of them indicated some practical experience with the electronic payments on the web, but only at the buyer's side.

Again, all of the respondents noted some theoretical experience with accounting, though just 7 percent of them

had some practical experience with accounting in an actual business. Approximately 35 percent adduced previous experience with creation of a business strategic plan as a part of a company's future development strategy.

These survey results indicate relatively wide knowledge and experience of students before the start of the EIS course acquired in their studies in initial years of their studies at our faculty. The second survey was carried out after the students' participation and completion of Economic Information Systems course. Its results are presented further.

Almost 95 percent of respondents reported, that during the EIS course they gained notable experience in establishing or managing company. Over 85 percent of course participants indicated obtaining some new information on the business establishing process within the framework of valid Slovak legislation. Above 42 percent of respondents adduced that the practical preparation of the business plan of their virtual firm was beneficial for them even though they already had some experience with business plan preparation. Over 98 percent of course participants indicated that acquiring practical experience with electronic communication with public administration authorities using virtual lab's electronic registry was beneficial for them. The use of the digital signature within the framework of this communication was also highlighted by students.

More than 29 percent of respondents reported that creating a website of their company brought them some new experience, even if they had previously created a website during their studies. Establishing and managing e-shop of their firm was a valuable experience for around 78 percent of students. Mainly, the possibility to experience the operation of an e-shop from the side of its administrator was appreciated by students.

Almost 63 percent of EIS course participants found the possibility to practically try out to keep an accounting of their training firms as beneficial. Especially, the experience with the first accounting period was highlighted by them. Around 65 percent of students also appreciated the task of strategic plan preparation for their virtual businesses into the following years (although beyond the horizon of ongoing course). The large majority of participants (93 percent) rated the course of Electronic Information Systems very positively and they welcomed the opportunity to practically experience entrepreneurship with the support of the virtual laboratory of electronic entrepreneurship.

In general feedback part of the survey, students provided suggestions for improvement of the course. One of the suggestions that are to be implemented was the possibility to train entrepreneurial soft skills in the form of e-learning besides the use of the virtual laboratory. This was one of the reasons for joining the RECREATE project team.

IV. RECREATE PROJECT

It is necessary for us to continually develop the EIS course and to improve entrepreneurship education at our faculty. Also, the surveys' results showed that students would like to have the opportunity to improve their skills and knowledge during the course in the form of e-learning. Therefore, our faculty joined the RECREATE project.

The RECREATE project (Recovery the Crisis through Entrepreneurial Attitude – Erasmus + Strategic Partnership – 2017-1-PL01-KA203-038438) is Erasmus+ program project, in which the partner subjects cooperate to provide students in higher education more innovative learning environments and curricula that stimulate independence, creativity and an entrepreneurial approach to harnessing knowledge [12].

Europe's future economic growth and jobs will increasingly have to come from innovation in products, services, and business models. Therefore, universities need to create structured partnerships with the business community and increase the relevance of education and training programs by adding entrepreneurial skills to scientific expertise and so to improve the career prospects of researchers and students [12].

A structured and better implementation of entrepreneurial learning aimed for the creation of links between universities and business will strongly support mutual exchange between universities, industries, the business community, and the wider society. The main innovation of the RECREATE project focuses on boosting the knowledge triangle. The training proposed focuses on the development of the entrepreneurial skills and to ease the employability of researchers and young graduates and boost the innovation potential of the territories involved [12].

Therefore, the training in RECREATE project will include enterprise creation and management, development of transversal and soft skills and a specific module on the creation of links with business. The aim is to favor the creation of structured partnerships with the business community (including SMEs), which can bring opportunities for universities to improve the sharing of research results, intellectual property rights, patents, and licenses (for example through innovation clusters, fablab, business incubators, etc.). Thanks to these links, universities can also increase the relevance of education and training programs through placements of students and researchers in business [12].

The main objectives of the RECREATE project are the following:

- develop tools such as platform (for sharing material), games (to better understand business rules), etc.
- provide workshops for students with mentors which describe and presents the issues about entrepreneurship
- to create links between high educational and business partners especially at the regional level
- the acquisition of entrepreneurial attitude among young researchers and students.

The investigation in the project will focus on the concrete obstacles and skill gaps that make the

collaboration between universities and business difficult. The scorecard tool is being developed to assess:

- the attitude and perception of knowledge-based entrepreneurship;
- the extent to which academic research can produce marketable products and services and have market knowledge;
- the barriers experienced in the creation of links with the business community;
- specific needs at a local/national level;
- attitudes towards risk-taking; and lack/needs of transversal skills [12].

The RECREATE project further aims to develop training materials and develop new content to enhance transversal competencies for entrepreneurship. Each module of training materials will be developed for a workshop focused on one specific theme. The final outcome will be a modular training course to be implemented with a set of workshops with the following topics:

- soft skills: leadership, risk-taking, communication, creativity (based on practical exercises);
- hard skills related to business creation: business idea formulation, market identification, a route to market, business plan, legal and fiscal issues (country-specific information);
- social media and marketing;
- making the knowledge triangle work: linking higher education, research, and business for excellence and regional development [12].

The education process in these modules will be supported by an innovative e-learning space created within the RECREATE project. The creation of the learning environment entails the development of the knowledge base allowing fast and easy access to materials and contents; a self-diagnostic tool that will guide the users to proper materials (e.g. educational games, simulations of the business creation process, forums, FAQs, manuals, etc.). The newly developed learning environment and its tools will be based on the methodology of mixing traditional training approach with informal learning (e.g. simulations, educational games) meant to favor the acquisition of key competencies through non-traditional methods. After its finishing, the RECREATE platform will be available for students of EIS course and it will complement the use of virtual laboratory of electronic entrepreneurship during the provision of the course [12].

V. CONCLUSION

The course of Economic Information Systems gives students the opportunity to acquire practical experience with entrepreneurship in the area of e-commerce with the support of the virtual laboratory of electronic entrepreneurship. Course participants gain practical experience with establishing a firm according to the legislative conditions of Slovakia. Furthermore, they try out the usage of electronic registry and digital signature in electronic communication, preparation of a business plan, the creation of the firm's website with e-shop implementation, management, and operation. Finally, students keep accounting and prepare a strategic plan for the of their virtual businesses. The feedback on the EIS course gathered by survey contained suggestions to provide a possibility to train entrepreneurial soft skills in e-learning form as support of their study in the course. This is planned to be implemented by using the platform developed within the RECREATE project.

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Engaging students in computer science with extracurricular projects – Oracle Academy Workshops in a Box use case

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Abstract **- Today's students have been surrounded by information technologies since birth and most often have no patience to learn programming as it is commonly defined in the traditional curriculum. The modern Croatian Curriculum of Informatics in Elementary and Secondary School defines the learning outcomes and (with certain recommendations) is giving complete freedom and responsibility to the teacher in the design of teaching during which the students will achieve the anticipated learning outcomes. However, today's society and the national economy expect a growing number of educated professionals in the field of information technology, but it is unfortunately not happening. In addition to motivating students, different extracurricular activities can be provided by the teacher, as well as other stakeholders who may not specialize in teaching in cooperation with the school (parents, volunteers, sponsors …). Taking into account the already implemented examples of good practice in Croatian schools, this paper lists examples of globally successful curriculum from Oracle Academy program, which are better known under the name Workshops in a Box. The paper also presents a short survey on the current implementation of computer science extracurricular programs in the Croatian schools.**

Keywords - Extracurricular projects, Oracle Academy

I. INTRODUCTION

According to the definition [1] the extracurricular activity is related to officially or semiofficially approve and usually organized student activities (such as athletics) connected with school and usually carrying no academic credit. However, today's extracurricular activities in the area of European education include the most diverse areas of arts, science, entrepreneurship, civil society and citizenship education [2]. In addition, the European Union promotes and finances the cooperation of educational institutions and other stakeholders in the development of various extracurricular projects as well as the exchange of good practice examples through the Erasmus+ program, Key Action 2 [3].

The transformation of the global economy in the 21st century has had an impact on the additional demand for staff from the Science, Technology, Engineering and Mathematics (STEM) area, especially in the area of information and communication technologies (ICT), but most European school systems have not reacted immediately to such trends in the labor market. Such a problem is significantly indicated by the Royal Society report [4] which pointed to a number of problems in the existing curriculum for subject informatics in primary and secondary British schools. The conclusions of the report referred to the main problem of the current curriculum, which did not enable students to acquire key knowledge in the field of information technology. Similar problems existed in the educational systems of most European countries and large number of stakeholders from the industry began to develop and finance a variety of extracurricular projects that should interest a large number of students in the field of ICT.

The role of external stakeholders in addressing the identified problem has also been recognized by the European Union through the special strategy of the Digital Skills and Jobs Coalition [5], which brings together member states, companies, social partners, non-profit organizations and education providers, who take action to tackle the lack of digital skills in Europe.

Meanwhile, most European school systems have begun reforming existing school systems in the direction of changing the existing curriculum of informatics in the direction of stimulating computer thinking and problem-solving based approaches. Particularly interesting is the new Royal Society report of 2017. describing what such an approach has achieved in a five-year period in British schools [6]. The report specifically emphasizes the role of extracurricular projects in the progress achieved.

In line with these trends, the Croatian school system is being reformed, and the curriculum reform for the informatics subject has been highlighted as a priority by the Decision on Curriculum for Subject Informatics for Primary and General Secondary Education in the Republic of Croatia [7]. The Ministry of Science and Education (MZO) has recognized the importance of extracurricular projects in the reform processes, and as the first presented was ProMicro project for development of STEM skills [8].

II. ORACLE ACADEMY EXTRACURRICULAR PROGRAMS

Today, most global companies from the ICT industry invest in various forms of extracurricular programs to

improve the perception of informatics. One of the largest and globally recognizable initiatives is the Oracle Academy (OA) program founded by Oracle Corporation. Through the aforementioned program, an investment of $ 1.4 billion is planned through various supports to the European Union member states for the advancement of education in the field of computer science (CS) in the period 2016-2019. Special attention is given to vocational training of teachers in Java programming language and databases.

A good example of such activity is the collaboration between the OA and Croatian Education and Training Agency (ETTA) in the period 2016-2018 through which the improvement of the teaching competences in the field of Java programming and databases for more than 200 Croatian teachers of informatics was carried out [9]. In such trainings, teachers acquire competences for the education of students in secondary vocational schools and faculties on extracurricular activities of long duration (including 30 to 60 hours of lectures), some of which are aligned with Oracle professional certifications. For example, learning outcomes at the Java Foundations course are comparable to Oracle's professional certification Java Foundations Certified Junior Associate (Exam: Java Foundations - 1Z0-811) [10]. These courses are suitable for interested students who want to acquire competencies during their schooling that are in high demand in the labor market because after education they have competences for certain jobs (Java programmer, data scientist), which is very important to employers.

It can be said that the aforementioned courses have demanding learning outcomes and are not designed to make the first computer experience in an engaging and fun way. Therefore, it was necessary to shape the forms of learning that are using the best practices of the academic curriculum (project-based learning, computational thinking), while simultaneously engages students with computer science in a fun and interesting way through workshops, including other academic disciplines. That's why the Oracle Academy program has designed such courses which can also be run through extracurricular activities under a common name Oracle Academy Workshops in a Box [11].

III. ORACLE ACADEMY WORKSHOPS IN A BOX

The Oracle Academy Workshops in a Box program currently contains five workshops for various stakeholders motivated by the popularization of computer science and available at [11]. Initial interface for access to workshops is shown in Figure 1.



Figure 1. Oracle Academy Workshops in a Box initial interface

Getting Started with Java Using Alice workshop teaches basic Java programming concepts in the context of 3-D Animations in Alice 3 program environment created at Carnegie Mellon University [12]. It represents a good introduction to the next Oracle Academy Workshop - Creating Java Programs Using GreenFoot. GreenFoot [13] is a simple Java development environment (JDE), created at the University of Kent that provides advanced learning on object-oriented programming terminology and concepts while creating 2-D games. There is also an optional robotics workshop for the GreenFoot platform, named as Programming the Finch Robot in GreenFoot, which teaches the basics of Finch Robot (a small robot designed by BirdBrain Technologies [14]) programming in GreenFoot environment using its light, proximity, and temperature sensors. An advanced version of such a workshop is available under the title Programming the Finch Robot in Java. The latest workshop Solve It with SQL teaches the basics of SQL language in a fun way using cloud-based database development.

The learning outcomes of all workshops are tailored to student beginners who have no knowledge of programming and databases. All listed workshops contain up to 16 hours of lectures, designed in such a way that they can be conducted by persons who are not trained teachers in the field of computing. Although workshops have a slightly shorter duration compared to school subjects, these courses have a full curriculum, preparation checklist, facilitators guide, tutorials and solutions that teacher can use in the preparation and implementation of lectures.

IV. COMPUTER SCIENCE EXTRACURRICULAR PROJECTS AND CROATIAN TEACHERS OF INFORMATICS

In the preparation of this paper, a short survey was carried out on computer science extracurricular projects in Croatian schools. According to a statement of MZO [15] from November 2017., the Croatian education systems was employed 481 full-time teachers of informatics in primary and secondary schools in school year 2017./2018. In the same time, 766 teachers lectured informatics with some other course to full teaching load. A total of 131 Croatian teachers of informatics answered the questionnaire, of which 64 were employed in primary education schools and 67 in secondary school.

The term of extracurricular project mentioned in this survey implies any form of extracurricular project carried out in cooperation with an external stakeholder for the purpose of popularizing computer science (e.g., computer programming workshops, robotics etc.). The main purpose of this survey was to find out how many such projects actually took place in Croatian primary and secondary education for the last two school years (2016./2017. and 2017./2018.). According to the responses received, 62% of schools held at least two such activities for their students in that period, which is a good result.

It was also important to find out whether the teachers themselves participated in such activities outside the school. According to the responses received, only 4% of teachers have confirmed their participation on one or more extracurricular workshops which were held outside the

school in the observed period. This result is not so good and it can be said that higher participation of teachers is expected in such educations.

Motivation of teachers was also examined with the question of whether they want to volunteer for such projects organized as workshops outside the school. Even 61% of respondents answered the question positively and it is an excellent result. If this result is compared with the answers to the previous question, the reason for the inactivity of teachers in out-of-school workshops is clearly not a question of their motivation.

Teachers were also asked whether they used some of the content of extracurricular projects in the regular teaching for subject informatics. On this question, 76% of respondents gave a positive answer which indicates a good quality of such projects in Croatian schools.

When asked whether they have heard about Oracle Workshop in Box extracurricular programs, 66% of respondents gave a positive answer. This result is somewhat expected on the basis of the activities that the OA program has carried out in the last three years in cooperation with ETTA [9].

V. CONCLUSION

Extracurricular projects are a significant global driver of the popularization of computer science and consequently participate in the reform processes of existing school systems. It can be said that the representation of extracurricular content in Croatian schools is satisfactory in the last two years. This was certainly contributed to activities resulting from the national reforms in Croatian school education. However, it is necessary to involve teachers more actively in computer science extracurricular projects which take place outside the school because they have the knowledge and motivation for their successful implementation.

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Improving Plagiarism Detection Using Genetic Algorithm

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***Abstract*—Detecting instances of plagiarism in student homework, with program code in particular, is a subject of active research for over 30 years. One of the early proposed methods was extraction and comparison of source-code metrics. Even though this approach has low algorithmic complexity, it is rarely used in recent papers with some authors claiming that better results are obtained using other methods. In this paper, plagiarism detection is treated as an information retrieval problem, specifically query-by-example (QbE). A feature vector is constructed from source metrics and compared using common similarity measures. Further, evolutionary computation methods are used to optimize the similarity measure. It is shown that, by several metrics used, detection results are on par with state-of-the-art methods with significantly lower execution time.**

***Keywords* -** plagiarism detection, real-coded genetic algorithm, feature extraction

I. Introduction

Detecting instances of academic dishonesty in student papers, and in particular in programming homework, has been a subject of active research for over 30 years. In the early years, a common approach was to extract a certain set of software metrics and compare programs based on this. Programs that have similar values for these metrics were suspected to be plagiarised.

Starting in the late 1980s, advances in algorithms for string comparison made it possible to compare programs directly. First, a preprocessing stage is performed where non-relevant parts of code are removed, such as comments (although some authors argue for preserving the comments [1]). Code is tokenized, and some typical substitutions are performed, based on experience with cheating attempts.

After such preprocessing, all non-overlapping common substrings are found using algorithms such as Rabin-Karp. Ratio of the sum of length of those common substrings to total program length represents a degree of similarity. Various literature reviews agree that methods based on substring matching give better real-life results, although they don't scale well with increasing program length and number of programs compared.

This paper starts from observation that methods based on code metrics presented in literature use fairly primitive distance metrics, such as simple sum of differences. Authors observe that different features have varying contribution to the probability of plagiarism, even after normalization, so a weighted distance measure is chosen. After evaluating Manhattan, Euclidean and Cosine distance, Euclidean was chosen for the best results.

Various optimization methods were evaluated for calculating weights assigned to each metric. This optimization problem is characterized with high dimensionality (32 weights are optimized) and a relatively slow fitness evaluation (several seconds on average). For these reasons, Real Coded Genetic Algorithm (RCGA) was chosen.

This paper also presents a unique set of features determined from authors' empirical knowledge from manually reviewing suspected instances of plagiarism. Several of these metrics correspond well to those known from literature, however authors believe that metrics from software engineering are not neccessarily applicable and a special set of metrics for plagiarism detection needs to be developed.

Work described in this paper is implemented as a tool named fvpd and is made available on authors' GitHub page.[1] In addition, anonimized dataset is available with homeworks of all students who have signed a consent form agreeing that their homeworks be used for plagiarism detection research.

The remainder of this paper is organized as follows. Previous related work is reviewed in Chapter 2. Chapter 3 gives an overview of features extracted from code. Chapter 4 gives a discussion of a customized version of genetic algorithm used in this paper. Chapter 5 gives experimental results and is divided into subsections on datasets used, evaluation methodology, comparison with state-of-the-art tools and possible weaknesses of presented plagiarism detection method. Finally, Chapter 6 gives a conclusion and proposals for future work.

II. Related work

Literature reviews on plagiarism detection [2], [3], [1], [4] usually classify detection methods and algorithms into three groups:

- methods based on extracting a set of numerical features (called *fingerprints* or *metrics*) from source code and comparing them using a distance function (e.g. [5]) or machine learning (e.g. [6]),
- methods based on finding sets of *shared substrings* in preprocessed source code (e.g. [7]),
- methods based on extracting a *syntax tree* from code and finding subtree or substring matches (e.g. [8]).

Of special interest is MOSS tool [9] that combines first and second approach, since fingerprints are extracted using hashed engrams of code.

Most reviewers agree that these groups of tools are sorted in decreasing speed but increasing precision. Earliest works in 1970s and 1980s focused on methods based on software metrics, however in more recent years such methods were abandoned. Tools that are used in production settings and give the best results mostly are based on the substring matching

[1] https://github.com/EnilPajic/fvpd.

approach, which clearly puts an upper limit on the total number of documents that can be processed in reasonable time.

In recent years authors turn to machine learning techniques to overcome these problems [6] with limited success. A number of recent papers focus on AST parsing and parallel processing as methods for reducing plagiarism detection running time on large datasets.

A related research topic is clone detection. Code clone is defined as a fragment of code that is repeated in the same file or across several files [10], [11]. Detecting such clones is a useful task in the process of code quality improvement. While clone detection uses similar methods and algorithms to plagiarism detection, there are differences that require use of specialized tools. In plagiarism detection more preprocessing is typically done, especially transformations that are specific to plagiarism and arise from teachers' experience. Plagiarism detection tools compare whole files and don't look for similarities within the same file. Also plagiarism detection tools output pairs of similar homeworks with a similarity score (usually a percentage) for human review. Clone detector output would have to be preprocessed to give a suitable form.

III. Features

Every instance of source code can be approximately represented as a set of numbers that we call *features*. Features are grouped in an ordered list called a feature vector, and one feature vector represents object (source code in our case). These features should uniquely represent source code in a way that two similar codes have similar feature vectors (hence the idea for a feature-based detection tool).

The challenging task is to select which features to extract for best performance and unique representation of code. After selecting features, the next step is preprocessing. Each feature is a real number, but features can vary in their magnitude (e.g. number of lines of code vs number of functions), therefore biasing the overall result towards one or few features. To avoid this, normalization is performed, scaling feature values to the range $[0, 1]$. Min-max normalization was used [12] with the formula

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}(Max - Min) + Min$$

where Max and Min are scaling boundaries (0.9 and 0.1 respectively, in our case).

Feature vectors were compared using a modified version of Weighted Euclidean distance. Every feature v_i was multiplied by weight w_i allowing better control over feature importance (e.g. number of functions is more important for similarity than number of comments). These weights were calculated by Genetic algorithm (GA) with real-number coding, optimized to minimize errors, as explained in the next Chapter.

The modification of Weighted Euclidean distance consists of allowing negative weights. The reasoning behind this is that similar values for some features might actually indicate that code is not plagiarised, since those values would typically be manipulated by novice plagiators [5].

Selection of static features is inspired by Halstead's software metrics [13] and other previous works [5], but mostly on authors' experience with plagiarism detection. The list of all static features used is provided in Table I.

A. Discussion of certain features

Some features appear to be similar, but in order to get precise and accurate results they must be interpreted differently. Examples of such features are `LOC` – lines of code and `SLOC` – source lines of code. Optimization results for `LOC`'s weight coefficients can be 10 times smaller than `SLOC`'s because the latter does not include lines consisting of whitespace alone, or multi-line commands.

Other important features for plagiarism detection include `ARRAYS` – number of defined arrays and `ARR ACS` – number of array accesses.

Features `LOOPS` and `BRANCHES` represent Cyclomatic complexity metric (introduced by McCabe in 1976 [14]) which is a commonly used software metric to represent program complexity. Two programs that have similar complexity are likely to be similar in general. Likewise, several features count different types of operators, so their sum can be compared to Halsteads operator count.

The `RARE OP` feature, which represents number of uncommon operators such as access to member via pointer `->*` (C++ only), binary and operator (`&`, `&=`), xor operator (`^`, `^=`) etc., is very important in plagiarism detection. If an expert programmer uses a rare operator (that was not explicitely required by the task), a novice programmer will leave it in their plagiarized code.

IV. Genetic Algorithm

As already stated, not every feature is equally important. Each feature is assigned a weight denoting its contribution to overall distance, indicating that programs are not plagiarized.

Optimization is performed using real-coded genetic algorithm (RCGA) [15]. IEEE754 standard is used to represent floating point numbers. Standard RCGA as described in [16] is implemented except for the mutation operator and the crossover operator. The standard mutation operator [17] suggests to use a Gaussian distribution of possible values centered on current value. This type of mutation exists in authors' tool, but also other types of mutation are used to allow for escaping local optimums. Sometimes a larger change in weights is needed to see measurable improvement, so multiplication and division by 2 are also possible. Finally, sometimes performance can be improved by setting a single weight to zero.

A random value of N which determines mutation type is made for each gene. Gaussian mutation is 4 times more probable than other mutation types.

Two types of crossover operator were evaluated: a random selection of genes from both parents [18] and using mean value of parent genes for each gene. Surprisingly, the best results were obtained when half of children use the first crossover

TABLE I
LIST OF FEATURES EXTRACTED FROM CODE

Feature	Description
LOC	Lines of code – total lines of code
SLOC	Source lines of code – effective lines of code (programming constructs, ignoring white-spaces, curly braces, etc.)
SLOC CMD	Number of distinct commands (semicolons)
NUMBERS	Number of numbers (numeric literals)
ARRAYS	Number of arrays
LINE LEN	Average line length
BLOCKS	Number of blocks (curly braces)
BRANCHES	Number of branches (if, else if, else, switch-case)
CHARS	Number of characters (a-z and A-Z) in code, ignoring punctuation, braces, numbers, spaces etc.
FUN NUM	Number of functions (including main function)
INCLUDES	Number of #include directives
LOOPS	Number of loops in code (for, while, do-while, goto)
LITERALS	Number of literals (string literals, character literals and numbers)
ARR ACS	Number of array accesses (e.g arr[i] = 5)
REL OP	Number of relational operators (>, <, >=, <=)
EQ OP	Number of (in)equality operators (==, !=, eq, not_eq)
PLUSMIN OP	Number of + and - operators (and +=, -=)
MULDIV OP	Number of * and / operators (and *=, /=)
ORAND OP	Number of logical operators for conjunction and disjunction (&&, ||, and, or)
RARE OP	Number of "rare" operators (that are not frequently used) such as $->$, &, |, ^, ...)
NEG OP	Number of negation operators (!, not, ∼, compl)
MOD I/D OP	Number of modulo (%, %=), increment (++x, x++) and decrement operators (--x, x--)
STRINGS	Number of string literals (quoted)
BRACES	Number of small braces in code
TRYS	Number of try-catch blocks (C++ only)
VARS	Number of variables in code (local and global)
WORDS	Number of words in code (word definition is by RegEx)
SCOMM	Number of single-line comments
MCOMM	Number of multi-line comments
COMMAS	Number of commas (,) in code
MAIN LEN	Length (in non-whitespace characters) of main function

type and half the second one, contributing to overall diversity of population.

GA is restarted when no improvement in fitness is made in top 10 individuals for 3 consecutive generations. Best performers are stored and reinserted into population after every 4 restarts.

V. EXPERIMENTAL RESULTS

A. Description of Dataset

Dataset construction for plagiarism detection is a challenging problem. Several papers use the output from existing known tools as a "jury" for measuring new proposed algorithms [3], [19]. Another common approach is constructing artificial datasets that reflect various realistic situations [4], [1].

The new dataset presented here is constructed from homeworks submitted by students during two one-semester college modules. The first module, named A, is a module on introductory programming in C. Module named B is delivered after A and consists of intermediate programming in C++.

Approximately 600 students enrolled into these modules in 2016, while in 2017, this number dropped to about 500. Homework is not mandatory for a passing grade and so many of them choose not to do homework at all, and homework participation gradually drops during the semester. Unlike some other similar modules, homework in this module consists of a large number (15-20) of relatively simple assignments. For some of these assignments, there are not many different ways to solve the problem correctly, and so existing plagiarism detection tools tend to report a very large number of false positive results.

The method to fight plagiarism used to date was to require up to 20% of students to deliver an oral defense of their homework. The choice of students for this oral defense is based on code similarity, but also on other criteria such as suspicious behaviour (copy-pasting homework, suddenly solving homework at the last minute, etc.) and also past success on the module. All students who fail to defend their homework are marked as plagiarized in a "ground truth" file in addition to those who have final code similar to someone else. Also, when two or more homeworks are found to be similar, it is expected that one of those students will succeed in their oral defense (the original author who shared their homework), so this original likewise remains in the "ground truth" file.

Further, instances of very short (unfinished) homeworks that were nonetheless submitted to the grading system were removed entirely from the dataset. Even though proper classification of such homeworks is certainly a useful feature, there is a large difference in how various tools handle such cases: some allow to specify a threshold for homework length, other tools use some undisclosed heuristic, and some tools will simply mark all such homeworks as plagiarized and let a human supervisor unmark them.

This basic ground truth represents a difficult task for plagiarism detection.

The structure of the ground truth file is such that some homeworks are grouped in similar pairs (triplets, quadruplets, etc.), while others are listed alone. Therefore, when evaluating a plagiarism detection tool, we do not verify if such tool correctly identified pairs of similar documents but simply count false positive and false negative results including both sides of their detected pairs.

Anonimized datasets are available from authors per request.

B. Accuracy vs. Recall?

How to evaluate a plagiarism detection tool? One approach would be to observe classification error or accuracy (see e.g. [1]). Classification error is defined as

$$Cerr = \frac{FP + FN}{S}$$

where FP and FN are the number of documents falsely classified as plagiarized (false positive) or not plagiarized (false negative) respectively, while S is the total number of documents in the collection. Accuracy is simply $1 - Cerr$.

Most plagiarism detection tools give output in the form of an ordered list of document pairs with their similarities

(in percents). So, to obtain a binary classification one must use a threshold. The issue of what threshold to use is rarely discussed in the literature.

While experimenting with tools based on substring matching found in literature [7], [20], an attempt was made to determine an optimal threshold for each collection with a view that there should be some relationship between similarity threshold and average document length or complexity. Our finding was that optimal threshold shows a very large variance and that no such relationship could be established.

The source of these problems with accuracy and error is that those measures are suited for unsupervised classification where the ultimate goal is to obtain 100% accuracy. While plagiarism detection tools have advanced in recent years, it is still not possible to use them without human supervision [21], [3] (see also MOSS project website).

Consider a collection that consists of 100 documents of which 5 are plagiarized. A null-algorithm that reports 0% similarity for all document pairs would have $FP = 0$ and $FN = 5$, which gives a fairly high accuracy of 95%. Another tool that correctly detects all 5 plagiarized documents but also reports 5 falsely positive results would have the same accuracy, even though such tool is clearly far more useful to a practitioner.

Typically, plagiarism detection tools are used such that a human supervisor scrolls trough the sorted list of documents and reviews each result, similar in a way to browsing through search results. During such use, false positive results are easily noticed and discarded, while real cases of plagiarism that are given low similarity (false negatives) are a far greater problem since a human supervisor will eventually give up after several pages of results. This suggests that metrics known from information retrieval would be better suited for comparison, specifically metrics that assign a greater penalty for false negative classification, such as recall.

Precision is defined as the number of correctly retrieved documents (true positives) among the top n results:

$$P_n = \frac{TP}{n}$$

while *recall* is the ratio of correctly retrieved documents (among the top n) to the total number of relevant documents in the dataset:

$$R_n = \frac{TP}{P}$$

The remaining issue is choice of n. Document collections in our dataset vary greatly both in the total number of documents and in the number of known instances of plagiarism. To account for that, we choose n to be the number of documents that are known to be plagiarized ($n = P$), such that a tool that correctly ranks all plagiarized documents before those non-plagiarized would have a recall of 1, while a null-algorithm described earlier would have recall of 0. Thus, our chosen metric represents both precision and recall.

A shortcoming of precision-recall as a comparison metric is that it cannot be used on collections in which there are no known instances of plagiarism.

C. Comparison with State of the Art

Experiments were performed using homeworks gathered in modules A and B during academic years 2015, 2016 and 2017. Final recall for all modules is given for our tool (fvpd) and contrasted with three tools found in literature that are predominantly used today: JPlag [7], Sim [20] and MOSS [9]. Results can be seen in Table II (our tool is labeled "fvpd").

To avoid overfitting, the dataset described above was divided into training set and test set. Three combinations were explored: coefficients trained just for C programming language (module A2017 is used for training set), just the C++ programming language (module B2015), and for both programming languages (modules A2016 and B2015 are combined into training set).

Firstly it can be observed that, for our datasets, Sim tool gave far superior recall to JPlag and MOSS, especially with early datasets A2015 and B2015, the result which was not found in literature. JPlag and MOSS in general have similar performance, except with B2016 dataset where MOSS was superior to JPlag and on par with Sim.

Our tool presented in this paper gave very good results that were comparable to JPlag and MOSS on all datasets for A module (C programming language). However, results were mediocre for B2015 dataset and very poor for B2016 dataset, regardless of which training set was used. Using C++ homeworks for training set slightly improved results on the C++ test set but not by much. This point needs to be further researched.

For completeness, another comparison metric is classification error at optimal threshold, given in table III. First, for each homework in dataset, an optimal threshold for binary classification of documents is determined such that error is minimal. Then, $CErr$ is calculated at that threshold. This table also supports the conclusions given above.

D. Time and Memory Performance

Tools based on substring matching have, in general, an exponential time complexity. A naïve implementation would have an $O(N^2n^3)$ complexity [3], where N is the total number of documents and n is their length in characters. However, clever programming and various tricks allow state-of-the-art tools to perform very well in most realistic usage cases. The worst-case complexity of $O(N^2n^{1,12})$ has been claimed [3], [22].

Method proposed in this paper consists of two steps: feature extraction and comparison. Using notation given above, feature extraction has time complexity of $O(Nn)$ and a negligible memory usage. Comparison step is a well known "k nearest neighbors" problem that has high performance approximate solutions using methods such as kd-trees [23] and Locality Sensitive Hashing (LSH) [24].

To verify this claim, two folders were created for the purpose of speed test: folder speed1 contains 4000 C programs of 4kB average size, while folder speed2 contains 1350 C++ programs of 14,5kB average size. On an Intel Core i7 CPU, our fvpd extractor took on average 2.25s on speed1 but only

TABLE II
RECALL FOR VARIOUS PLAGIARISM DETECTION TOOLS (MORE IS BETTER)

Tool	A2015	B2015	A2016	B2016	A2017
JPlag	0.5171	0.6474	0.5488	0.4722	0.5395
Sim	0.8432	0.8158	0.7075	0.6304	0.6629
MOSS	0.5251	0.6336	0.5390	0.6268	0.5556
fvpd (C)	0.5697	0.4229	0.6506	0.1024	0.5313
fvpd (C++)	0.5438	0.5188	0.5204	0.2004	0.4291
fvpd (C&C++)	0.5770	0.4653	0.6626	0.1716	0.5256

TABLE III
CLASSIFICATION ERROR AT OPTIMAL THRESHOLD FOR VARIOUS PLAGIARISM DETECTION TOOLS (LESS IS BETTER)

Tool	A2015	B2015	A2016	B2016	A2017
JPlag	0.1705	0.0448	0.1566	0.0251	0.1741
Sim	0.1122	0.0311	0.1471	0.0244	0.1517
MOSS	0.1869	0.0500	0.1598	0.0174	0.1726
fvpd (C)	0.1610	0.2011	0.1500	0.1269	0.1755
fvpd (C++)	0.1698	0.1554	0.1643	0.2069	0.2010
fvpd (C&C++)	0.1604	0.1987	0.1479	0.2069	0.1791

1.55s on speed2. Meanwhile, Sim tool [20] took on average 1.14s on speed1 but 4.96s on speed2. From this we can see an important effect of average document length as well as programming language used on overall extraction speed.

Sim is a highly optimized plagiarism detection program based on substring matching, written using C in 1988, and is by far the fastest plagiarism detection tool available today. Conversely, our extractor was written as a proof of concept and surely can be optimized further. JPlag tool was much slower, while testing the speed of MOSS tool in these test cases was difficult since this tool is only available as a web service, therefore network latency dominates the overall detection time.

E. Plagiarism Detection Weaknesses

There are several possible venues of attack on the method presented in this paper. Plagiators can insert large quantities of code which is never executed or doesn't affect the correctness of output, skewing the metrics presented. To avoid this, a preprocessing stage could be added which detects and eliminates such superfluous code. Further, C++11 and later standards introduced a number of new programming constructs that should be separately counted.

VI. CONCLUSION

A method for plagiarism detection based on extracting features, or software metrics, from source code is presented in this paper. It is shown that, using an appropriate distance function, results that are broadly on par with state-of-the-art are possible. This is important since feature extraction and retrieval can be delivered much faster on a very large dataset compared to traditional methods based on substring matching and hashing.

These results can also have impact on code clone detection techniques, which is a venue for future research.

Much further work is needed, especially in the area of selecting features. A thorough statistical analysis needs to be performed to find if some of the features are redundant, and new features should be introduced, especially those that are targeted at object-oriented code.

Different distance metrics can be explored such as generalized Mahalanobis distance.

The method described in this paper has produced a set of weights that shows a surprising level of programming language specificity, even with languages that are otherwise very similar, such as C and C++. One possible explanation is that plagiators use different cheating strategies in modules A and B. In production usage it may or may not be practical to use different pretrained weights for each language used. Further study in this regard should be performed. Authors also plan to address the weaknesses described in previous chapter.

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Behind the Dystopian Sentiment: a Sentiment Analysis of George Orwell's 1984

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Abstract - **Recent daily political events returned the focus of the general public to a fictional work of art that may yet prove to be one of most influential through the use of its concepts and language – George Orwell's 1984. The language of Orwell's novel, specifically its terminology, has been proven by linguists and other researchers to be in common use in media speech and writing. The author's intent, in which he unanimously succeeded, was to create a dystopian world reminiscent of totalitarian regimes, through the careful use of style and language. Could this intent be somehow investigated and measured by using precise natural language processing methods? Basing this research on related work, the aim of this paper is to evaluate if it is possible to observe how the dystopian atmosphere of the Orwellian concept is created in the novel by applying sentiment analysis on the sentence level, and by exploiting a polarity lexicon as well. Moreover, can a computer by utilising a classification technique based on the Bayes' theorem demonstrate Orwell's intention of creating a dystopian atmosphere? In addition, this paper tries to highlight the possible applications of sentiment analysis of fictional work of art in academic curricula.**

Keywords - natural language processing (NLP); sentiment analysis; naïve Bayes classifier; George Orwell's 1984; dystopia; Newspeak; automatic classification; machine learning; information and communication sciences

I. Introduction and Motivation

George Orwell's 1984, one of the most well-known works of English literature, shows to the present day that it may be one of the most influential through the use of its dystopian concepts, known as the Orwellian concept, and its language – specifically, the fictional language "Newspeak" used by the characters in the novel.

Linguists and other researchers have proven the novel's terminology to be in common use in media speech and writing, even more so in today's age of fake news.

Orwell's intent was that of creating a dystopian world reminiscent of totalitarian regimes. This paper tries to show if this intent, created through the careful use of style and language, could be investigated and measured by precise natural language processing methods.

In a previous research on Orwell's 1984 [1], the authors tried to show, through computational concordance analysis of fictional literary work, how "terms related to the Orwellian concept, such as "Big Brother" or "Newspeak", are applied in an affirmative and positive way, and that a computer is not suitable for distinguishing the totalitarian implications of those terms, as computers are inherently not able to put them in the context that is in fact a dystopian work of fiction".

Furthermore, in another paper the authors conducted a computational analysis of frequencies of the dystopian terminology used in Orwell's novel [2].

Basing this particular research on previous work, the aim of this paper is to investigate and measure Orwell's intent. By applying sentiment analysis on the sentence level, and by exploiting a polarity data set as well, an evaluation will show if it is possible to observe how the dystopian atmosphere of the Orwellian concept is created in the novel. Moreover, this paper investigates if a computer could demonstrate Orwell's intention of creating a dystopian atmosphere by utilising a classification technique based on the Bayes' theorem.

II. Motivation

One differential study [3] with informal and formal writing styles has shown that sentiment analysis has a wide range of applications, from social media texts to poetry. The study accentuated that "literary arts (poems, novels, essays, plays etc.) are the one of the complex examples of formal text".

On this note, the goal of this paper is to study through computer-based sentiment analysis, if and how the hypothesised and expected atmosphere of "doom and gloom" in a dystopian work of fiction is constructed. As a proof of concept for further research of interesting phenomena, this method could perhaps be used to reveal the implicit rules of the fictional Newspeak language used in the novel. If a novel in general is indeed a complex example of formal text, a novel like Orwell's 1984, with its specific terminology and a whole language invented for its purposes, is a proof of concept.

This paper also suggests possible application of time-efficient techniques and precise methods in dystopia research and research of literary corpora, as part of e.g. literature studies or linguistics in higher education.

The following related work section shows previous applications of sentiment analysis on literature and other types of texts (and speech).

III. Related Work

This section lists the wide applications of sentiment analysis on literary works of fiction, with an emphasis of its use in higher education and the academic curricula.

One author uses sentiment analysis to "identify concepts that orient us toward a history of emotions in comparative literature" on examples of Spanish literature [4].

Its application varies from the use as a tool for automatic irony detection [5] to the sentiment analysis of English literature using a task-specific semantic ontology [6].

On the topic of English literature, [7] conducted a study on character-to-character sentiment analysis in Shakespeare's plays.

Furthermore, [8] hypothesised that a "sentiment network can be used to distinguish a document's genre (tragedies versus comedies), detect a given character's enemies and allies, and model the overall emotional development of a play".

There have also been studies on word occurrence statistics and emotions in social media, especially Twitter [9, 10, 11]. Moreover, a study evaluated the different techniques and possible applications of emotion recognition in speech [12].

IV. Research

The following subsections describe the chosen and analysed data set, the applied research methodology and natural language processing techniques.

A mathematical approach was used in order to detect the sentiment in the data set at the sentence level. The research focuses entirely on studying affective states that are present in sentences from the data set. They are examined quantitatively at first, and then evaluated qualitatively by a human evaluator (manually).

All of the research steps derive from the field of natural language processing (NLP). They can be employed in higher education and for purposes of academic curricula, e.g. for efficient data analysis training, teaching information extraction from specific corpora and subsequent analyses etc.

A. Data Set Preparation

The authors of this paper analysed the novel 1984, also known as "Nineteen Eighty-Four", written by George Orwell and published in 1949.

The whole novel content was used as the testing data set (test set) in this experiment. The authors used a preprocessed version of the data set [1, 2]. Preprocessing of the initially messy data set included file format conversion, saving the data set as a raw UTF-8 plain text file, stripping of any formatting etc. Regular expressions were applied in order to remove redundant characters and to fix specific characters – e.g. 3200 apostrophes were restored.

The data set was split into sentences (or smaller segments where applicable) and then tokenised with specific tokenisation rules. In the final step, the data set was manually checked for errors (e.g. omission of apostrophes, incorrect quotation marks etc.) and corrected.

Python and Perl were used to carry out most of the preprocessing steps. After finishing the process of data set preparation, sentiment analysis was performed.

B. Sentiment Analysis

The main goal of sentiment analysis is detecting, i.e. identifying the subjective opinion, appraisal, attitude or emotion (feeling) in a given text (or speech) with regards to an arbitrary topic or subject [13, 14]. It is an important natural language processing taks used nowadays for analysing markets, public relations, politics, product reviews, feedbacks on customer satisfaction and so on.

There can be many possible outcomes of different sentiment analysis approaches. One could, e.g. examine the level of objectivity or subjectivity in a text, or look for the subjects, objects and entities in a text, or try to identify the topic of a text, or just analyse the polarity, i.e. the general sentiment of a text (or its constituent parts) [13, 14].

Very often researchers analyse only the polarity of text – i.e. whether a text is considered positive, negative or neutral – or the subjectivity of a statement in text – i.e. whether a text chunk is considered a subjective opinion or objective fact. Polarity is usually presented as a decimal number in the range of [-1, 1], where -1 and 1 denote negative and positive sentiment, respectively. On the other hand, subjectivity is typically presented as a decimal number in the range of [0, 1], where 0.0 means "very objective" and 1.0 means "very subjective" [13, 15].

Many times, researchers are interested in classifying text according to some external resources (mostly lexicons), which can be crafted for general purposes or task-specific domains.

Text classification is a common semantic-related objective in natural language processing (NLP), with vast practical applications besides sentiment analysis. It has been heavily utilised for spam identification, data filtering and organising, context mining, information extraction, topic modelling, (social) media discourse analysis, business intelligence for making key decisions, trend monitoring etc. The intent of text classification is to classify source text into meaningful systematised, but fixed categories, marked with a discrete classification label [13, 14].

In machine learning, the naïve Bayes classifier is a probabilistic classifier – an algorithm used for learning models and predicting model output, with strong naïve assumptions of independence between model features, i.e. predictors [15-17]. It is based on the Bayes' theorem, as shown in (1).

$$P(A \mid B) = \frac{P(B \mid A)\, P(A)}{P(B)} \tag{1}$$

The Bayes' theorem allows one to find the probability of an event *A* happening, given that event *B* has occurred. *B* is called "evidence" and *A* is called "hypothesis". In this case, *P(A|B)* is the probability *P(label|features)*, *P(B|A)* is the *P(features|label)*, whereas *P(A)* is *P(label)* and *P(B)* is the *P(features)* probability [17].

Instead of computing *P(features)* explicitly, the algorithm calculates the numerator for each label, and normalises them so their sum is 1 [17]. If the classifier encounters an input with a feature that has never been seen with any classification label, then rather than assigning a probability of 0 to all labels (too harsh penalisation), it will ignore that feature [17].

The assumption, however, is that the features are independent of each other. In other words, one feature does not affect the other – that is why the classification procedure is actually regarded as "naïve". Moreover, all features are considered to have an equal effect on the overall probabilistic outcome, and they jointly determine which classification label should be assigned to a specific input [17].

In order to define the "correct" classification label for a specified input, the classifier calculates the prior probability of each label, which is determined by examining the frequency of each label in the training data set. Then, each feature's contribution is combined with this prior probability, to obtain a likelihood estimate for each label. The label with the highest likelihood estimate is subsequently assigned to the input value [17].

Classification essentially means choosing the correct label for a given input. In its basic form, classification inspects each input in isolation from all other inputs, whereas the set of labels is defined in advance [17].

Classifying text from a natural language is a process usually comprised of two fundamental steps – training and prediction [17].

During training, a feature extractor is used to convert each textual input into a feature set – this is done as part of the so-called feature extraction process. The feature set is typically a numerical representation of the provided text in form of a feature vector. Each element of the feature vector symbolises the frequency of a word in the training data set.

These feature sets hold the basic information about each input that should be used to classify it. Then, pairs of feature sets (feature vectors) and classification labels are fed into the machine learning algorithm in order to create a classification model. Basically, the model learns how to associate a specific input, in this case, the text from Orwell's novel, to the correct output (labels "pos" or "neg") with regard to the content from the training data set.

During prediction, the same feature extractor is employed to convert unseen textual inputs into feature sets (feature vectors). These feature sets are then passed to the classification model, which generates predicted classification labels.

Here the authors of this paper chose the classical bag-of-words (BOW) approach, which records words along with their frequency. At first, a vocabulary is created by collecting all different words that occur in the training data set, and each word is associated with a count of how it occurs [16].

The BOW model is a simplification, which greatly reduces the level of language complexity, and allows a sentence to be represented as a plain "bag" with a mixture of its inherent words, but at the cost of losing some valuable information about the surroundings of the word. Nevertheless, for sentiment analysis the end result is mainly determined by a few high-impact keywords that provide critical semantic information.

This "bag" is typically implemented as a multiset – a set modification that allows for multiple instances of each of its elements. BOW does not take any grammar, syntactic knowledge or word order into account, but just keeps track of word occurrences and multiplicity, i.e. the number of times a multiset member appears in a multiset [18].

Many recent sentiment classifiers make use of sentiment lexicons [13, 15], which act as a compact representative of emotions from the real world. Those lexicons are in fact lists of words and corresponding sentiments they convey. However, as they can be of different types and domains, crafting lexicons is a very distinct process and varies from task to task. So it is not surprising that there is no gold standard, i.e. general agreement on how to treat and label the very subjective affective states within individual lexicons.

In this experiment, the authors chose to approach the sentiment analysis task as a typical classification problem in natural language processing. This was done computationally by employing an automatic classification method.

For that purpose, a machine learning model was trained in form of a classifier, which was then used to discriminate words based on their frequency, i.e. the number of occurrences of each word. The frequency was, thus, used as the training feature in the model. The main idea was to forward text, i.e. sentences from Orwell's novel, to the classifier and obtain the corresponding classification labels.

Here, the authors used supervised machine learning and single-closed-class classification:

- classification was "supervised" since the classifier was generated using a training data set (polarity lexicon) which contained the correct label for each input – the machine learning algorithm learned during the training phase what the expected output was for a given input sample;
- each instance could be assigned only to a single label at a time;
- all the possible labels were determined beforehand (closed class).

The authors had to process the data set at first, then a feature extractor was applied in order to extract the features (which words in the training data set occur in the

data set). The machine learning algorithm learned these features in order to predict against unseen, i.e. new text – in this case, Orwell's novel 1984.

The authors created a naïve Bayes classifier by passing the training data set in form of an already available polarity lexicon [19]. The lexicon consisted of 6790 words in total. All words were labelled either with the label "pos" (for positive sentiment) or "neg" (for negative sentiment):

- 4783 words labelled with "neg" (ca. 70.4%);
- 2007 words labelled with "pos" (ca. 29.6%).

Neutrally labelled words were not present in the training data set, i.e. polarity lexicon. Although the lexicon was decent in size, machine learning typically relies on larger high-quality training data sets, due to the fact that the classification model depends on the quality and quantity of features (predictors). The lexicon was converted into CSV file format for easier later-stage processing and analyses.

In this experiment, the implementation of the naïve Bayes classifier in Python was fairly simple, but the model itself had a significant downside. As already mentioned before, features should be completely independent, but in real natural languages, and especially in literature, this is very often not the case. Certainly, this obstructed the classification accuracy.

V. Results And Discussion

This section deals with the experiment results and discusses the various experimental aspects. In addition, the authors list the different drawbacks of the conducted experiment in the second subsection.

A. Experiment Results

The experiments were carried out on a 64-bit quad-core machine (8 threads) with 16 GB of RAM. Training the classifier took relatively long. More than 5.2 GB of RAM were consumed during the training phase due to the reasonable size of the training data set.

All of the 6905 sentences (or lines in same cases) from the data set, i.e. from George Orwell's novel 1984, were automatically classified as either positive ("pos") or negative ("neg"). Lines were understood as text fragments present in the data set that were not ending with a punctuation mark, i.e. with a sentence delimiter.

The authors decided to perform a manual quality analysis of the trained classifier afterwards. For that purpose, 300 sentences/lines were randomly extracted from the original data set (about 4.3% of the entire data set). The number 300 was chosen arbitrarily by the authors. Out of the extracted subset, 204 sentences/lines were classified as "neg" by the classifier, and 96 as "pos".

One evaluator checked if the classifier had correctly classified the 300 sentences/lines, and to what extent – in total, 134 were manually marked as "correctly classified", whereas 165 were marked as "incorrectly classified". In other words, only ca. 45% of all the 300 randomly extracted and qualitatively evaluated sentences/lines were confirmed to be accurately classified. On the other hand, 55% were erroneously classified, which indicates that the trained classifier performed poorly. Some of the reasons for the insufficient quality will be discussed in the next subsection.

But by and large, in order to provide more adequate conclusions on whether this applied natural language processing technique is suitable for analysing dystopian novels, or other related literary works, more extensive research is needed and planned for future work.

B. Experiment Drawbacks

The authors of this paper would also like to emphasise the caveats and limitations of the experimental setup.

During the manual evaluation of the 300 randomly selected sentences, on some occasions it was not easily determinable whether a sentence was correctly classified, due to a number of reasons:

- the only two labelling options were "pos" (positive) and "neg" (negative), since there were no words present in the training data set (polarity lexicon) that were labelled as "neutral", which would sometimes definitely be much more suitable;
- the training data set (polarity lexicon) was of general domain, and did not contain any of the specific Newspeak words (fictional language very frequently used in Orwell's 1984), which made the correct classification sometimes impossible;
- analyses of expressed affective states were occasionally challenging and difficult due to the linguistic and stylistic complexities of the selected novel – such as sarcasm, metaphors, irony, specific terminology etc.;
- in some of the sentences the classification labels were hard to differentiate due to the tone and nuance of particular expressed subjective opinions;
- observing sentences as isolated units and, hence, the lack of larger context, made it oftentimes hard to examine the correctness of the classification;
- the semantics of some of the sentences could not be accurately interpreted, as affective states were not clearly and explicitly stated, but the semantic information derived from other sentences located elsewhere in the novel;
- the lack of directly expressed opinions made it sometimes hard to grasp what the sentence was truly about;
- analysing some of the sentences was very demanding, as the necessary word span for correctly identifying different semantic concepts was very large (e.g. when one sentence refers to another, large sentence

range, problems with anaphora resolution etc.).

Also, whenever the evaluator came across a dubious sentence or dilemma, and was not sure about the correct classification, the preference was given to the "neg" label. Also, if the classifier labelled a completely neutral sentence/line as "pos" or "neg" the evaluator marked such an occasion as a classification error. This was indeed crucial and resulted in additional, but artificial, penalisation (decreasing) of the classifier's accuracy during the manual evaluation phase.

Furthermore, the uneven distribution, i.e. disproportion in the number of negatively and positively labelled words in the polarity lexicon skewed the probability results towards an overall negative sentiment. There was just a higher chance of bumping into a negatively labelled word. Namely, almost 2.5 times more "neg" labels were present in the polarity lexicon, which was used to train the classifier in the first place. However, this did not have a purely bad effect on the evaluation outcome, and was not entirely noticeable, as in Orwell's work – a dystopian novel – the negative sentiment is dominant anyway.

VI. Future Research

The authors plan to increase the training data set (polarity lexicon), i.e. to increment it with all of the specific Newspeak words from Orwell's novel.

Furthermore, a specific domain lexicon should be crafted with specific (dystopian) vocabulary from the 20th century literature in order to capture the zeitgeist of 1940s and 1950s world, i.e. the time frame when Orwell's novel 1984 was written and published. Using pondering (favouring specific terminology) in the classification model could also be useful.

It should also be explored what other sentiment lexicons exist on the market, and which of them are freely available and editable.

Also, adding the "neutral" category with corresponding neutral words to the lexicon is important in order to allow for a more fine-grained sentiment analysis.

Perhaps adding more polarity labels, i.e. categories (e.g. "very positive", "positive", "neutral", "negative", "very negative") would also be beneficial to the classification quality and precision.

Here the sentiment analysis is done only on the level of a single sentence/line which leads to a certain loss of semantic information. Due to the fact that most sentences are mutually not independent and the lack of larger context very often hinder the evaluation task and make an objective discrimination of polarity labels very complicated.

One specific CAT tool [20] provides means for discovering concordances, and showed to be very effective in context analyses. The authors plan to investigate the possibilities of using it for fast lookups of concordances or its fragments.

The authors plan to increase the validity of the manual quality evaluation by conducting sentiment analyses:

- on the level of the whole corpus, i.e. data set – a final sentiment score is given for the entire document (Orwell's novel);
- on the level of multi-word expressions – which are treated as a single grammatical unit – collocations and idiomatic expressions within a sentence/line [21, 22];
- on the aspect level of specific text chunks within sentences/lines, which can be identified with part of speech (POS) tags.

In this experiment only one evaluator did the qualitative analysis of the classifier's output. More evaluators should repeat this experiment in order to verify the performance of the classifier. Moreover, an inter-rater agreement analysis could provide interesting insights into the consensus and reliability of human judgement [23], i.e. the difficulties of accurate classification of dystopian novel content by humans.

Besides, a larger evaluation data subset should be used (much more than 300) and, later on, F-measure, as the harmonic mean of precision and recall [24], should be calculated for more elaborate evaluations of the classifier accuracy.

The classifier in this experiment behaved naïve. To be more precise, it actually classified Orwell's novel on the word level – the sentiment analysis score of an entire sentence/line derives from the word level probability calculations of words that comprise them. That way sentence level classification did not consider any linguistic knowledge or syntactic information on how sentences and paragraphs are structured. The possibilities of applying appropriately trained language models and calculating the perplexity of the model [23] could help to increase the classifier's predicting capabilities.

Source code should partly be rewritten to speed up training, reduce loading time and to enable quicker data access later on. The authors plan to apply alternative data structures and object serialisation (pickling) for faster loading, which is especially important for consecutive analyses and evaluation runs.

VII. Conlusion

Sentiment analysis is fast and unbiased, and, unlike human subjective judgment, applies consistent criteria. It relies purely on a mathematical framework, deprived from any personal points of view, assumptions, impressions, opinions, understanding, feelings, convictions and reasoning.

The authors have shown that the absence of the neutral label in the polarity lexicon makes assessing a classifier's accuracy more difficult. Still, defining the exact meaning of the "neutral" sentiment is not always straightforward. Even though identifying some expressions as neutral can also be a demanding task, granularity has shown to be very valuable in sentiment analysis.

In addition, resorting to a general domain polarity lexicon did not prove to be beneficial to the quality of classification of dystopian literature.

Also, qualitative manual evaluation and error analysis have demonstrated to be very context-sensitive. The meaning of a given sentence/line is, most of the times, inferred from the surrounding text. That is why during the evaluation phase a larger context window should be presented to the evaluator. This should help to reduce errors and improve evaluation consistency.

The authors are convinced that the applied research methodology can be adopted in academic research and education, and that automatic natural language processing approaches indicate a huge potential, especially since numerous problems and experimental drawbacks have been identified, out of which all can be taken into consideration in future research.

Despite the low accuracy of the classifier, the results still look promising. Further investigation should yield definitive conclusions on whether an automatic natural language processing approach, in form of sentiment analysis, is appropriate for analysing the dystopian literature and its unique style.

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Through the Limits of Newspeak: an Analysis of the Vector Representation of Words in George Orwell's 1984

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***Abstract* - The era of fake news, media manipulation and information wars has been beneficent to the lasting fame and continuous acclaim of George Orwell's 1984. The novel, published in 1949, influences to the present day the terminology of various political and social analysts through the use of its fictional language called "Newspeak". The question arises – can the inner connections of the concepts present in Orwell's 1984, when analysing the text on a semantic level of the words in their contextual environment, be used to further the understanding of the inner-workings of the novel's language itself? More specifically, the aim of this paper is to examine whether a reader without knowledge of the subject of a fictional work of art, exemplified by Orwell's 1984, could gain deeper comprehension of the text just from analysing word vector representations, without the use of external resources and only through an overview of the established similarities on the semantic level of words in a given text. In fact, word vector representations, as a form of word embeddings in a vector space model, are a machine learning technique sometimes applied in natural language processing, which attempts to identify semantically similar words.**

Keywords - natural language processing (NLP); word vector representation; word2vec; word embeddings; vector space model; George Orwell's 1984; dystopia; Newspeak; machine learning; information and communication sciences

I. Introduction and Motivation

George Orwell's novel 1984 has had a wide influence on the terminology of various political and social analysts to the present day. Its fictional language "Newspeak", as well as the Orwellian definition of concepts such as *war* or *power* are all relatable to the present era of fake news, media manipulation and information wars.

When analysing the text of Orwell's 1984 on a semantic level of the words in their contextual environment, can the inner connections of its concepts be used to further the comprehension of the inner-workings of the language itself?

Could a reader, without any knowledge of the subject of a novel, play or other fictional works of art, gain a deeper understanding of the text just from a survey of words that were identified as semantically most similar by vector representations of words?

These vector representations on the semantic level, more specifically, an overview of the established similarities on the semantic level of words in a given text, could aid students to investigate the text without any topic-related knowledge or the use of additional resources. The application of such a method on a complex, literary text, could be a proof of concept for all other possible applications on simpler texts.

This approach, when applied with natural language processing techniques, could, therefore, enhance methods of text examination in literary studies, higher education and the academic curricula itself.

II. Motivation

The aim of this paper is to study, on the example of Orwell's 1984, if a reader could comprehend the meaning of the text just from a brief survey of its "semantic network", the vector representation of words, without the use of any other resources, and only through an overview of the established similarities between words in the text.

Word vector representations, as a form of word embeddings in a vector space model, are a machine learning technique sometimes applied in natural language processing, which attempts to discover semantically comparable words.

This paper is a proof of concept – if one can successfully examine the "semantic network" of a fictional work of art, and in this case a complex novel with various important concepts and a whole fictional language used by the characters and invented specifically for it, then one could presumably apply this approach on less-complicated, non-fictional texts for various analytical purposes.

III. Related Work

The terminology of Orwell's 1984 has attracted a lot of attention and was examined by a wide range of scientists in higher education, not only from the field of literary studies but also from politics, media, information and communication sciences, linguistics and sociology, just to name a few.

In recent years, publications concerning the use of Orwellian terminology in politics and in the media has

been on the rise due to the so-called era of fake news. In relation to language, between ideology and power in Orwell's 1984, [1] asserts that "ideology gains shape and manifests itself only through a semiotic system that is called "language", and thus, whoever controls the language, controls the ideology, and consequently the power structures of a given society. By devising the concept of Newspeak in 1984, Orwell manifests his profound awareness of the relationship between language and the power relations in society". Reference [2] uses the example of the novel's famous quote "The object of power is power", to reveal "tautological symbolic lack [...] as an unnerving point of convergence between the totalitarian state envisioned by Orwell and the modern social democratic structures" – a claim that the paper exemplifies by examining British Prime Minister Theresa May's tautology "Brexit means Brexit". "Inspired by Orwell's chilling account of brainwashing, propaganda and the obliteration of the lines between fiction and truth...", [3] discusses the topic of fake news, alternative facts and "[...] the challenges that the advent of fake news organisations and the dissemination of alternative facts as truth pose to deliberative civics education, specifically how the trend of a diminishing space of truth and fact undermines efforts to teach students how to engage effectively and productively in democratic deliberations". Within the field of future studies, [4] tries "to depict how the state of inverted totalitarianism is emerging in post-postnormal times, and to illustrate how it shares many of the same features of the totalitarianism depicted in the novels Brave New World (A. Huxley) and 1984 (G. Orwell)". In the field of semiotics, [5] states that the interesting aspect encountered in Orwell's 1984 is the vicious unended cycle and the war that will never end between the stated groups within the framework of the ideology/axiology perspective". When it comes to word embeddings applied to literary arts, [6] extracted a social network from a literary text and "the experiments suggest that specific types of word embeddings like word2vec are well-suited for the task at hand and the specific circumstances of literary fiction text". One paper [7] demonstrates that building word embeddings on annotated literary texts of 19th century fiction "can provide us with an insight into how characters group differently under different conditions, allowing us to make comparisons across different novels and authors. These results suggest that word embeddings can potentially provide a useful tool in supporting a quantitative literary analysis". A research conducted by [8] on applying word embeddings and semantic lexicons to literary texts "demonstrates the importance of examining implicit assumptions around default strategies, when using embeddings with literary texts, and highlights the potential of quantitative analysis to inform critical analysis". Furthermore, projects such as the LAPPS Grid have developed a platform – [9] states that "providing access to a vast array of language processing tools and resources for the purposes of research and development in natural language processing (NLP), has recently expanded to enhance its usability by non-technical users, such as those in the Digital Humanities community (DH)", but "it is only recently that Computational Linguistics (CL) methods and tools have begun to be made more accessible to non-technical users, and are beginning to be widely adopted by the DH community; however, there remains considerable work to be done to fully adapt CL tools and methods in order to be used by DH scholars". One paper [10] tried to demonstrate, through the use of a computational analysis of frequencies of dystopian terminology in the text of George Orwell's 1984, that it is possible to measure how the Orwellian concept is created, constructed and structured in the novel. Such a computational approach, when made with word embeddings, can help to create a "semantic network" of words from Orwell's novel. Another research [11] showed how conducting a computational concordance analysis of Orwell's fictional literary work could be applied for the purpose of analysing terms related to the core Orwellian concept. To analyse specific textual corpora, statistical approaches have been proposed [12, 13], with special emphasis on concordances [14, 15], terminology extraction [16, 17] and language modelling [18].

IV. RESEARCH

This section is divided into two subsections – Data Set Acquisition and Preprocessing, and Word Embeddings and Vector Representations. The first subsection deals with the process of acquiring the experimental data set, and the following preprocessing phase. The second subsection discusses the applied research approach and selected natural language processing method.

The authors of this paper decided to employ an objective, precise and cost-effective mathematical way to analyse the chosen data set by constructing a vector space model in order to identify semantically similar words in the data set. This paper concentrates on exploring the possibilities of utilising word embeddings in form of word vector representations for the purpose of analysing a very specific data set – a dystopian novel written by George Orwell. This paper analyses not only the quantitate aspects of the resulting word vectors, but also evaluates the results on a qualitative level. The foundations of this research originate in the studies of artificial intelligence and, mainly, natural language processing.

Both studies and their corresponding techniques are applicable in higher education and for purposes of academic curricula – especially in selected courses in information and communication sciences, and computer science, that deal, among others, with various aspects of natural language understanding and generation, computational language analyses, knowledge and information extraction, intelligent machine behaviour etc.

A. Data Set Acquistion and Preprocessing

The experimental data set contained the whole content of George Orwell's well-known novel 1984, which came out in 1949. No other data was added to the data set.

The already preprocessed version of the data set was initially used for the purposes of [10, 11]. The preprocessing step encompassed various tasks – conversion of file format from HTML to plain TXT with UTF-8 character encoding, getting rid of style and text formatting etc. Superfluous and undesired characters were deleted from the data set using regexes. The data set content was then split into sentences or segments (text

lines not ending with a sentence delimiter), tokenised afterwards using custom tokenisation rules, and manually inspected for any potential errors – e.g. orthographic mistakes, various oversights, missing or faulty characters, such as apostrophes, quotation marks, dashes, hyphens, brackets and other punctuation marks and typographic symbols.

Most of the preprocessing was made with the use of Python, Perl, sed and awk. Once the data set was ready, it was used as the input for generating distributed word vector representations.

B. Word Embeddings and Vector Representations

The vector space model [19] represents an algebraic model for the simplified representation of text or its constituent parts in form of vectors.

Word embeddings are a language modelling and feature learning technique. They allow transforming, i.e. mapping of distinct words from a text (so-called vocabulary) into numbers – generally, real numbers [20-22]. This is needed since machine learning algorithms usually rely on numeric values. Namely, such algorithms are limited by the type of qualified or desired input, and usually cannot work with plain text straight away. Using input that is represented by a corresponding vector of continuous values in a predefined vector space is only one of the possible approaches to this problem in natural language processing. But this way the complexity of the text can be reduced to a purely mathematical problem. Not only that this method reduces the dimensionality of the problem [22], it allows to inspect the contextual similarity of vectors [20] – namely, the word context serves as the principal feature in the word representation model. In very low-dimensional vector spaces, the values in a vector can be interpreted right away by humans.

The classical bag-of-words (BOW) [23] approach typically generates enormous and sparse vectors for a textual input, due to the one-hot word representation strategy. Here the vectors' dimensions are determined by the vocabulary size of the textual input, as each dimension corresponds to a separate word. If a word appears in a textual input, the matching value in the resulting vector will be a non-zero value. Besides computational complexity as a result of the large number of dimensions, with BOW there is always a risk of model overfitting, a common problem in machine learning – when a model's prediction performance is very good in a small number of specific situations but terrible in most other cases due to the large amounts of noise that sparse vectors hold. Also, here the vectors are generally unaware of the underlying similarities between words [23].

With word embeddings machines can learn how to create word vector representations, i.e. how to point each word to one specific vector with values that can be inferred from the ways of using individual words. They can preserve the contextual surroundings of a word and, hence, its contextual similarity [20, 21, 23]. Namely, words that appear nearby in a text will also be in close proximity in a vector space [23]. Put differently, words that come from the same or similar context and are utilised in a comparable way can be associated with each other, since they share a similar vector representation, which encapsulates and explicitly encodes their semantic or syntactic similarity, many linguistic regularities, analogies and patterns, or the mutual interrelations of words [24]. Likewise, words that do not share any similarities tend to not share the same context.

That words with similar context share similar meaning is, in fact, not a novel finding. According to the well-known distributional semantics hypothesis in linguistics, "words that are used and occur in the same contexts tend to purport similar meanings" [25]. According to [26], "a word is characterised by the company it keeps". In other words, the ways of using a particular word define its distinct meaning.

Word vectors are low-dimensional dense vectors of fixed length which makes them computationally very efficient due to the low space and time complexity [23]. The fixed length arises from the fixed and limited vocabulary size of a textual input. Each word is illustrated by a relatively small vector with, usually, hundreds of dimensions. This is much lower than thousands and, possibly, millions (or more) dimensions that are needed for sparse word representations like in the BOW model. A huge benefit of the dense representations is generalisation power [27].

Since word vectors are just a numerical representation of contextual similarities between words, they can be treated and mathematically processed just like regular mathematical vectors. For instance, one could measure the vector similarity by calculating the cosine angle between two non-zero vectors, which is called cosine similarity [23]. The cosine of 0° equals to 1, and it is less than 1 for any angle in the interval $(0, \pi]$ radians. So, no vector similarity (similarity of 0) is present at a 90° angle. Total similarity (similarity of 1) is expressed as a 0° angle – those are vectors with the same orientation and complete overlap. Two vectors that are diametrically opposed have a similarity of -1.

In natural language processing, one popular algorithm for generating high-quality word embeddings is word2vec [24]. Word2vec is, in fact, a neural network that is capable of recognising similarities within text and automatically producing a set of vectors [19, 20]. But it is not a deep neural network – it can only build numerical representations that can be interpreted by deep neural networks [20].

The word2vec algorithm uses statistics and linear algebra (calculating dot products in co-occurrence matrices, matrix transposition etc.) to learn word vector representations from textual input [19, 20, 22, 24]. It is able to capture the syntactic and semantic coherences in a language. Each relationship is characterised by a relation-specific vector offset, which allows vector-oriented reasoning based on the offsets between words [28]. If sufficient data and context are provided, word2vec can predict the meaning and associations of words quite accurately.

There are two different models within word2vec used for learning word embeddings – Continuous Bag-of-Words model (CBOW) and Continuous Skip-Gram Model

(CSGM) [19]. CBOW modelling means learning word embeddings for predicting an individual word by observing the word's adjacent context, whereas CSGM works the other way around – for a provided individual word the corresponding neighbouring words (context) are predicted [24]. Both models base their findings on the local context window, which, as a parameter in the model, can be adjusted to the user's specific needs.

The context window size impacts the vectors similarities strongly. Large context windows generate vectors that reflect topical similarities, whereas smaller window context windows tend to produce vectors that exhibit more functional and syntactic similarities [27].

In this research, all of the experiments were done on a multicore machine with a 64-bit operating system, an Intel Core i7 processor (4 cores, 8 threads) and 16 GB of RAM. All available threads were used to train the model in order to decrease training time. The authors constructed a 100-dimensional vector space model, which means that for every word present in the model there were 100 features available. The authors used Python 3, Gensim [29] and word2vec for that purpose. Gensim (short for "generate similar") is a robust open-source vector space modelling and topic modelling toolkit implemented in Python. It was specifically designed to handle large text collections using data streaming and efficient incremental algorithms.

The basis for constructing the model was the preprocessed data set containing George Orwell's novel 1984. The data set was also lowercased in order to avoid multiple versions of the same word. As for the training algorithm, CBOW was chosen. Window context size, i.e. the maximum distance between the current and predicted word within a sentence, was set to 5, meaning that at the same time 5 words were taken into consideration. Words with a total frequency less than 3 were ignored (minimal count). Generating word vector representations has shown to be very CPU-intensive.

Then for every single keyword, chosen freely by the authors, 20 semantically most similar words (identified though word vector representations) from the same data set were extracted. Similarity was obtained by computing the cosine similarity between a simple mean of the projection weight vectors of the given words and the vectors for each word in the model [29]. Afterwards, the authors carried out a detailed manual qualitative analysis on 6 keywords and, in total, 120 words that were unveiled as their most similar corresponding words – 20 words for every chosen keyword. Among the 120 words most of the functional words were ignored during the evaluation phase, as they usually convey very little information and provide limited semantics (meaning) – such as articles, adpositions, auxiliary verbs, conjunctions, interjections, junctions, particles, expletives, pronouns, pro-sentences etc. The remaining content words were then thoroughly analysed.

V. Results and Discussion

Here the authors present and discuss the results of the experiment, as well as its implications. Additionally, the authors point out the various downsides and limitations of the experiment in one of the following subsections.

A. *Results of the Experiment*

At first, the authors chose to obtain word vector representations for 40 keywords in total – 24 were related to the Newspeak dictionary and the Orwellian concept [30], whereas 16 belonged to the general domain. Keywords related to the Newspeak dictionary and the Orwellian concept were: "newspeak", "brother" (refers to "big brother"), "thoughtcrime", "101" (refers to "room 101"), "winston", "party" (refers to "inner party", "outer party", "party members"), "telescreen", "julia", "oceania", "eurasia", "ingsoc", "goldstein", "eastasia", "doublethink", "brotherhood", "vaporized", "oldspeak", "crimestop", "crimethink", "minipax", "minitrue", "duckspeak", "prole" and "speakwrite".

Keywords from the general domain were: "war", "moment", "people", "world", "voice", "word", "free", "freedom", "time", "hate", "love", "youth", "best", "worst", "good" and "bad".

From this base of 40 keywords the authors decided to perform a manual quality analysis on a sample of 6 word vector representations (15%). Those 6 keywords were chosen arbitrarily by the authors, and 5 of them were words related to the Newspeak dictionary and the Orwellian concept: "**newspeak**" – is the fictional language in Orwell's novel 1984; it is "politically correct" speech taken to its maximum extent; "**doublethink**" – refers to reality control; "**winston**" – refers to Winston Smith, the main protagonist that the reader most identifies with in Orwell's novel 1984; "**telescreen**" – refers to a fictional surveillance and communication device, which is operated by the ruling Party in a totalitarian system, in order to keep its citizens under permanent observation; "**julia**" – refers to the fictional character Julia, who pretends to be supporting Big Brother and the ruling Party, but in fact, despises the system; and "**war**".

Fig. 1 shows the 100-dimensional vector representation of the word "newspeak". Since the numbers in the vector are cosine values they can range from -1 to 1.

```
[-0.64516115  0.1579973  -0.18486351 -0.03695639  0.28924885 -0.09498847
 -0.43030658  0.15431975  0.1239115   0.17329243  0.21807285 -0.21267048
 -0.22992504  0.24730667 -0.4451861  -0.04412757  0.31399828 -0.23861146
  0.11274178 -0.70143986 -0.12033968  0.20097078 -0.34433937  0.0200157
 -0.17284475  0.43762085 -0.01585343 -0.16477302  0.13359785 -0.3297498
 -0.27070326 -0.45194244 -0.15027043  0.13564251 -0.31725803 -0.71317255
  0.23994786 -0.06365798 -0.2350698   0.12471341 -0.33628556 -0.45893794
  0.0239193  -0.01461021  0.7949769  -0.1963934  -0.38624054 -0.18512818
  0.00129966 -0.09555561  0.23405671  0.32197502 -0.04406496 -0.14301962
 -0.06501128 -0.10083073  0.1285449   0.08399501  0.19720553  0.0606354
 -0.22448681 -0.557067   -0.22160476  0.06177633  0.534892   -0.1717653
 -0.567688    0.5929364  -0.14680988  0.78627753 -0.09622003  0.00605357
  0.31533802  0.21695644 -0.5902365  -0.2347756   0.32014322  0.29467028
  0.2876221  -0.18719622 -0.44544363  0.37007272 -0.09240708  0.4406842
  0.20087402  0.22351162 -0.23393816  0.18165983 -0.05705923 -0.2805166
  0.6086521   0.2634202  -0.28903696  0.18512465  0.01641486 -0.09391
  0.06074792  0.06188582 -0.26275593  0.47158718]
```

Figure 1. Vector representation of the word "newspeak".

The results of this research have shown some interesting correlations between the selected words.

The word "newspeak" can semantically be associated mostly with the word "power". Newspeak, the fictional language used by the characters of the novel, is the official language of Oceania. It is based on standard English, with words describing "unorthodox" political ideas removed. It is the principal means of the totalitarian ruling Party to retain power, through the control of language. In this context, the correlation between "newspeak" and "power"

is very precise. Fig. 2 shows the top 20 words that are most similar to the word "newspeak". All words are ranked according to semantic similarity (vector similarity).

```
newspeak
[('power', 0.9998126029968262), ('place', 0.9998035430908203),
('itself', 0.9998026490211487), ('after', 0.9997938871383667),
('also', 0.9997918605804443), ('every', 0.9997901320457458),
('who', 0.9997891783714294), ('still', 0.9997843503952026),
('except', 0.9997826814651489), ('being', 0.9997739195823669),
('people', 0.9997645616531372), ('great', 0.9997643828392029),
('upon', 0.9997624158859253), ('somewhere', 0.9997613430023193),
('work', 0.9997608065605164), ('love', 0.9997607469558716),
('life', 0.9997593760490417), ('war', 0.9997585415840149),
('use', 0.9997546672821045), ('hours', 0.9997512102127075)]
```

Figure 2. Words most similar to the word "newspeak" (according to vector similarity).

The word "doublethink" is semantically connected mainly with "proles". Doublethink is the power to hold two completely contradictory beliefs in one's mind simultaneously, and to accept both of them. "Proles" are proletarians, ca. 85% of Oceania's population. Although not as closely and rigidly observed as members of the Party, proles, as it is stated in the novel, were taught to be inferior through the principles of doublethink.

The word "winston" predominantly corresponds to the word "julia". Winston Smith and Julia are the two protagonists of the novel and tragic lovers. Their relationship is precisely shown on the semantic level.

The word "telescreen" is primarily related with the adjective "white", but amongst others, also with the words "table", "floor", "street", "front", "bed", "down", "middle", "out" and "body" giving a sense that the telescreen, a two-way television and tool of control by the Party, is always unavoidably present.

The word "julia" is mostly linked with the word "it", but second by similarity is the word "winston", which confirms their relationship also on the semantic level, as with the previous example of the word "winston".

The word "war" is most closely affiliated with the word "newspeak". The Orwellian concept of an ongoing war correlates well with that of the Newspeak language, as the two concepts are the two means of control by the Party, and this is also confirmed on the semantic level.

B. *Downsides of the Experiment*

The disadvantages and shortcomings of the experiment are highlighted in this subsection. As the authors chose to use all of the unoccupied CPU power (8 threads) in order to increase the training speed, Python's *seed()* functionality was, unfortunately, not available due to the limitations of Gensim and controlling hash randomisation [29], and the problems with thread scheduling in common operating systems. Seed is essential for the initialisation of the random number generator and, hence, for the initialisation of vectors for each word with a hash of the concatenation of a given word and the seed value [29]. Using *seed()* would allow to exactly and fully deterministically reproduce all of the experiments with the vector space model, which is not the case with this research.

Nevertheless, the authors undertook many training runs, and the differences in the resulting vectors were not significant. Only slight modifications were observed, mostly changes in word ranking within vectors – but, semantic similarity, when seen in general, was not altered considerably.

VI. Future Research

The authors plan to significantly increase the dimensionality of the word vectors and analyse the impact on the word vector representations, in form of a cost-benefit analysis (consumption of CPU power, model training time and performance, memory requirements etc.). This should result in additional generalisation power.

Furthermore, the plan is to increment the data set with additional dystopian texts (novels) in order to increase the data set size. It would also be interesting to inspect what exact words contribute positively, and what negatively to the overall word vector similarities. The authors also plan to increase the context size (context window), and the minimal number of word occurrences that should be considered during the process of generating word vectors.

Furthermore, experiments with the Continuous Skip-Gram Model (CSGM) and evaluating the performance differences between the hierarchical softmax and negative sampling approaches should be carried out [24]. The possibilities of the related doc2vec algorithm should also be investigated [23]. Algorithms for vector visualisation, such as the t-Distributed Stochastic Neighbor Embedding (t-SNE) [31], should be tested as well. Alternative models, such as GloVe (Global Vectors for Word Representation) and Facebook's fastText should also be applied on this data set. GloVe trains on global word-word co-occurrence counts and makes efficient use of statistics [32], whereas the main improvement of fastText over the original word2vec implementation of vectors is the inclusion of character n-grams [21], which allows computing word representations for words that did not appear in the training data (OOV, "out-of-vocabulary" words).

The authors would also like to examine the *seed* functionality with regard to the cost of training speed and make the generated models freely available online in order to enable experiment reproducibility. Source code could possibly also be rewritten to allow experimenting without lowercasing, with lemmatisation, and implementing stop words and lexicons of function words for filtering purposes.

VII. Conlusion

Word vectors representations are just one of the many possible approaches to computationally representing words. In order to analyse George Orwell's novel 1984 on a semantic level, the authors chose to build a 100-dimensional vector representation model from the novel's content, which preserved the relations between the words and its contextual similarities. This approach was chosen due to the fact that words with similar meaning often have similar word embeddings in form of word vectors. This method has shown to have the potential to be applied for studies of literature, in academic curricula and other fields of higher education. For instance, students could investigate a literary work and gain valuable knowledge about it only through the observation of semantically most

similar words identified through word vectors, and without using any other external resources. Students could then, without having any prior knowledge of the literary work, study the internal connections, the work's narrative (time and space), language and style, the context and meaning of individual words or (fictional) characters within a literary work and, therefore, try to summarise its key concepts on a semantic level.

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Using robots to master simple mathematical assignments

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***Abstract* - In this paper, an educational robot-scanner for solving simple mathematical assignment is presented. The robot: (i) scans the mathematical assignment that consists of three characters: two one-digit numbers and a mathematical operation, (ii) recognizes the numbers and the operation using optical character recognition, and (iii) gives the solution. The robot-scanner was designed and programmed using MATLAB and LEGO Mindstorms EV3. The scanner can be used by secondary school students for teaching them basics of mechanics and programming. Further, it can be used for encouraging interest in mathematics and robotics for pupils. After solving the assignment by their own, they can check their solution using the robot-scanner.**

Keywords - LEGO Mindstorms EV3; optical character recognition; central moments; pulley wheels; educational robotics

I. INTRODUCTION

In this paper, we propose a design of the Lego robot that scans an easy mathematical assignment and gives the solution. Robot can be used within two target groups: (ii) secondary school students to demonstrate basics of mechanics (e.g. converting rotational motion into linear motion), programming and data science (using Matlab), and (i) young pupils with the aim of increasing interest in mathematics using modern technology.

As an educational tool, robots are commonly used in teaching programming [1][2][3], science and physics [4][5][6], a second language [7][8], and mathematics [9][10][11]. The main principle that is used is the movement of the robot: e.g. for teaching concepts of rotation and transformation [9], to interpret angles and geometry [10], or symmetry and basic calculus [12]. We will present new model of the robot that can be used as an additional educational tool in promoting math to the first graders and in promoting engineering to older students.

This paper is organized as follows. Section 2 describes robot design and Section 3 describes program of the robot. An example of using the robot with the students is given in Section 4. Conclusion is given in Section 5.

II. ROBOT DESIGN

The goal is to design a robot that can scan area 200x150 mm where an easy mathematical assignment is written using black color. After the scanning, the robot recognizes the mathematical assignment and gives the answer. The assignment consists of two one-digit numbers and a mathematical operation (plus or minus) between them. All symbols are of the same font and the same size (Fig. 1).

The central part of the robot is Lego Mindstorms EV3 Brick [13] (Fig. 2). The Brick is a programmable computer with 4 inputs and 4 outputs, ARM 9 processor, 64 MB RAM, 16 MB Flash and 178x128 px display. It communicates over USB, Wi-Fi and Bluetooth. The Brick is responsible for the whole scanning process since it manages all motors and sensors.

The scanning is carried using color sensor which measures the intensity of reflected or ambient light and can detect eight colors. Sampling rate of the sensor is 1 kHz. To achieve the best accuracy, the color sensor must be placed vertically, close to the viewed surface, without touching it.

The touch sensor is used as an edge detection sensor. It detects when its front button is pressed, released or bumped.

Two large motors are used for moving the robot between rows (forward and backward), i.e. longitudinal robot movement (Fig. 3). The large motor runs at maximum speed ω_{max} = 160-170 rpm, with a running torque of 20 Ncm and a stall torque of 40 Ncm [14].

The medium motor runs at ω_{max} = 240-250 rpm, with a torque of 8 Ncm and a stall torque of 12 Ncm [14]. It is faster but less powerful than the large motor. The medium motors are used for left-to-right moving of the color sensor during the scanning process, i.e. transversal robot movement.

A square *stroller* contains the color sensor. It slides on a rectangular construction called *tracks*. A single touch sensor is attached on each end of the *tracks*. The touch sensors are used to register when the *stroller* reaches the starting and the final scanning position. The medium motors are mounted on the outer sides of the *tracks*. In this way, the weight is effectively distributed on each end of the *tracks* and the *stroller* achieves a straight movement. In order to improve stability and balance, a steel ball is placed in the middle of the robot configuration. To reduce vibration and to gain certain construction rigidity, white Lego plates are placed along the robot (Fig. 4).

The normalized speed of large and medium motors is a number that ranges between -100 and +100. The speed

selected from this interval represents a percentage of the maximum angular velocity in revolutions per minute (rpm):

$$\omega = \frac{\omega_n}{100} \cdot \omega_{max}, \quad (1)$$

where ω_{max} is the maximum motor angular velocity, and ω_n is the selected normalized speed. Our robot scans with normalized speed of the medium motors ω_n = 15, thus its angular velocity is ω = 15/100 · 250 rpm = 37.5 rpm. While retrieving the sensor to its starting position, the normalized speed of the medium motors is -35. The negative sign represents the rotation in the opposite direction. At the same time, the robot moves itself longitudinally at a speed of the large motors ω_n = 20.



Fig. 1. Mathematical assignment.



Fig. 2. Basic elements of the robot: EV3 Brick, Color sensor, Touch sensor, Large motor and Medium motor.

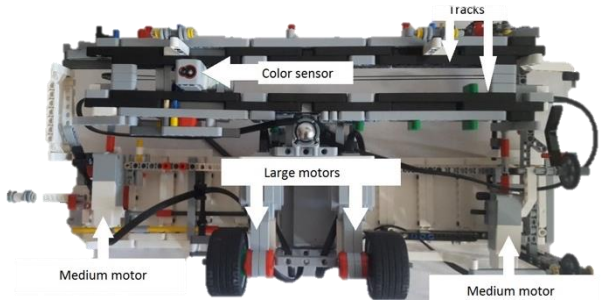

Fig. 3. Bottom side of the robot.

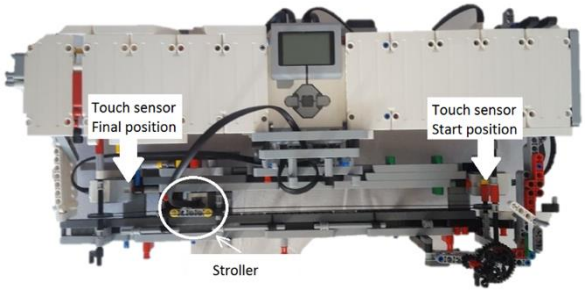

Fig. 4. Upper side of the robot.



Fig. 5. Lego medium pulley wheel.

A. *Transversal robot movement*

Scanning the width of the assignment is achieved by converting the rotational motion of the medium motors to the linear motion of the *stroller* on the *tracks*.

The simplest solution to this kinematic conversion is to use a gear rack and a gear. Since the Lego gear rack is only 30mm long while the width of the scanning area is a = 200mm wide, 7 gear racks are needed. That exceeds available number of gear racks. Consequently, this conversion is performed using two Lego medium pulley wheels with radius r = 11mm (Fig. 5). Each pulley wheel is connected to one medium motor. They are mutually connected with a rubber band.

The radius of the rubber band in ideal case is given by $r_{rb} = 0.95 \cdot (r\pi + a)/\pi = 71\text{mm}$, where a is the width of the mathematical assignment. The decrease of 5% is necessary to avoid excessive tightening and stretching of the rubber on the pulley. However, the requested rubber band was not available. Instead, the most similar available rubber is used, with the radius of 60 mm which causes significant tension. This difference causes stochastic tightening and stretching that accelerates the *stroller*.

Several possible constructions of *tracks* were taken into consideration:

1. Binding the pulley wheels with a tight string or a thread. A slipping problem can stochastically occur and greatly disrupt the scanning process. Hence, this method is discarded.
2. One pulley is attached to the shaft of the medium motor (a drive pulley) while the other pulley is fixed, without the motor, on the opposite side of the *tracks* (a driven pulley). In this scenario, while returning from the final scanning position, the medium motor stretches the rubber band on the driven pulley. As a result, the *stroller* sometimes does not return to the start position.
3. Both pulleys are connected to mobile shafts, but with only one of them connected to the medium motor. Stochastic stretch still occurs during the returning the *stroller* from the driven to the drive pulley. This stretching time is approximately 0.21s depending on the power developed by the medium motor. This time delay causes problems during programming and execution of the scanning process, e.g. the *stroller* is incapable of scanning the entire width of the mathematical assignment.
4. Finally, by mounting both pulley wheels to the medium motors and simultaneously starting them as drive pulleys, the stretching is minimized. Thus, we accept this construction solution.

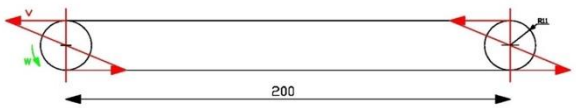

Fig. 6. Movement of the pulley wheels. Red arrows represent tangential velocity.

An additional construction problem occurs with Lego cables that connect sensors with the EV3 brick. The cable for the color sensor lifts the sensor and disturbs its linear movement. Moreover, the rubber band fails to overcome the stiffness of the Lego cables and is further stretched. By accepting the design solution with two drive pulley wheels and by reinforcing the *tracks* on both sides, the impact of the Lego cables is minimized.

The pulley wheels rotate counter clockwise (Fig. 6), with angular velocity ω, given by (1). The *stroller* exhibits a linear motion with its velocity equals to the tangential velocity of the pulley wheels:

$$v = \omega \cdot 2\pi r. \quad (2)$$

Given velocity is also scanning speed. We use normalized speed ω_n = 15 and ω_{max} = 250rpm, thus the scanning speed is v = 2591.8 mm/min = 43.2 mm/s. In each scan, the *stroller* makes a path of approximately 200 mm. Therefore, the scanning time for each row equals to 4.63 s. The actual scanning time is obtained experimentally and amounts 3.75 s, due to the previously mentioned construction problems. Consequently, this problem will reflect on the scanned image.

While returning to the start position, the pulleys rotate clockwise giving the linear velocity to the *stroller* of -100.8 mm/s.

B. Longitudinal robot movement

Longitudinal movement along the height of the mathematical assignment is realized through the large driving motors and associated wheels with radius 27.5 mm. If $\omega_n = 20$ and $\omega_{max} = 160$ rpm, the actual angular velocity given by (1) is ω = 32 rpm and linear tangential velocity of the whole robot-scanner given by (2) equals to v = 92.2 mm/s.

Each longitudinal movement is set to 0.03 s. This time makes shifts long enough to generate a precise scanned image of the mathematical assignment. Each shift is equal to $s = v \cdot t = 2.76$ mm. Due to the imperfectness of the system, the shifts are rounded to 3 mm.

Since the height of the mathematical assignment is 150 mm and each shift is 3 mm, 50 iterations are needed to scan the whole assignment. Consequently, the scanned image will have 50 rows.

C. Scanning process

Described robot design allows scanning of the easy mathematical assignment using the following procedure:

1. Medium motors are activated at the same time in the counterclockwise direction at the normalized speed of ω_n =15. Scanning is performed with the 3.75 s scanning time.
2. The large motors and the entire robot move longitudinally for 3 mm at the normalized speed of ω_n =20.
3. Medium motors move clockwise at the normalized speed of ω_n = -35 to bring the *stroller* back to the start position.
4. When the touch sensor registers that the *stroller* is on the starting position, the middle motors are reset to the normalized speed of ω_n =15 and the entire procedure is repeated from step 1.
5. The scanning process is completed when the large motors pass through the entire height of the mathematical assignment, i.e. after 50 iterations.

III. Robot Programming

Robot moving, scanning and optical character recognition of the scanned calculus equations is developed in MATLAB using commands from MATLAB® Support Package for LEGO® MINDSTORMS® EV3 Hardware [15].

A. Scanning algorithm

The robot movement and scanning process is mutually interwoven. Each reading of the color sensor represents an element of an intensity matrix. The color sensor is used in its Reflected Mode. It uses the light of its own LED and measures the reflected light of the LED from the surface. Measured values are between 0 and 100, where 0 means no reflection (completely black), and 100 means completely white.

Color sensor scans one row at a time, during clockwise rotation of the medium motors. The sampling time, i.e. the time between two readings of the color sensor values, is fixed to 0.05s. Therefore, samples are stored in the intensity matrix with 3.75/0.05=75 columns. Due to the longitudinal movement, the intensity matrix has 50 rows.

Further, execution of the scanning commands adds extra 0.0232 s to the scanning time of each row. Since the sampling time is of the same order, additional samples are generated. Although an expected number of samples is 50x75=3750, the scanning process can generate up to 3776 samples. This additional samples are placed at the beginning of the next row. Resulting intensity matrix is given in Fig. 7a. To solve this problem, the extra time is forcibly subtracted from the scanning time giving the final intensity matrix (Fig. 7b).



Fig. 7. (a) Intensity matrix with too many samples, and (b) final intensity matrix.



Fig. 8. Binary intensity matrix.

B. *Optical character recognition*

Optical character recognition applied in this work consists of the following steps:

1. Preparation of a binary intensity matrix,
2. Division of characters,
3. Calculation of central moments, and
4. Character recognition.

First step is the transform of the intensity matrix into binary intensity matrix, where 0 represents black and 1 represents white. Threshold depends on the light conditions and needs to be calibrated before each scanning (Fig. 8).

For easier optical character recognition, the binary intensity matrix is divided into three smaller matrices, each containing only one character: two matrices with one-digit number and one matrix with a mathematical operation. The matrices are considered one at a time using central moments [16]. If (*x*,*y*) denotes position of a pixel in binary intensity matrix I, the image moments are:

$$m_{pq} = \sum_{(x,y)} x^p y^q , \qquad p \geq 0, q \geq 0. \tag{3}$$

Matrix I consists of m_{00} pixels. Its center of the mass is $x_c = m_{10}/m_{00}$, $y_c = m_{01}/m_{00}$. Two orders central moments are defined by:

$$\mu_{pq} = \sum_{(x,y)} (x - x_c)^p (y - y_c)^q , \qquad p \geq 0, q \geq 0. \tag{4}$$

The central moment is translation invariant, therefore $\mu_{01} = 0$ and $\mu_{10} = 0$. Moments μ_{02} and μ_{20} are moments of inertia and μ_{11} is a moment of product. They are used to distinguish characters. If the central moments have similar values, it is not possible to distinguish the characters. Therefore, each character is divided into 8x8 parts and the central moments are calculated for each part. The results are stored in central moments matrix (Fig. 9).

In fourth step, the central moments matrix is compared to already stored matrices containing one-digit number masks (Fig. 10). Comparison is done by multiplying the central matrix with inverted number mask. The product that contains the most zeros has the largest probability of being the best match, i.e. being the scanned number.

$$\begin{bmatrix} 0.02 & 2.54 & 2.24 & 2.54 & 2.24 & 2.54 & 2.24 & 0 \\ 0 & 0.05 & 0.04 & 0.04 & 0.04 & 0.16 & 2.24 & 1.81 \\ 0 & 0 & 0 & 0 & 0 & 0.03 & 2.25 & 2.43 \\ 0 & 2.14 & 1.89 & 2.11 & 1.89 & 2.40 & 2.24 & 0 \\ 0.02 & 2.54 & 0.23 & 0.15 & 0.14 & 0.15 & 0.14 & 0 \\ 2.32 & 2.55 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2.24 & 2.54 & 0.43 & 0.03 & 0.04 & 0.04 & 0 & 0 \\ 2.25 & 2.55 & 2.25 & 2.55 & 2.25 & 2.55 & 0.01 & 0 \end{bmatrix}$$

Fig. 9. Central moments matrix for character “2”.

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

Fig. 10. Number mask for number “2”.

Final part of the whole process is calculating the given mathematical assignment. The result is presented on a computer desktop.

IV. EXAMPLE

The robot was tested as part of the motivational exhibition at the University of Zagreb Fair 2017 to engage potential future students (Fig. 11). The aim of the University of Zagreb Fair is to show curricula, undergraduate, graduate and postgraduate studies, equipment of each faculty, achievements in scientific areas and places for employment in certain professions. More than 80 faculties, colleges, universities and study programs were presented by their students and employees [17]. The robot-scanner was used as the exhibit for the Faculty of Electrical Engineering and Computing.

During the Fair, the following observations have been noticed: (i) primary school pupils were briefly intrigued by the very appearance of the robot itself and (ii) secondary school students, who were the target group of the Fair, were fascinated and intrigued by the way the robot works. Since the goal of the robot was to attract the students for the mathematics, robotics, programming and engineering, the robot-scanner fulfill its role.

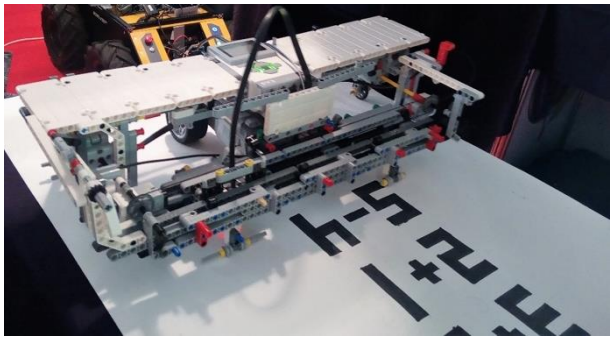

Fig. 11. Robot was an exhibit at University of Zagreb Fair 2017.

V. CONLUSION

In this paper, we presented a robotic scanning tool with optical character recognition for solving simple mathematical assignments. The robot is made from LEGO parts, Mindstorms EV3 Brick, motors and sensor, and programmed with MATLAB. In spite of its technical disadvantages caused by construction limitations, the robot-scanner has successfully fulfilled its task and gained the interest of its target audiences.

Future work and progress on the robot-scanner can be made in these areas: (i) improvement of the robot itself. Specifically, to upgrade the robot so that it is capable to write the solution on paper or to print it on the Lego display, or (ii) creating a more approachable robot-scanner, which can be used in workshops with students. Simpler version, with less LEGO elements and easier programming environment can emphasis knowledge in physics and mechanics.

ACKNOWLEDGMENT

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Towards a justified choice of gamification framework when building an educational application

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***Abstract* - Gamification has been a leading global phenomenon since 2010 and represented in a variety of domains including education. Yet whether the application of game elements in non-entertaining contexts is effective, still sparkles an ongoing debate which aims to be solved by the application of gamification frameworks. A gamification framework analyses the core drives in human motivation in a system that can be easily applied to produce an effective strategy for successful implementation of gamification. On our journey to design and develop an educational application, implementing game design elements, that supports university students enrolled in a Web development course, we analyzed a variety of gamification frameworks in order to define the right one for our needs. In this paper, we present an in-depth analysis of the different gamification frameworks, leading towards a justified choice in the context of our research. Outcomes of our study and a work-in-progress implementation of the educational application are also summarized.**

Keywords - Gamification framework, Gamification in education, Game design elements, Web design and development

I. INTRODUCTION

Games have been an integral part of human cultures and essential social interaction since the ancient past and represented in various forms. Later with the introduction of video games during the 20th century, mainstream popularity was gained and video gaming established itself as a preferred form of entertainment and a crucial part of modern culture. Yet with the evolution of the gaming industry supported by the adoption and usage of social media and mobile technologies, games are present in our everyday lives. That's why it's essential to identify the possibilities to use this environment or specific parts of it as a source for engaging experience in different contexts.

Gamification has been a leading global phenomenon since 2010 and represented in a variety of domains including education. Due to the broad area of applications, a common and popular definition is the usage of game design elements in non-game contexts [1]. However, due to the various and intertwined disciplines and vast adaptations and definitions that are framing gamification, recent researches suggest that the concept and its modern technological implementations are still young, evolving and adapting. In today's digital world and emerging technologies, a gamification can have a complex entity and higher levels of abstraction in a way that it can be a process, a service, an experience, a product, a system or all at once [2].

From a marketing perspective, gamification has its roots in the past century with the introduction of the retailer loyalty programs, aiming to engage and motivate individuals, eventually turning them into loyal customers. Nowadays, it's a common practice to gather a digital version of certain points on purchases and later redeem them for discounts on products or services, or other user-related benefits.

Apart from the various definitions, the implementation of gamification approaches in different domains has increased in the last years, becoming an emerging and promising trend. Yet whether the application of game elements in non-entertaining contexts is effective, still sparkles an ongoing debate as researches suggest that a clear design strategy is the key to successful gamification [3]. A gamification design and frameworks analyze the core drives in human motivation in a system that can be easily applied to produce an effective strategy for successful implementation of gamification.

The main goal of this paper is to identify the right gamification framework that can be applied when designing and developing an educational application that supports university students enrolled in a Web development course. Therefore, we decided to structure the paper as follows. First, we introduce some general concepts, key differences, and rules related to game design elements, gamification design elements, gamification of learning and game-based learning in Section II. In Section III, we focus on developing an in-depth analysis of the existing gamification frameworks as we reference recent studies, define methodologies and concentrate on the existing gamification design frameworks which can be applied in the context of our research. Finally, in Section IV, we propose an approach for implementing gamification design elements in an educational application, based on the researched frameworks and introduce a work-in-progress, together with summarized outcomes of our study.

II. GAME DESIGN VS. GAMIFICATION DESIGN - GENERAL CONCEPTS AND THEORETICAL BACKGROUND

A. General concepts

Game design is a popular concept in game studies and involves not only the process of creating the art, but also

defining the game system and applying the rules. It works as a system directed towards a gameplay, with entertaining outcomes. On the other hand, gamification design elements are game-like elements that are applied for the sole purpose of enhancing the engagement in different contexts. This outlines the main distinctive feature between the two concepts, namely that the first is designed for fun, and the second – to meet certain objectives.

The application of gamification in the domains of learning and education has a promising potential not only because it can enhance motivation and increase the retention levels but also shape desired behavioral objectives and performance metrics, and further deepen the engagement of the students with the subject matter.

Gamification of learning, game-based learning and serious games, although similar etymologically, are distinctive concepts and approaches. In Section I we introduced the widespread and accepted definition of gamification but we also highlight the fact that it's still a young and evolving concept. Yet in the context of our research, it's important to differentiate the corresponding terms and enhance our overall understanding of the matter. While gamification uses elements from game design in non-game environments, serious games are often referred to as immersive learning simulations or gaming simulations [4]. They are games designed with the core purpose to improve learning while playing but their objective is not entertainment. In most scenarios, serious games describe and simulate real-life situations that when played and executed are preparing the players to handle that in reality. Serious games find application in the field of military training, healthcare, formal and corporate education, and many others. Game-based learning, on the other hand, is used to enhance the learning experience by implementing digital games in the learning process with the primary objective to achieve specific pedagogical goals and outcomes [5].

B. Theoretical background

When it comes to designing a game, although there are different approaches shared in literature from a theoretical perspective, a set of game design fundamental principles is proposed by Salen and Zimmerman (2014) which suggests that the process should follow an iterative design methodology as shown in Figure 1 and described below [6]:

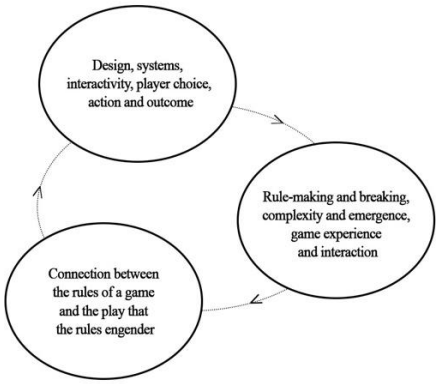

Figure 1. Game design fundamental principles

- Understanding design, systems, and interactivity, as well as player choice, action, and outcome.
- Including a study of rule-making and rule-breaking, complexity and emergence, game experience, game representation, and social game interaction.
- Adding the powerful connection between the rules of a game and the play that the rules engender, the pleasures games invoke, the meanings they construct, the ideologies they embody, and the stories they tell.

Game design should also be approached in a way to identify the smallest parts of a game, often referred to as atoms, and it's necessary to set an understanding of what these parts are and how they interact in order to design or analyze a complete game [7]. This necessity leads to the development of Mechanics – Dynamics – Aesthetics model, which later turn to become one of the very first formal frameworks trying to conceptualize the approach to understand games and attempting to bridge the gap between game design and development, game criticism, and technical game research [8]. The framework would be presented in details later in Section III.

On our journey to design and develop an educational application, implementing game design elements, that supports university students enrolled in Web development course, we also stumbled upon a similar approach. In the context of designing and developing a web, mobile or universal application, the concept of atomic design or atomic approach is often used as a way of creating and maintaining effective coherent design systems. Atomic design is a methodology composed of five distinct stages working together to create interface design systems in a more deliberate and hierarchical manner [9].



Figure 2. Five stages of atomic design methodology

Another popular process that is often suggested when approaching or implementing gamification is the usage of user-centered design philosophy.

Some sources suggest that there's a difference between the user-centered and human-centered approach in the scope of human-computer interaction (HCI) and the design of information systems (IS). Yet in the context of this paper we would refer to the human-centered approach as a philosophy that puts the users (players) and their goals, at the center of the design and development process, in comparison to function-focused or data-driven which refer to efficient and result-oriented activities [10]. The human-centered approach is opposed to the traditional, technology-oriented approach, which prioritizes computer-based information processing and technology-

mediated communications over humans and their communicative collaboration [11].

III. GAMIFICATION FRAMEWORKS

In Section II, we introduced some general concepts and key differences between game design elements and gamification. We can conclude that gamification as a concept has a complex definition and gathers various and intertwined disciplines under one hat, including game design and theory, user interface and system design, computer and software engineering, psychology and more.

In order to understand better the concept of a gamification framework, namely in the way that it analyses the core drives in human motivation in a system that can be easily applied to produce an effective strategy for successful implementation of gamification, our research would focus on the established gamification frameworks existing in literature with focus on their main features.

A. MDA framework

The MDA framework is one of the first basic formal frameworks trying to conceptualize the approach to understand games. It puts emphasis on the fact that games, in comparison to other entertainment activities, have relatively unpredictable consumption, which makes them a preferred medium. It suggests that games can be broken down into three levels of abstractions main components – mechanics (rules), dynamics (system) and aesthetics (fun), as [8]:

- Mechanics are the particular components of the game, at the level of data representation and algorithms.
- Dynamics are the run-time behavior of the mechanics acting on player inputs and each other outputs over time.
- Aesthetics are the desirable emotional responses evoked in the player when they interact with the game system.

The MDA framework also shapes the one-way connection between the three abstractions, approached both from the game creator's and player's perspective as shown in Figure 3:

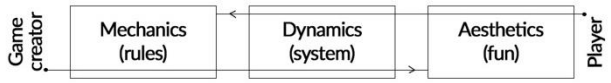

Figure 3. MDA framework abstractions

As is seen on the figure, the creator constructs the functions and develops the features (mechanics) of the game, which produce different types of interaction and behavior (dynamics), and this leads to particular player emotions and experiences (aesthetics). The player, on the other hand, formulates their experiences based on the aesthetics and they engage in specific activities based on that [12].

B. MDE framework

Being one of the first frameworks for gamification puts the MDA framework at a starting point of a gamification research. Through the years, the framework has been modified by different authors and it was grounding the foundations of either adaptations or extensions, in order to fit different contexts.

One of the modifications was the MDE framework. The MDE stands for Mechanics – Dynamics – Emotion model. As obvious from the title the aesthetics abstraction was replaced with emotions. Robson et al. (2015) suggest that aesthetics describes the desirable emotional responses (as fantasy, fellowship, or other) evoked in game players when they interact with the game, which makes them more relevant to specific game context but not for gamification design as gamification is not a game [13]. In that context, emotions as an abstraction are more related to the engagement outcomes.

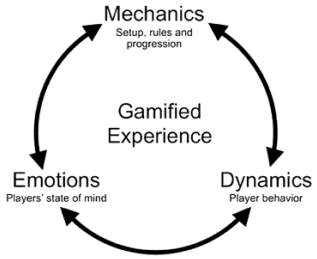

Figure 4. MDE framework abstractions by Robson et al. (2015)

To summarize, the MDE framework outlines the interdependent relationship of the gamification principles of mechanics, dynamics, and emotions, and how these principles relate to one another as the key for successfully gamifying an experience [13]. This is also one of the distinct features that differentiate the MDE framework from the MDA framework that has a one-way relationship and the different components don't affect each other as shown in Figure 4.

C. 6D framework

The 6D gamification framework has a business background and conceives the following approach to gamification [14][15]:

- Define business objectives – this step puts emphasis on the fact that the specific application goals have to be well-defined, for example: "Teach the concept of a basic HTML structure ";
- Delineate target behavior - specify the tasks that the users must perform and metrics to assess these tasks, for example: "Increase students' motivation through exercise";
- Describe your players - define the known characteristics about the players, demographic, age groups or behavior types, for example: "Students, no previous experience in Web development";

- Devise activity loop - specify the tasks that students should repeat to keep them engaged and to progress their skill level;
- Don't forget the fun - after specifying goals, the tasks, the players and their behaviors, the authors recommend to review the application and see if the goals of creating something fun is still on focus;
- Deploy appropriate tools - based on the previous steps apply the necessary mechanics, metrics, and tools that focus on the target player and the application goals, for example – what Point-Badge-Leaderboard (PBL) systems would be integrated, what and how achievements would be unlocked, how the avatars would be customized and other;

D. GAME framework

GAME framework is a simpler framework for gamification design process [16]. The name of the framework is an abbreviation of the four main stages proposed:

- Gather information by asking – at this stage the following questions should be answered: "What are you gamifying?", "Why are you gamifying it?", "Who are you gamifying it for?", "How is success measured?", etc.;
- Act – After the information from the first step is collected actions towards design should be made, depending on the goals, engagement, experience of the users, and then everything should be tested;
- Measure – Measure the users' performance and the outcomes, and how they relate to the goals from the previous step. This feedback should be used for iteration and improvements.
- Enrich - the system should be enriched over time, following an iterative path (new challenges, engaging content).

E. Octalysis framework

Octalysis framework is a complete gamification framework, proposed by Yu-kai Chou [17]. From the author's perspective, the gamification is a design that places the most emphasis on human motivation in the process.

The framework itself focuses on a Human-focused design, instead of Function-focused design to achieve results quickly. The author, having a strong background in game mechanics, suggests that there are eight different types of core drives that motivate us to engage in certain activities. The approach he proposes is based on an octagon shape with eight core drives represented on each side: epic meaning and calling, development and accomplishment, creativity and feedback, ownership and possession, social influence and relatedness, scarcity and impatience, unpredictability and curiosity and loss and avoidance. The core drives push us in different directions as not everybody is motivated by the same drive.

Visually, the Octalysis framework has a shape of an octagon where the core drives are represented in each corner as shown in Figure 5.

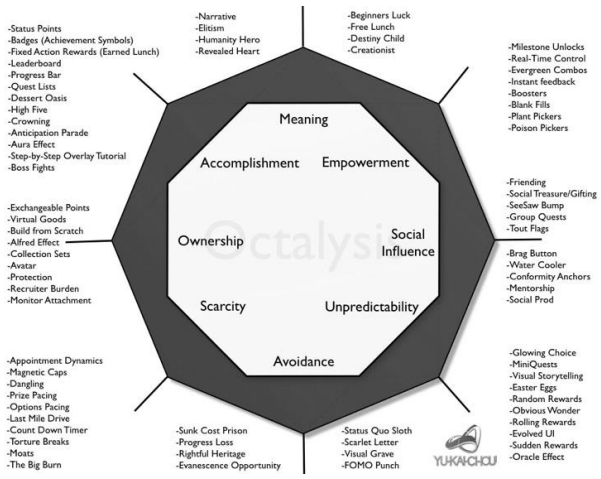

Figure 5. Octalysis framework as proposed by Yu-kai Chou

He also suggests other approaches to understanding the framework, namely dividing the drives, as these on the right side represents the creative, artistic and social aspects, while these on the left side represents the logical and intellectual aspects. Moreover, he emphasizes the importance of understanding that these drives favor either extrinsic or intrinsic motivation. The key point in this framework is that it's not necessary for an application to possess all core drives to be successful.

F. Other frameworks

In recent systematic research on gamification design frameworks, out of 2314 unique works initially, Mora et al. (2017) analyze a definitive list of 40 works, after applying a systematic filtering process [18]. Apart from the fact that some frameworks are based on or extend the proposed ones, the research also introduces hybrid versions. Some key outcomes from that research are:

- A clear predominance of gamification design frameworks in a business context, with less available research concerning generic, learning and health frameworks;
- Most of them are conceived as user-centered designs;
- From a logical point of view - extensive importance is given to the engagement loop;
- Measuring also seems to be a critical issue for gamification and the majority of the frameworks explicitly refer to the use of analytics and the importance of data collection;
- The psychological perspective presents a high relevance in almost all of the frameworks, as a key element that must be present in the design process;

- Interaction fundamentals are also extensively referred to, emphasizing gamification as user experience in itself. The need or desirability of developing software taking into account the possibilities provided by digital environments is also extensively referenced;
- Additionally, a closer relationship between the principles and elements of game design and gamification has been shown. Moreover, the results have revealed the heterogeneity of the analyzed frameworks, from a highly theoretical objective through to conceptualization, including the perception of gamification from different contexts and areas of interest;

Considering the above, we would propose an implementation of gamification design elements in an education application in the next section, based on the background in Section II and the analysis in Section III.

IV. Implementation of Gamification Design Elements in an Educational Application

A. Why should we use gamification in web development course?

In order to answer this question, it's important to understand the current state of the World Wide Web or the Web. Today's web pages have nothing to do with the 1989 version of Tim Berners-Lee invention. And not because something drastically changed, web pages are still documents supported by other web resources, interlinked by hypertext links and accessed via the Internet. But the web pages built back then served one basic purpose – to provide a simple and yet effective way of creating, sharing and connecting documents with information together.

Yet with the expansion of the Internet, together with the hardware advancements, rise of social media and content creation, the Web also evolves rapidly. This fact affects not only the coding techniques and web development approaches, but it also forces the introduction of new concepts as "grids", "responsive design", "mobile-first", "CSS pre-processors", "progressive enhancement", "unobtrusive JavaScript" and many more. This progress puts a lot of challenges in terms of how to teach effectively web technologies to the students and constantly adapt the classes when introducing new techniques in the curriculum.

That's why we consider that the presence of a tool that can enhance the learning process in a non-obtrusive way, and even better – possessing and implementing a gamification approach would be beneficial.

B. Current generation

Current Generation Z (Gen Z) is perfect to conduct our research as it refers to the students born in the early to mid-1990s up through 2010, that grow up in an environment exposed to technological progress, Internet and the rise of social media. In order to plan and implement creative and engaging teaching strategies that maximize the retention of the students, it's important to understand how Gen Z perceives and processes information.

Some distinctive characteristics of Gen Z in terms of socialization and learning are [19]:

- They prefer interactive environments and consume most of the information on mobile devices.
- They like to be instantly connected and express themselves via different social media channels.
- They have increased visual learning ability which is enhanced by complex video games and digital images.
- They are described as growing up too fast with vast exposure to news, media, video games which foster a desire to keep up with the game lifestyle and therefore expect school and work to be fun.
- 43% prefer a digital approach to learning and find it easiest to learn from the Internet.
- They like to have random access to information, love to explore using their own routes, rely on visual content, and require positive outcome and rewards, and instant feedback.
- They are multi-taskers that read less than 20% of text and spend only 4.4 seconds for every 100 words on the page. Thus, they need guidance how to focus their attention on a single task that has depth and complexity.

C. What gamification design elements should we choose?

In Table 1, we specify different elements that can be applied when we approach the design and development process of the application.

For every gamification application, a set of design mechanisms has to be outlined before its development. These are the elements which combine and interact to create a gameplay. The overall experience of gameplay depends on how well the system design elements are kept in mind to enhance user experience [20].

If we refer to the analysis we conducted in Section III, we can conclude that the approach we've taken in this section is quite similar to the stages proposed by the 6D framework in terms that we define our goal and expected outcomes in Subsection A. Then in Subsection B, we describe our player persona, and later in subsection C we focus on the fun, mechanics, system and desired behavior.

Although the defined gamification elements in subsection C are not described in the context of a game loop, the proposed mechanics would still be organized in a system and evoke certain emotions when adopted by the students. In that way, the proposed approach is also similar to the fundamental gamification design frameworks as MDA and MDE.

TABLE I. GAMIFICATION DESIGN ELEMENTS

Gamification design element	Adaptation in the educational application
Levels/ Milestones	Section/ topic in the course should be split into separate levels and each level should contain specific information about the topic.
Rewards / Points / XP	A reward system should be present in the form of points/XP that the students gather when they complete a level/task successfully, as well as if they participate in activities to better their coding skills such as challenges, unlocking badges, etc.
Hints	Students could use hints if they are stuck at a certain task. In order to obtain a hint, a student would have to exchange his/her previously collected reward points.
Badges	Students should be able to unlock a badge depending on their activity within the application.
Challenges	A challenge could be like problem-solving but providing specific goals and outcomes. For example, resulting in doubling the current points or boosting the performance.
Goal setting	A goal setting should provide students with a possibility to set certain goals (how often they want to play or to gain a certain number of points each day). A notification system has to be utilized to serve this functionality.
Progress/Story	Course progress.
Time frame	Time pressure mechanism could be applied when dealing with challenges.
Immediate feedback	After a level/challenge is complete.

V. CONCLUSION - DISCUSSIONS AND FUTURE WORKS

In this paper, we have conducted a research and analysis of some of the existing gamification frameworks in the scope of our study, namely developing an educational application that utilizes gamification to support university students enrolled in a Web development course. Although our initial intention was to choose only one framework, due to the possibilities of adaptation depending on the content and domain, we opted for a justified hybrid approach.

The actual implementation of the application is going to be tested with several groups of students, as we plan to use experiments to assess the effects of these system design elements on learner engagement and learning achievement and wrap the results in subsequent and follow-up research.

ACKNOWLEDGMENT

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Flipped Classroom Model for Advanced Networking Courses

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***Abstract* - Gaining competences in the field of Computer Networks is almost impossible without practical skills. Since theoretical knowledge is not enough, courses related to networking, especially advanced ones, should put emphasis on gaining practical knowledge.**

Traditional classroom teaching style is not very well suited for that purpose. To try to overcome that problem, we decided to implement Flipped Classroom, with its learner-centric methodology, on some of our advanced networking courses. This approach leaves more classroom time to be dedicated to the higher level concepts, more hands-on practices and it should give students an opportunity to go with the lecture at his or hers own pace.

In this paper, we introduce a concept of Flipped Classroom, discus its advantages and disadvantages and describe how we applied it in our courses.

***Keywords* - Flipped Classroom, Computer Network Education, Teaching Methods**

I. INTRODUCTION

Practical skills play an important role in the field of Computer Networking. It is no wonder then, that in our classes, we try to put emphasis on hands-on labs, discussions, troubleshooting in simulated environment and practicing what was learned in theoretical part of the subjects. Even more so as the courses become more specialized and dealing with advanced networking topics. Yet, it often happens that the students just do not have enough class time to do some more challenging tasks in the scope of the lecture. They often cannot go deep into a particular subject they are interested in or cannot have enough hands-on practice to become more confident in their work.

On the other end of the problem scale are theoretical lectures. Presenting a lecture in a traditional way has become boring and many students find it waste of time, since they can find this information by themselves. Most of them are generations who grew up surrounded by Internet and smartphones and are used to finding relevant information online when they need it. Lecturing in the field of computer networking is even more challenging because it contains a lot of details, numerous protocols and great diversity of subtopics, making it rather abstract to students. This leads to students losing their focus and switching it to their smartphones or laptops. Research in literature shows that the same problem exists on other universities [1]. Another problem is that the pre-existing knowledge of the students is often not unified. Moreover, with topics like IoT, Cloud computing and Virtualization, which we need to incorporate into curriculum to stay up-to-date, there is not much time to cover everything in depth.

For all of those reasons, we gradually switched over the recent years towards blended learning methodologies and decided to implement Flipped Classroom model. For the reasons discussed later in this paper, we decided to try it just on our advanced networking courses and not the basic ones.

The rest of the paper is organized as follows: Section II describes the main method we used, Flipped Classroom. Section III covers implementation of the model to our courses, in Section IV we give the results and Section V brings Conclusion and our ideas for future work.

II. FLIPPED CLASSROOM MODEL

The idea behind Flipped Classroom (FC) is to reverse order in which the new lecture with its contents, related assignments and homework is delivered to the students.

In the traditional classroom, teacher has the active role and the students take the passive role. Usually, they sit and listen to a lecture without too many interruptions and at the pace set by the teacher. In addition, the lecture usually covers basic concepts, while the more complex ones are often left to be tackled by students during their homework assignments. In the Flipped Classroom model, this approach is "flipped" – the students cover basic lecture material by themselves before class and after that, in the classroom with a teacher as a mentor, they do what was in a traditional classroom homework assignments.

This model seemed very suitable for networking courses, where the lectures can be partitioned into more narrow topics and therefore presented as a greater number of shorter video lectures. Even if left as a long video lecture, depending on the student's needs and pre-existing knowledge on the topic, a student is able to pause, rewind or go through video at a faster speed. Practical work and more complex assignments play a great role in achieving learning objectives and have much more impact if conducted with the presence of a teacher or done in a

group. With the students who have more advanced knowledge then their peers, teacher is able to do even more complex assignments or those students are able to improve a different set of skills like leadership, teamwork or expressing themselves.

A. *Related work*

The idea of inverted classroom dates back from 2000 [2], but Flipped Classroom or Flipped Learning approach became popular around 2012 (Figure 1) with the work of Bergmann and Sams [3]. We could argue that the main reason for much wider adoption of this model in that period is their timing, which overlapped with the everyday availability of new technologies such as smartphones and *anytime and anywhere* high-speed Internet connectivity, which, in turn, enabled content such as video lectures to be easy to access.



Figure 1. Google search popularity of the term "Flipped Classroom" from 2008-present

With the rise of FC implementation across the globe and into higher education institutions such as universities, came the rise of number of research papers (Figure 2) with different results regarding the success of the FC model. A review paper [4] shows that majority of studies claim students greatly benefit from FC and outperform the traditional classroom model, but there are also reports that claim that students might not be ready for or benefit from this type of learning [5].

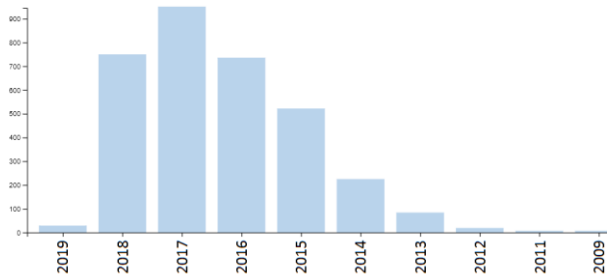

Figure 2. Number of published papers with keywords related to FC through the years

In this work, we will focus on the ones directly related to the topics in the field of computer networking; detailed analyzing other results is outside of scope of this work.

Although there is not many empirical studies related to computer networking, those that exists show that implementing FC was a success. For example, Tian et al. [6] have found that experimental FC group has achieved higher average score on quizzes by 4% and they mostly performed better on synthesized questions, which showed the ability to put learned knowledge to practice. Moreover, the students themselves reported improved abilities to resolving a new problem, to expressing themselves and to cooperate within a group.

Research conducted within the Computer Network course for the final-year engineering students [7], shows that significant number of students in experimental group reached *apply* level of objectives of Bloom's Taxonomy [8], compared to the control group where students mostly reached only *remember* level. Majority of students in the same study reported enjoying the FC's activities.

Another paper [9] states that the results gathered from comparison of two groups of students, one using FC, the other using traditional classroom, show that the FC is better in the overall achievement with a difference of approximately 20%.

The rest of the literature regarding the courses of Computer Networking [1],[10],[11] deals mostly with implementing FC model into existing course, but without empirical data showing either success or failure.

B. *Advantages and Disadvantages of Flipped Classroom Model*

There are numerous benefits of FC model which some of the related works summarized [7], [10] and we mention here the ones relevant to our study:

- Students move at their own pace
- More face-to-face time with the students brings more interaction and means to clarify difficulties
- Teachers can more easily customize curriculum
- Classroom time can be used more effectively and creatively
- Use of technology is flexible and appropriate in today's environment
- Students share knowledge in class, which leads to reinforcement of what they had learned
- Short video lessons more interesting for students than long lessons

Some disadvantages of the FC model, among others include [5], [7], [10],:

- Students may come unprepared for the class and are therefore unable to actively participate. Usually it is because FC model puts them in an active-learner role, which requires more self-control and independent learning.
- The prepared material, such as video lectures and readings, must be carefully prepared to

be interesting and engaging. This requires extra time and effort on teacher's part.

- It can be difficult to implement FC into university's standards that belong to governmental program
- Size of the class; it is much harder to implement FC into an obligatory course taken by hundreds of students than in a small course
- Different personalities among students make it impossible to satisfy everyone's needs, e.g. shy students can resent presenting results publicly

Although it is not a general disadvantage, we would like to present another potential problem with implementing a FC model and that is age of the students. Research shows [5] that junior classes are more ready than freshmen to learn by Flipped Classroom model. Readiness to participate and accept this method of learning plays a significant role in overall achievement results. This finding, together with the size of the class is the main reason we decided to implement Flipping Classroom only to our advanced networking courses.

C. *Flipped Classroom Teaching Design*

There is no one design that fits all courses and classes, but most of the designs includes the following:

- A recorded video lecture, accompanied by
- PPT slides or lecture notes prepared by the teacher
- In-class activity, usually practical, Q&A sessions
- Group activity and group assessment
- Quizzes

It has also been experimentally confirmed at Zagreb University of Applied Sciences that well-formed interactive multimedia design (including PowerPoint presentation, FC video content, etc.), give better results than the traditional face-to-face teaching (F2F). This is proven especially if using Merrill's basic principles of instructional design with cognitive theories of multimedia learning and Mayer's principles of multimedia learning [12] .

III. IMPLEMENTATION OF FLIPPED CLASSROOM

Our advanced networking courses are based on Cisco Certified Network Associate (CCNA) Routing and Switching education version 6.0. It consist of four modules witch are separated in four courses accordingly. These courses are fully integrated in classes at master's degree study, but several courses from bachelor's degree study also use these materials in their classes. Since networking courses put great importance on practical skills, Cisco Networking Academy has prepared variety of materials for their educations. All materials are located on learning management system and all Cisco academies and their instructors have central place for educations where they can improve and personalize materials [13]. Also, they can import some chapters and modules from other educations and by that extend original course with additional curriculum. These materials consist of Instructor PTT slides, interactive online quizzes, videos, online simulators, networking simulation software Cisco Packet Tracer with dozens of exercises, as well as prepared hand-on labs, which are often solved in pairs or groups with following discussion.

Our implementation of Flipped Classroom model utilizes those materials, since they cover almost every important design feature mentioned in Section II.C. What we were lacking were video lectures for students to prepare them for the class activities.

From year 2017, we have decided to record all lectures within these four modules and we came up with total of 49.5 hours of video recordings. Courses started in February 2017 and finished in January 2018. Each course has been eight weeks long and classes were held once per week in groups of 12 students, each in various durations, depending on length of chapters and their complexity. Given that, we were spending roughly 50 hours on lectures per group each year. Those hours could have been better used for practical exercises in lab environment.

As videos were uploaded on YouTube channel [14] several weeks after recording due to editing, in that academic year these recordings were used just for re-watching missed or misunderstood chapters and as a tool for studying for exams. As part of Flipped Classroom model for theoretical preparation for practical exercises, recordings were ready to be used only the following year.

Since networking courses demands detailed research of some topics, we decided to keep traditional lectures for first module (Introduction to Networks) because it is the most extensive one and it has to prepare all master-level students with different levels of foreknowledge for complete networking education. We decided the same on our bachelor-level networking course, but for the reasons mentioned earlier in this work – we argue that the age of the students is relevant factor in their readiness to accept FC style of learning and the introductory networking course has over one hundred students, which makes it hard to implement as FC. Other three master-level courses and one advanced bachelor-level networking course did not have full-length traditional lectures but only brief theoretical introduction on subject for practical exercises that followed. At the beginning of the second course, students were able to watch videos as a preparation for upcoming exercises.

IV. RESULTS AND DISCUSSION

At the end of fourth and last course for master-level students, we conducted a small survey and asked students their opinions on video recording. We also reviewed the statistics of video ratings.

A. *Survey results and video ratings*

Summary of YouTube statistics from January 2019 is shown in Table I.

TABLE I. - Video ratings

	Views	Average view time (minutes)	Watch time (minutes)	Number of videos	Video length (h:mm)
Introduction to networks (Module 1)	1812	8:46	13995,90	16	19:03
Routing and switching (Module 2)	546	6:38	3530,30	12	11:01
Scalling Networks (Module 3)	693	7:25	4188,30	12	10:25
Connecting Networks (Module 4)	480	8:37	3698,60	8	9:00
Total (sum) Total (avg)	3531 882	 7:52	25.413,1 6353,3	48 12	49:29 1:01:51

It can be seen that average length of a video is roughly one hour, but average watch time is just 7:52 minutes.

Video viewing trend (Figure 3) showed that the students' motivation for watching videos rapidly drops after a few first lessons. Only anomaly is in first module with eighth lesson recording 333 views.

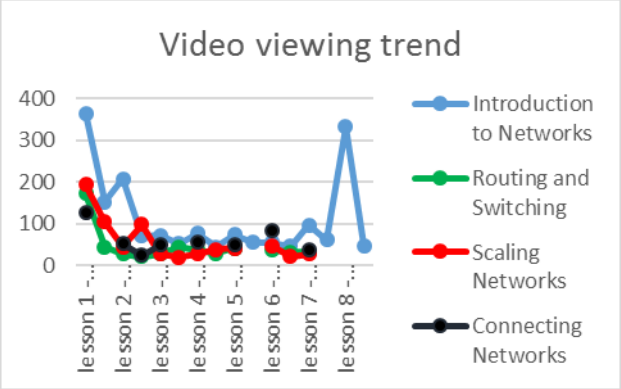

Figure 3. Video viewing trend of each lesson in all the courses

When asked on preferred learning method, students replied as shown in Figure 4.

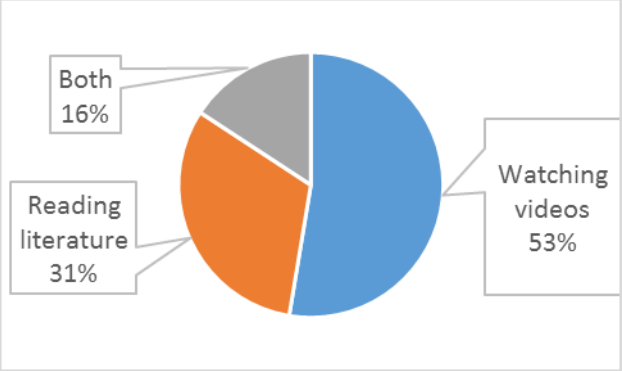

Figure 4. Students' answers for question: What do you prefer as a learning method?

As students said in survey, they "would be more motivated to use videos if they were given an award in form of bonus points". In addition, some of them noted that they "would be more motivated to watch videos if lecturer would not hold short theoretical introduction to practical exercise". Student opinion is shown in Figure 5.

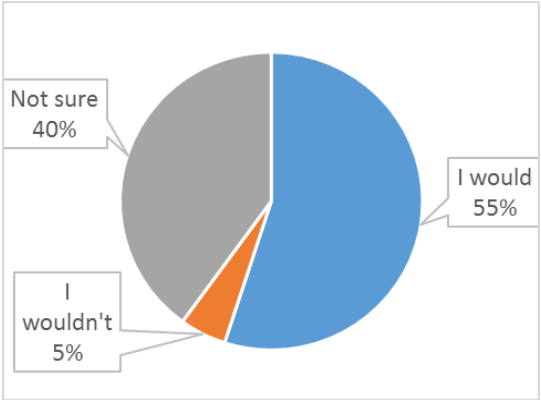

Figure 5. Students' answers for question: Would you watch video lectures more often if there were no introduction at the beginning of the lab?

Another singnificant statistic are students' final grades shown in Figure 6. It shows grades of one generation of students who were studying by the FC model.

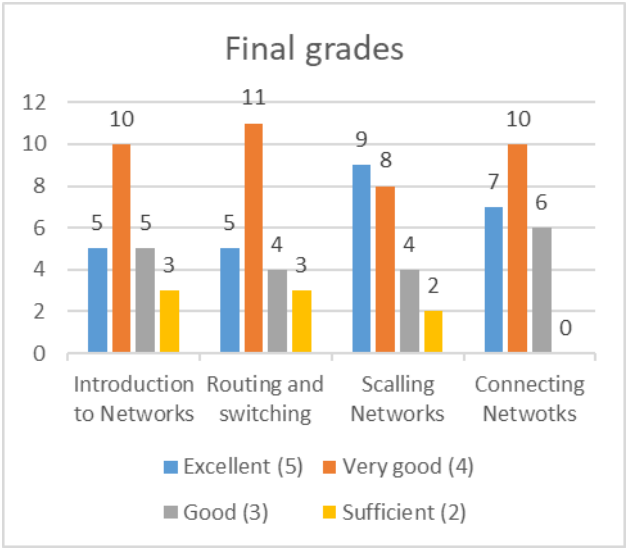

Figure 6. Student's final grades throughout the four networking courses.

B. *Discussion of the results*

Following end of the first module, students have noticed that short theoretical introduction at the beginning of the practical labs was mostly enough for them to successfully solve an assignment with usage of class based materials. One of consequences was that usage of video lessons started to decline as course was reaching its end as it is shown in Figure 3.

The anomaly in the statistics is expected because eight lesson is subnetting which can be tricky for some students

and it requires more practice than other topics on Introduction to Networks course.

Although viewing trend and survey results state that the majority of students did not watch videos, teachers report that the students mostly came to the classes well prepared, probably through other type of materials, e.g. books, other YouTube videos, lecture notes, Cisco Networking Academy course materials, and were able to do the assignments. Final grades, achieved through the exams, also show that majority of students reached learning objectives. This shows us that implementing Flipped Classroom was still a success.

In the future, we plan to make some improvements, such as cut video lessons in smaller chunks and introduce a small quiz at the beginning of the hand-on labs for extra points. At this time, removing short introduction at the beginning of the lab we find counterproductive.

V. CONCLUSION

Advanced courses in computer networking are highly practical courses where hands-on experience and collaborative work are of the essence. It is also a rapidly evolving field with emerging new technologies that students need to be acquainted to be prepared for the job market.

Flipped Classroom model of teaching, with the basic lecture left to be covered by students at home before the class, leaves extra hours of that precious face-to-face time for hands-on labs and discussion of higher-level concepts, as well as introducing new and interested topics. Research shows that implementing FC model was usually very successful.

Our own experiences shows us, although with a wide room for improvement, that Flipped Classroom is indeed suitable for advanced courses dealing with networking and we will continue with its implementation.

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An educational tool for visualising actor programs

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Abstract **- Object-oriented programming (OOP) is probably the most popular programming paradigm today. Because of this, it is often taught at faculties associated with computer science. The general idea of OOP is to break a complex problem into abstractions called objects which interact with each other via method invocation.**

On the other hand, the actor model provides a computation model based on agents that are called actors. Actors in the actor model are similar to objects in OOP, but unlike objects are concurrent and communicate by message passing.

At our faculty, a game-based approach is used to teach students about OOP. The actors in a game can be taught as agents that interact with an environment. Furthermore, students program agent behaviour in our artificial intelligence course. Therefore, students have experience with both objects and agents.

However, students still find it difficult to understand the actor model and build applications with it. In order to help students, we have developed a visualisation system for actor-based applications. We collected responses on the system after presenting it to students that were taught the model. In this paper, we i) present the developed visualisations system and ii) report the results on the responses collected.

Keywords – actor model; message-passing; notional machine; object-oriented programming; program visualisation

I. INTRODUCTION

Computer science students at the Faculty of Science learn about the actor model as part of their graduate study. We chose this concurrent computational model because it most closely resembles object-oriented programming (OOP) [1]. The actor model has been used for building multiplayer games (with virtual actors, but based on the actor model) [2], Ericsson's 3G mobile network [3], Intel's big data streaming engine [4], and other applications that require a high degree of scalability [5, 6].

In literature, the actor model was first introduced as a formalism in artificial intelligence [7]. The basis of this model is an actor, that is an agent that is invoked by receiving messages. The basic premise is that actors can uniformly model any mode of behaviour, or rather that any mode of behaviour can be defined as sending messages to actors.

Whereas actors are the basis of the actor model, objects are the basis of OOP [1]. However, the main difference between an actor and an object is that the former is concurrent. Therefore, actors execute their actions concurrently and asynchronously with other actors. The actor model is even sometimes referred to as a combination of an object-based view of the world with concurrency. All computer science related undergraduate study programmes at the Faculty of Science in Split include a course in OOP.

Therefore, we were surprised when many students, despite its similarities to OOP, found programming with the actor model very difficult. One of the main issues seemed to be that students failed to understand how to organise the communication between actors, even for basic examples with none or minimal concurrency. It seemed as students failed to see the connection between sending messages and receiving responses and invoking methods and receiving a return value. Because of this, we believe that students were missing an essential perspective on OO programs - as a collection of interacting objects.

Another issue for students may have been the inability to access an actors' state directly. However, students were taught about and programmed agent-based models in NetLogo [8]. NetLogo agents, similar to actors, cannot directly access the state of other agents. Instead, they need to ask one another to do something, which we may think about as message passing.

In order to write programs and reason about them, students need a valid model of the notional machine. The notional machine is an abstraction that results from the constructs of the programming language and their relationship to the to the execution of the program [9]. There are different notional machines for different programming languages and paradigms [10]. Even a single language can have more than one notional machine.

Sorva suggests that understanding OOP requires two notional machines [10]. The first one is an extension of a notional machine for imperative programming, while the second one describes the communication between objects. These provide different perspectives on OOP. With regards to the difficulties described earlier, students might have experienced OOP as merely an extension of imperative programming. Therefore, they might be

missing the other perspective on object-oriented programs.

In order to address the mentioned issues, we have developed an educational tool for visualising a high-level notional machine that focuses on the interchange of messages. The tool provides students with a graph-based layout of the exchanged messages and a timeline that shows when each of them was sent. We presented the tool to a group of students and collected their responses via a questionnaire. In this paper, i) we present the visualisation tool that we developed at the Faculty of Science in Split and ii) report on the student responses regarding the visualisation presented to them.

II. PROGRAM VISUALISATIONS AND NOTIONAL MACHINES

Program visualisation tools have often been developed in order to visualise the notional machine with the aim to provide students with a correct model of the machine [11]. Over as many as fifty different visualisation tools have been identified in the literature [11, 12]. Therefore, it has become relatively difficult to come up with new and unique ways of visualising execution. Tools such as JaguarCode have started including different the visualisation of different aspects of code to complement one another [13].

The visualisation that we introduce here is most similar to Novis [14], akka-viz [15] and akka-visualmailbox [16]. Novis visualises the execution of OO programs with a focus on communication. It also provides a view at different levels of detail. However, it is not intended for the actor model, and it currently is unknown to us if it is actively developed or abandoned.

Akka-viz [15] and akka-visualmailbox [16] are open source systems found on Github which visualise actors and their message exchange. However, neither appears to be an educational tool. Akka-visual-mailbox visualises the number of messages exchanged between actors, but that seems to be all. Akka-viz seems to provide more details but is developed to be a debugging tool and not an educational one. Both systems are developed for use with Akka and are therefore unusable with .NET, which our students use. Akka-visualmailbox visualises message exchange by collecting sent messages using a custom type of actor mailbox. We use the same approach for collecting messages in our tool. On the other hand, Akka-viz uses AspectJ for instrumentalisation. Furthermore, given that no significant updates have been logged in years, it would seem that both systems have been abandoned.

The goal of the tool we present here is to facilitate students learning about the actor model. It provides an additional view of a timeline that none of the other presented systems has, can also be used with OO programs and new features are currently in development.

III. ACTOR MODEL

The actor model is a mathematical model for concurrent computations [17]. We already mentioned some of its applications in the introduction. It is often used to build applications that need to handle tasks asynchronously, such as parallel programming, programming of distributed systems, distributed artificial intelligence [18] and many more. Although our students have seen agents in AI when programming agent-based models, the actor model gives them an asynchronous note.

The reason for its broad application in the field of computer science lies in the fact that the actor model alleviates the developers from having to take care of thread management and locking [19]. This level of abstraction enables the usage of multi-threaded behaviour without the use of low-level concurrency constructs [20].

The basis of the actor model are actors, which are computational agents that communicate via message passing. When compared to software agents, actors are passive and react only when a message is received. Upon receiving a message, an actor may send messages to other actors, create new ones or update its local state. Updating local state may include changing the actors' behaviour. Any actions the actor takes is concurrent and asynchronous with other actors. Actors cannot access the local state of other actors; they can only influence other actors by sending messages.

Each actor has an associated mailbox which stores the received messages [17]. Messages are stored in order of arrival and processed synchronously in first-in-first-out (FIFO) order. All messages are processed synchronously. Therefore, all behaviour inside a single actor is synchronous, which greatly simplifies reasoning about actors.

Actors are very similar to objects in OOP. Both of these entities encapsulate some state and manifest behaviour [1]. Invoking a method on an object is even sometimes referred to as message passing. Unlike actors, objects can directly access and modify each other's state. However, we can limit the accessibility of an objects' state by using properties and the appropriate access modifiers. By changing some local state, objects may also change their behaviour. Although, it is worth to mention that this is not the same as changing the behaviour of an actor.

The actor model, just like OOP, allows us to decompose programs into a set of self-contained interactive components.

IV. AKKA.NET

Akka.NET is an implementation of the actor model for the .NET framework [20]. It is a port of the popular Akka toolkit for Java and Scala that allows programming message-driven, concurrent and parallel applications [21]. We chose to use Akka.NET in teaching because our students mostly use C# in their courses and because of Akka's popularity.

V. AKKAVISUAL

Students often find it difficult to understand and program in the actor model. One of the main issues seems to be that students find actor communication too abstract. They often find it difficult to perceive which actors will communicate with each other during program execution and which messages they will exchange. Therefore, we developed AkkaVisual, a web-based tool for visualising

message passing between actors. The tool can also be adapted to visualise the interactions between different objects in OOP. Thereby, for both the actor model and OOP, the tool visualises the higher-level message-passing notional machine.

The tool is a web application that exposes a web API to collect data. The API receives the details about the exchanged messages. Typically, these details will include the sender, receiver, message content and type of message. Once received, the data is pushed to the web client in real-time using SignalR. On the web client, the visualisation is drawn in real-time as the program executes. We use Vis.js to draw the visualisation [22].

Data can be sent to AkkaVisual's exposed web API via a standard HTTP POST request. However, for convenience, we have developed a library that contains a custom mailbox which may be used by Akka.NET actors. To use this mailbox, students need to include it in their project and specify its use when configuring their actor system. The library also keeps track on the order of messages via a vector clock.

Typically, when an actor receives a message, it is placed on the queue in the actor's mailbox. The actor processes the messages in FIFO order. In addition to this, our custom mailbox forwards the details about received messages to AkkaVisual's web API. These details also include the value of the vector clock for the message.

AkkaVisual offers:

- View of messages and actors exchanging those messages
- Information about the type of actor
- Information about the properties of each message
- Slow replay option
- Zoom in and zoom out options and ability to drag graph in the window
- Timeline view
- View of programs running on computers connected to a cluster, containing a legend of which process sent which message

Since AkkaVisual is an open-source project, additional functionalities can be added to an existing library or library can be translated to Scala or Java by anyone in the community. Figure 1 shows an overview of how the system works along with our custom mailbox.

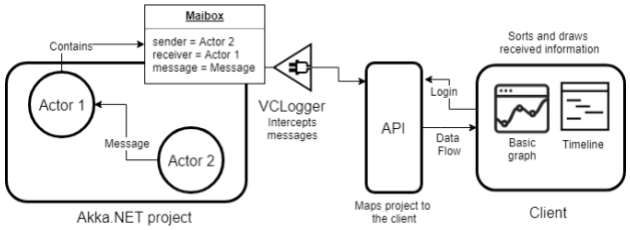

Figure 1. An overview of how data is collected and displayed in AkkaVisual

VI. METHODOLOGY

A. Participants and tool presentation

We presented AkkaVisual to a group of students enrolled in second-year graduate studies. Students that did not learn the actor model as part of their graduate curriculum, as well as those that knew who made the tool, were excluded from the study. The latter were excluded to avoid peer bias. We refer to the remaining nineteen students as participants. All of them learned about the actor model as part of their graduate study curriculum during the second semester. However, for reasons that we will discuss latter, only eleven participants were considered for the qualitative analysis.

Due to classroom restrictions, the students were not able to try out the tool themselves. Therefore, we introduced the tool via a presentation that included images of the user interface and available features. Additionally, a live demo was carried out. All of this lasted for about 20 minutes, after which the participants had about 10 minutes to fill out a questionnaire.

B. Data collection tool

Data was collected using a questionnaire that consisted of seven 5-point Likert-scale questions, one dichotomous question and a single open question. The Likert-scale questions consisted of one question regarding the tools appropriateness for learning the actor model and the other six regarding the usefulness of existing features and the potential value of planned ones [23]. The purpose of the single open-ended question was to collect any suggestions and complaints the participants might have about the tool presented. The dichotomous question only asked if a legend should be present on the tools' user interface.

C. Data analysis

We analysed the collected quantitative and qualitative data separately.

Cronbach's alpha for the quantitative data is 0.869, which is considered highly reliable [24]. For each item, we report the frequency and distribution of values. Additionally, for the top four features that got the top average scores, we try to give a possible explanation of why the feature got its score.

For the qualitative data, we use content analysis. Weber suggests that content analysis may be used to code open-ended questions [25]. Although the participants' answers are short, they provide useful insight into the students' impression of the usefulness of the tool for learning the actor model. We take an inductive content analysis approach in which we derive the codes and categories from the data [26]. After familiarising ourselves with the data, we assigned the initial codes to segments of the answers. We refined these codes as we reread the data. Once we were satisfied with the codes, we grouped them into categories and counted their frequencies. We report the categories and codes, as well as the frequency of their occurrence.

TABLE I. FREQUENCY SCORES FOR THE TOOLS' FEATURES

#	Question	Score				
		Mean	*Median*	*Mode*	*Std. Deviation*	*N*
1	The tool is adapted for first-year graduate students learning about the actor model for the first time.	4.05	4	4	0.911	19
2	I would like to see a timeline of the execution of each thread or process where the exact time of sending and receiving each message is displayed.	4.21	5	5	0.976	19
3	The replay feature seems useful.	4.16	4	5	0.898	19
4	The timeline seems to be useful in visualising the concurrency of the system.	**4.32**	4	5	0.749	19
5	It is useful to see the features of the messages sent and the type of the actor.	**4.37**	5	5	0.761	19
6	It would be useful to save the generated visualisation and play it without rerunning the program.	**4.53**	5	5	0.697	19
7	It would be useful to send a message to an actor from the web application.	**4.32**	4	4	0.582	19

Out of the total of nineteen students, fifteen left any responses; the others left the question blank. Out of these, two participants left an answer with no information relevant to the study, e.g. "no complaints". Two others simply stated "great tool". Therefore, we coded the answers of the remaining eleven participants.

When determining the codes, it is worth noting that multiple codes may have been assigned to the same answer, and also the same code may have been assigned to answers from multiple participants.

VII. RESULTS AND DISCUSSION

The goal of the questions regarding the tool's features is to obtain feedback on which features participants found most useful and guide future development of new ones. The descriptive statistics are reported in Table 1. The first question is not so much about the usefulness of the tools' features but rather to see if students feel the tool is appropriate for use by graduate level students. Questions two to five refer to existing features of the tool, and questions six and seven refer to features we plan to add in the future. We can see that the mean scores of all of the questions are above 4. Therefore, we conclude that students believe that all of the existing features and all of the features we plan to add are could be useful for them to learn the actor model.

For brevity, we will further look into and expand only on the top four highest scored features. The top scored question is number 6, which refers to saving and replaying a visualisation without executing the program again (avg. = 4.53). We offer two possible explanations as to why this feature got the top score. The first possibility is that students would like to share the visualisations they obtain without sharing their programs. This would allow students that have completed their assignments to share how their program executes without sending the program itself. Additionally, it would allow students who were not able to complete their assignments to compare the execution of their program with that of their colleagues.

The second explanation is related to the time it takes for the program to run entirely. Students probably do not want to re-run the application over and over again, especially if the computations take a long time or a large number of values need to be input manually.

The second to top scored question is related to the usefulness of displaying the type of actor and details related to the sent message (avg = 4.32). Actor applications often have different types of actors that can handle the same type of message. Hence, we assume that students feel it would help clarify why some behaviour occurred.

The third and fourth top scored questions have the same mean score (avg = 4.32). One of them refers to the usefulness of visualising the concurrency in the system with a timeline. Displaying the exchanged messages in a graph-based layout does not allow simple tracing of the order in which messages were exchanged between actors. Therefore, the timeline provides one way to compensate for this as it shows the exact time each message was sent.

Finally, the last of the top four scored questions refers to sending messages to the actor system from the web client. This feature would mostly be useful for debugging as users could see if the actor can receive certain types of messages and respond to them appropriately.

Regarding the open-ended question, we derived eight codes from the answers of the thirteen participants. We grouped them into three categories: *positive about the tool*, *the tool needs improvements* and *tool isn't useful*. The category positive about the tool contains codes that refer to the participants' perception that the tool could be useful for learning the actor model. The second category contains the codes related the improvements that need to be made the tool. Finally, the category tool isn't useful contains codes for reasons that may impede the tool's usefulness. Figure 2 shows a map of these categories and code. Code frequencies are reported in Table 2.

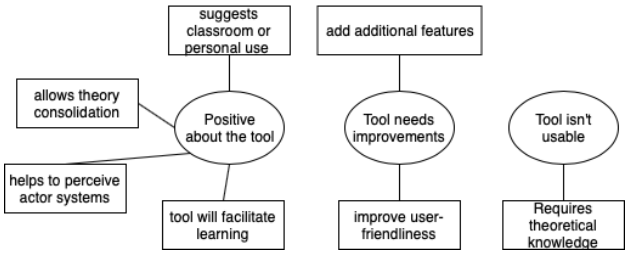

Figure 2. A map of categories and codes derived by content analysis

TABLE II. CONTENT ANALYSIS CODE FREQUENCIES

Code	Frequency
the tool will facilitate learning	5
suggests classroom or personal use	3
add additional features	2
helps to perceive actor systems	2
improve user-friendliness	2
requires theoretical knowledge	1
allows theory consolidation	1

Concerning the reported code frequencies, we can conclude that the participants mostly believe the tool could be useful for learning the actor model. In fact, the top three most frequently occurring codes are grouped into the positive about tool category.

Participants have most often expressed that they think that the tool will facilitate learning (45,45%) about the actor model in general. The fact that many participants point out this belief suggests that they are aware that students have difficulties to program with actors.

A few participants have expressed their desire to use the tool themselves or in class (27,27%). One of them stated that they think they "will use it [AkkaVisual] when taking the course". Another believes that the tool would have helped him/her achieve a better grade: "I think my results in the course would have been better with the use of this visualisation". Therefore, we may conclude that students are prepared to use the tool in class and while learning.

A couple of participants recognised the difficulty in correctly perceiving actor programs (18,18%). Students may find it hard to trace the execution in actor systems because they find the actor model abstract. One of the participants noted that he would try to sketch actor systems while learning, but would often make mistakes. Participants also noted that the tool could allow theory consolidation (9,09%).

The second category includes codes that do not dismiss the tool but point out that it needs improvements. A few participants noted that the tool requires improved user-friendliness (18,18%) and additional features (18,18%). Participants believe that further work is required on the tool with features mentioned in the questionnaire. Some participants noted that the visualisation is drawn too fast, which, we assume, refers to the replay feature. Slowing down the real-time visualisation during program execution may not be beneficial without slowing down the execution of the program itself. Otherwise, the program would complete much before the visualisation finishes.

Finally, the third category includes those codes that seem to dismiss the usefulness of the tool. One such code is included: "requires theoretical knowledge" (9,09%). One individual believes that having specific theoretical knowledge is required to use the tool. However, the example he provides in tightly related to the example provided in class. Furthermore, a small theoretical background is always provided for whatever is taught, be it OOP, the actor model, or something else.

VIII. LIMITATIONS OF THE STUDY

The main limitation of the study is that the participants did not have a chance to try out the tool themselves and no standardised test was used to score the tool. However, we will address this in a future study.

Therefore, we plan to do a second study in which students will be able to try the visualisation first hand and fill out the system usability scale (SUS) [27]. Furthermore, we plan to conduct a pilot study that will evaluate the tool's effectiveness in helping students learn about the actor model.

Another limitation of the study is the small number of participants. We retained nineteen participants for the quantitative analysis and eleven for the qualitative. Given that his is a preliminary study and the small number of students at the graduate level, we couldn't avoid this. To accumulate more participants and confirm our findings, we plan to repeat this study for the next few years.

IX. CONCLUSION

The actor model remains a difficult computational model for students to understand and use to write programs. To facilitate student learning and success in programming with the actor model, we have developed and introduced a visualisation tool called AkkaVisual. Although it still needs some improvements, participants noted that they would like to use the tool. Some of them believe that the tool might have helped them achieve better results when they were learning about the actor model. One of the reasons is that the participants are aware of the difficulties they had when they first started learning the actor model.

Some stated that they had trouble with perceiving actor systems and made mistakes when trying to sketch them on paper. They note that this tool could provide students with a correct perception of actor systems. These findings indicate that we were correct in our assumption that students find actor communication too abstract. However, further research is needed to test this assumption.

Some additional work on the system is required to improve user-friendliness. Some participants believe that additional features should be added to increase its usefulness. The scores for existing and requested features is reported in Table 1. It would seem that most of all participants would like to be able to save and replay a visualisation.

We will continue our work by implementing the requested features based on the provided survey and participant responses. Furthermore, we will give students a chance to try out the tool and introduce a standardised test to score the tool's usability. Finally, we plan to carry out a study of the tool's effectiveness in learning the actor model.

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Students' Viewpoint about Using MIT App Inventor in Education

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Abstract - **The paper presents Ruse University students' point of view about using Android application development environment MIT App Inventor in different levels of education. The research was done via the survey method. A questionnaire was made for the purpose. It consisted of 21 questions, merged in several parts: personal information about the respondent (age, gender, speciality, year of education, mobile devices possessed, programming skills and experience), students' opinion about the qualities of the environment, its user-friendliness and which level of education it is most suitable for. The final part of the questionnaire included 2 open questions and the answers had to contain the advantages and disadvantages of MIT App Inventor compared to other programming environments. Within three consecutive years – 2016, 2017 and 2018 – a total number of 73 students (11 women and 62 men) from Computer Systems and Technologies master program were asked to answer the questions. The analysis of the results from all the three years shows that, according to Ruse University students, MIT App Inventor is most appropriate for use in a bachelor degree of education, followed by a master degree and a secondary school.**

Keywords - education, mobile application, programming environment, survey

I. INTRODUCTION

The rapid and widespread penetration of computer and mobile technologies into industry and everyday life requires more and more people to have computer thinking and skills. On the one hand, modern students use almost constantly smartphones and tablets, and on the other hand they have difficulty or do not have a particular interest in studying programming. It is therefore useful to add student and student addiction to mobile devices for introduction to computer thinking by including the MIT (Massachusetts Institute of Technology) App Inventor mobile development environment in the learning environment. This allows learners to program and test their applications using their mobile devices, increasing their motivation and the desire to learn new knowledge.

This report presents masters' students at Ruse University viewpoint about using MIT App Inventor programming environment at different levels of education.

MIT App Inventor [1] is a visual on-line environment that uses the block-programming paradigm that even enables users who are not familiar with programming languages to develop quickly mobile applications running Android OS. The environment consists of two basic modules - Designer for User Interface Development and Block for Block Programming.

Developing mobile applications as opposed to developing PC applications requires either a mobile device emulator or a real mobile application testing device. App Inventor provides both options, but for full testing mobile devices should be used if mobile applications use any sensors (camera, compass, GPS, acceleration sensor, etc.).

Justify both left and right columns. On the last page of your paper, adjust the lengths of the columns so that they are equal. Use automatic hyphenation and check spelling. Do not add page numbers.

II. LITERATURE REVIEW

The literature review shows that scientists' research can be divided into several main groups depending on the level of education where App Inventor is used.

Researches about using App Inventor in the primary education:

- S.-W. Kim and Y. Lee have conducted a study [2] on the possibility of including App Inventor in the national curriculum for primary school students in South Korea. The results show that the use of this program does not improve the ability of small students to creatively solve problems, and that more time is needed for learning.
- P. Voštinár describes in his report [3] a mobile application that can be used for mathematics training in converting Roman to Arabic numerals. According to the author, the application can be used as an example of programming for mobile applications in primary school.

Researches about using App Inventor in the secondary education:

- In USA, a study [4] was conducted whether App Inventor is a suitable platform for providing computational thinking. The results show that App Inventor is an affordable and powerful platform that can provide a very good introduction to programming.
- S. Grover and R. Pea present in their report [5] a workshop curriculum that includes the training of high school students in programming and

introduction to the functional concepts of computer science, with students developing mobile apps with App Inventor.

- S. A. Nikou and A. A. Economides, in a study [6] among 38 high school students in Greece, point out that using Scratch and App Inventor in learning leads to an increase in intrinsic goal orientation, task value, control of learning beliefs and self-efficacy.

A big part of researches are about using App Inventor in the higher education:

- E. Spertus, M. L. Chang, P. Gestwicki, and D. Wolber [7] stated that ten years ago, twelve different colleges and universities in the USA used App Inventor in a wide range of computer science courses.
- The author B. MacKellar made a study [8] of using App Inventor in the Healthcare IT Course at St John's University, Queens, USA. The students of the course were commissioned to develop mobile applications in the field of health care, after which a study of their opinion was conducted. The main conclusion of this study is that App Inventor is suited for students with no programming experience to quickly begin developing mobile apps, and for experienced students offering many opportunities to engage them in the development.
- In Qassim University, Egypt, authors M. Amasha and S. Al-Omary made comparison [9] between using the Blackboard Learning Management System (LMS) and a mobile application developed with App Inventor. 114 students were surveyed, and analysis shows that student learning outcomes improve when using mobile applications, and that the students prefer to use mobile learning applications rather than LMS as they feel more engaged.
- The App Inventor was successfully used by the Technical University of Cluj-Napoca, Romania, not as a learning environment, but as a tool for the development of mobile applications in the field of mathematics, which could then be used by students [10].
- At the Jackson State University, USA, an innovative educational module is used in the existing Emergency Management Technology course. The report [11] describes the design of the module, which includes use of App Inventor. The purpose of the module is to motivate course students to be interested in computer technologies and to provide them with a broad foundation for computational thinking.
- A. Soares and NL Martin, in their report [12], look at the results of a study with 40 students enrolled in the Android Application Development course during the 2013 and 2014 spring semesters. App Inventor application development is used in the course. The course requires that students have basic programming skills. According to the authors, the positive responses to the study support the practice of using App Inventor in teaching not only beginners but also advanced programmers. The paper also shows that App Inventor can be used to support the teaching of more advanced computing concepts.
- A. Soares in another report [13] examines the opportunities and challenges of teaching Mobile Application Development with App Inventor at Midwest University, USA. The report shows that App Inventor has great potential to be used to teach advanced computing concepts such as Software Engineering, Information Assurance and Security, Data communication, Database Design, and more.

The literary review shows that App Inventor can be successfully used in both secondary and higher education for teaching of beginners and advanced programmers. App Inventor is still not suitable for use in primary education.

III. RESEARCH METHODOLOGY

The survey was conducted using the questionnaire method. For this purpose, a questionnaire was developed. It includes 21 questions, merged into five parts: Part 1 - personal information about the interviewed (age, specialty, gender, course, owned mobile devices, programming languages that they have knowledge of and experience in programming). The next three parts are about students' viewpoints according to the technical implementation of the environment (Part 2), the friendliness of the environment (Part 3) and in which educational degree App Inventor could be used (Part 4) and include questions with possible answers in the five score Likert scale. Respondents had to indicate their agreement / disagreement by choosing one answer from 1 = “I strongly disagree” to 5 = “I strongly agree”. Part 5 of the questionnaire includes two free-answer questions that students had to say about what they think are the benefits and disadvantages of App Inventor over other programming environments.

For three consecutive years, 2016, 2017, and 2018, a total of 73 students (11 women and 62 men) of the Master's program in Computer Systems and Technologies were surveyed. The survey was implemented three times with different students for each of the years. This target group was selected for a survey as the students are in their last level of education, they have experience in using App Inventor as a part of the training in the Mobile Technology course. At the same time, Master students have a viewpoint about educational process at all previous levels of education, they use different programming environments and languages (C ++, C #, Java, PHP, JavaScript, etc.) and can make comparisons and reasoned suggestions on where to use App Inventor, and what are its advantages and disadvantages compared to other development environments.

IV. RESULTS

The questionnaire included a question about student-owned mobile devices. The results of the responses are shown in Fig. 1. Over the past three years, the most commonly owned mobile devices are smartphones (between 80% and 100%), followed by laptop computers (between 45% and 73%). The sum of the percentages exceeds 100 because many respondents have indicated they have more than one device. The analysis of the questionnaire results (Fig. 2) shows that 31 students (42.47%) have only one mobile device and most often it is a smartphone (27 students, i.e. 36.99%). Two mobile devices have 42.47% of students, while three and more devices have 15.07%.

The next question explored what programming languages the students use. The purpose of this question was to find out how the students appreciated their knowledge of programming languages and thus adequately assess the capabilities of MIT App Inventor. The results are shown in Fig. 3. The most common programming languages which students use are C ++, Java, and JavaScript. PHP and Object Pascal are found in other programming languages. Very few students have programming experience with Objective-C (less than 5%). In this question again, the sum of the percentages exceeds 100, as many respondents have indicated they have more than one programming language.

The question of how many years the students are involved in programming was also studied. The answers ven by the students were in the range of 1 to 10 years, with great differences, which explains the large standard deviation (SD). Fig. 4 shows the average results and the standard deviation for the three years. It can be seen from the figure that the most experienced (average 4.09) had students who were trained in 2018 and the smallest ones – these trained in 2016. The highest standard deviation (2.71) is seen about students from 2017 (there are students with 1 year of experience as well as with 10 years of experience).

The results of the students' answers to the questions in part 2 are given in Table I. It gives both the mean values and the standard deviation (SD) for each of the three years as well as the average averages for all years. The analysis of the results shows that the highest degree of approval amongst the students is the assertion that App Inventor

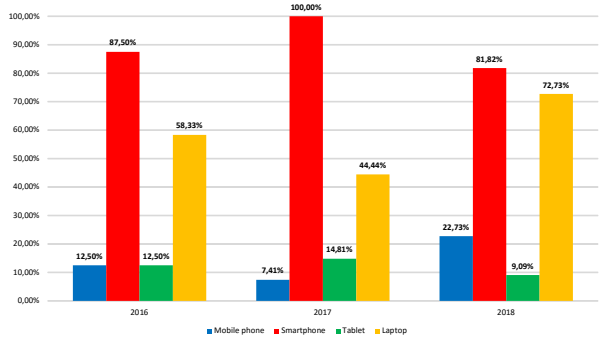

Figure 1. Mobile devices possesed by the students

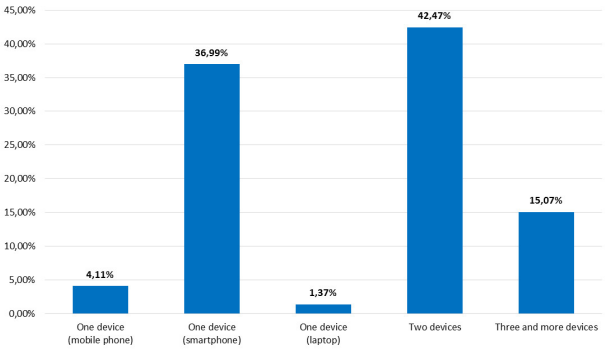

Figure 2. Number of mobile devices possesed by students

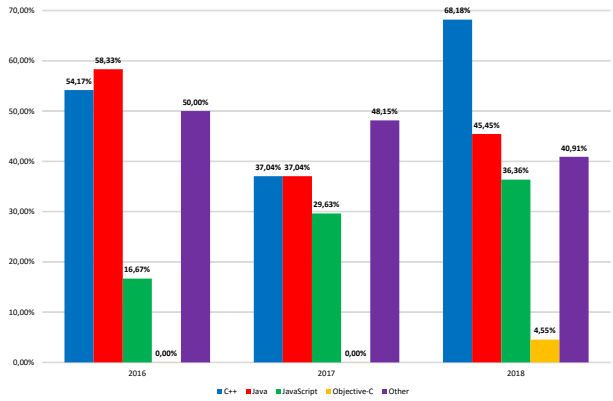

Figure 3. Programming languages used by students

programming is easy, and the second is claiming that web-based architecture is a very good solution. The lowest score is the assertion that the environment offers enough resources to develop the design of mobile applications. This statement also has the largest dispersion, i.e. students have indicated different responses on the Likert scale.

The results of the answers to the questions of part 3 are given in Table II. Here, again, the highest approval is obtained about the question is it easy to use App Inventor (for students from 2016 and 2018). The least approval (but still above 4) suggests that students will recommend the use of the App Inventor to other users. Interestingly, according to the students of the 2017 class, this is the most approved issue. The standard deviation analysis shows that the answers with the highest approval have the least standard deviation.

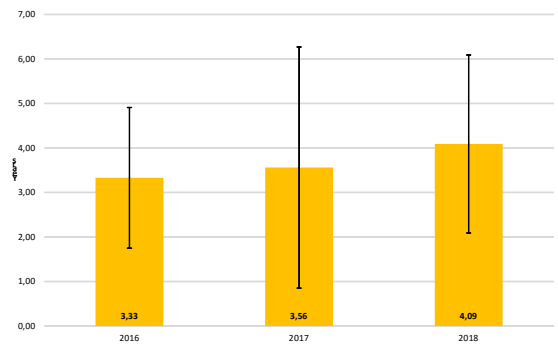

Figure 4. Average years of programming experience and standard deviation

TABLE I. RESULTS FOR THE PART 2 "TECHNICAL IMPLEMENTATION"

Statements	2016		2017		2018		Average	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Web-based architecture is a very good solution.	3.95	0.88	4.30	0.72	4.18	1.01	4.13	0.87
Programming in App Inventor is easy.	4.54	0.66	4.44	0.85	4.23	1.07	4.40	0.86
The environment offers sufficient resources to develop the design of mobile applications.	3.75	0.99	4.07	0.96	3.95	0.84	3.93	0.93
The environment offers enough blocks to develop the logic of mobile applications.	3.92	0.93	4.11	0.75	4.09	0.75	4.04	0.81

TABLE II. RESULTS FOR THE PART 3 "USER FRIENDLINESS"

Statements	2016		2017		2018		Average	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
The graphical user interface is well designed.	4.46	0.59	4.52	0.64	4.23	0.88	4.40	0.70
It is easy to use App Inventor.	4.54	0.59	4.52	0.80	4.55	0.66	4.54	0.71
I will recommend App Inventor to other users.	4.13	0.95	4.63	0.63	4.14	0.99	4.30	0.89

TABLE III. RESULTS FOR THE PART 4 "IN WHICH EDUCATIONAL DEGREE APP INVENTOR SHOULD BE USED"

Statements	2016		2017		2018		Average	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
App Inventor should be taught in primary school.	2.75	1.51	3.41	1.05	3.82	1.33	3.33	1.30
App Inventor should be taught in secondary school.	3.50	1.53	4.33	0.83	4.14	0.99	3.99	1.12
App Inventor should be taught in a bachelor's degree.	4.08	0.97	4.44	0.70	4.45	0.86	4.33	0.84
App Inventor should be taught in a master's degree.	3.79	1.35	4.11	0.93	4.41	0.91	4.10	1.06

Table III shows the results of the answers to the questions in Part 4. Apparently, students believe that App Inventor should be taught in a bachelor's degree, followed by a master's degree and a secondary education. The least approval comes to the assertion that App Inventor should be taught in primary school, and again here the standard deviation is very high, which shows a great variety in student responses.

The results of Table III were analysed according to the students' gender, the number of mobile devices they owned, their programming experience and the number of programming languages they used.

The Fig. 5 shows the results of the students' opinion, relative to their gender, about the level of education that is best suited to use MIT App Inventor. Both men and women believe that this environment is best to be used in the bachelor's degree. Men believe that the next level where App Inventor must be used is a master's degree followed by secondary education. Unlike men, women give the same assessment (4.18) of the possibility of using this environment in master's degree and secondary education. Women's results of all responses are higher than those of men, and the standard deviation is less.

The Fig. 6 shows the students' viewpoint about the level of education where App Inventor can be used depending on the number of mobile devices they own. For students who have one or two devices the most appropriate is the bachelor's degree, followed by master degree and secondary school. There is a difference in the group of students who have three mobile devices - they think that App Inventor should be used primarily in secondary school, followed by bachelor and master degrees.

The Fig. 7 shows how programming experience influences students' viewpoints of where to use App Inventor. Interestingly, students with the least experience as programmers believe that this environment should equally be used in both secondary and bachelor's degrees. The opinion of students with more experience is that the environment should be used in the bachelor's degree,

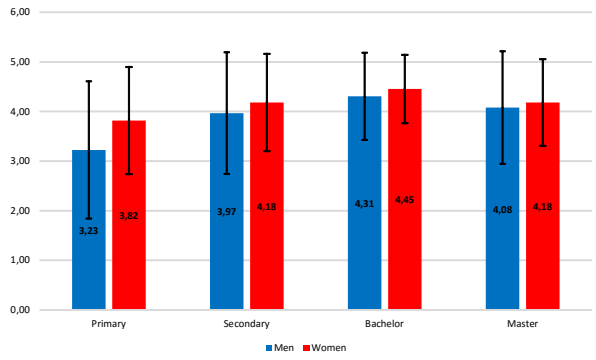

Figure 5. Students'opinion about using App Inventor in the education depending on their gender

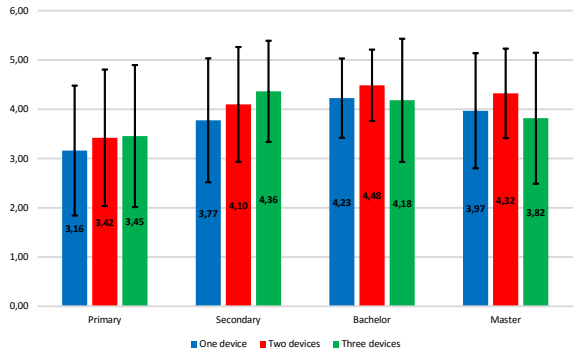

Figure 6. Students'opinion about using App Inventor in the education depending on number of mobile devices they own

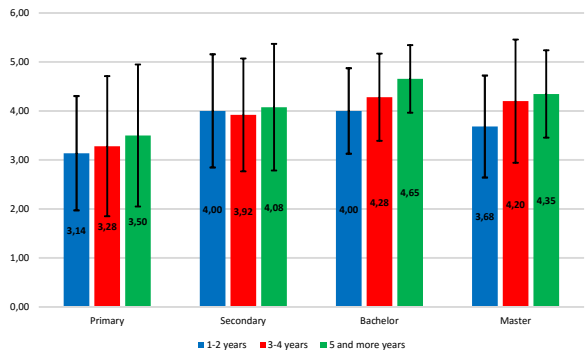

Figure 7. Students'opinion about using App Inventor in the education depending on their programming expirience

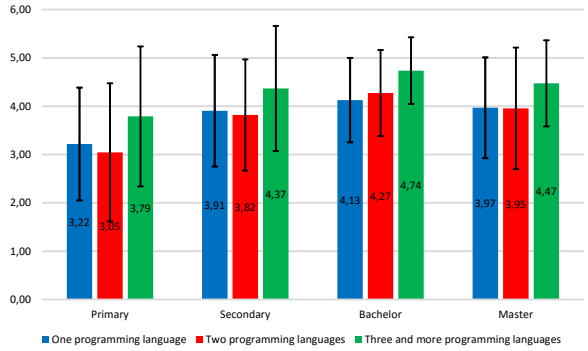

Figure 8. Students'opinion about using App Inventor in the education depending on their programming languages knowledge

followed by master's degree and then secondary school. The results show that when the students have more experience in programming, the average result of their choice is higher.

The Fig. 8 shows how fluency in programming languages affects students' attitudes of using App Inventor. The results show that, regardless of the number of programming languages they know, students believe that this environment should be used first in the bachelor's degree, followed by the master's and then in the secondary school. It can be seen that the more programming languages the students know, the higher are the ratings that they give to the statements.

V. CONLUSION

The analysis of the results from all the three years shows that, according to Ruse University students, MIT App Inventor is most appropriate for use in a bachelor degree of education, followed by a master degree and a secondary school. These results confirm the findings of the literary review.

The study shows that according to the gender there is not much difference in the students' opinion about where App Inventor can be used. Both men and women think that first of all it should be used in the bachelor's degree. The women are more categorical in giving higher ratings and less deviation than the men.

The analysis, depending on the number of mobile devices owned, shows two different results. Holders of one or two devices believe that App Inventor is best to be used in the bachelor's degree, while the holders of three devices find that it best suited to secondary school.

Depending on programming experience, there is also a difference into the results. Students with less programming experience (1-2 years) believe that App Inventor can be used in the secondary school as well as in the bachelor's degree by giving the same ratings. Students with more experience point out that this environment is best to be used in the bachelor's degree.

The analysis shows that the number of used by students programming languages do not affect their opinion. The students point out that App Inventor should be used firstly in the bachelor's degree, followed by the master's degree and after that the secondary school.

All results show that according to the students, App Inventor is the most unsuitable for use in primary school.

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Implementation of LMS Activities in the Adoption of ESP in Higher Education

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***Abstract* - Ever since they first appeared, Learning Management Systems (LMS) have had an important role in higher education. Their role has proven to be of extreme importance in the teaching of the English language for Specific Purposes (ESP). The reason behind their importance lies in the fact that they help activate the six levels of the cognitive domain in Bloom's taxonomy, which then facilitates and enhances the process of language adoption for non-native speakers. As the article deals with the adoption of ESP in higher education, the emphasis is on the students' acquisition of vocabulary, which paves the way for them to enter the world of their chosen profession beyond the borders of their native language. We have thus narrowed down the area of our interest to three LMS activities connected to the ESP vocabulary acquisition – *Glossary, Hot Potatoes, Wiki*. Nowadays, students at various engineering departments use LMS in their ESP courses, and hence, a case study approach has been examined in terms of their use of the above-mentioned activities and the advances students procure with the help of the system.**

Keywords* - *LMS, ESP, e-learning, higher education, Bloom's taxonomy

I. INTRODUCTION

As it has already been discussed, in order to fulfill its mission of educating competent professional personnel for the needs of the real economy, University North implemented Moodle, an open-source Learning Management System [8], which is one of the most successful and widely used e-learning systems in higher education. Moodle has been implemented by 230 countries, resulting in nearly 150 million users all over the world [1]. As the youngest public university in the Republic of Croatia which has in the previous years introduced a number of departments belonging to the area of Technical Sciences, University North constantly needs to follow the swift technological advances in computer-aided teaching in order to provide its students with the best possible learning environment [7]. This has proven to be of vital importance for the courses dealing with English for Specific Purposes. Students of Technical Sciences are faced with a double challenge. They not only have to acquire the knowledge of their chosen profession and follow the technological advances of their profession, but they also have to have good knowledge of the English language if they want to be competitive on the ever-expanding market. Apart from grammar, which is the foundation upon which other language skills are built [3], vocabulary should not be pushed to the background. Moreover, it should be noted that with the help of the Moodle platform, the processes behind vocabulary acquisition "awaken" the cognitive domains established according to Bloom's taxonomy. That is the case due to the fact that Moodle activities force students to activate the complex cognitive levels present in their brains, from knowledge to evaluation. Due to its functionality and intuitive user interface, Moodle can be satisfactorily used with just the course page and the most accessible activity types such as Resources and Assignments [5], but there is a myriad of other features that can be used to help students get acquainted with the various facets of the English language. Based on our previous research [8], in this study we have decided to narrow down the area of our interest to three LMS activities we believe best enable the ESP vocabulary acquisition – *Glossary*, *Hot Potatoes*, *Wiki*. We therefore took into consideration several case studies which examine the students' acquisition of the English language with the help of the above-mentioned activities. Moreover, we also examine the advances the subjects of those case studies believe to have procured with the help of the system. Since University North consists of many engineering departments, such as the Department of Civil Engineering, the Department of Electrical Engineering and the Department of Mechanical Engineering, we believe that by introducing those three Moodle activities, along with the ones already in use, and which we will discuss further in the paper, students will greatly advance in their overall language competences, but especially in their ESP vocabulary acquisition.

II. MOODLE ACTIVITIES AND BLOOM'S TAXONOMY

As multi-faceted as Moodle is, simply using Moodle will not make a course better by itself; only by applying effective educational practices can teachers truly leverage the power of Moodle [7]. At the University North, as it has been stated, Moodle is actively used, but its features, i.e. activities, have not been used to their fullest potential. There are 2200 enrolled students at the University North and 752 active Moodle courses.

TABLE 1. MOODLE USAGE STATISTICS AT THE UNIVERSITY NORTH (2018)

Moodle activity	Instances
Assignment	800
Database	10987
Forum	856

From Table 1, it can be seen that generally, the three most frequently used Moodle activities at the University North are the Assignment, Database and Forum. In all courses, including the ones dealing with English for Specific Purposes, these three activities have been and still are the dominant ones. Before further discussing the benefits of the three most commonly used activities, it is important to identify the six levels of the cognitive domain as categorized by Bloom's taxonomy. They are a very important feature of ESP teaching outcomes and one of the bases behind our choice of the three LMS activities we perceive as the most closely related to the ESP vocabulary acquisition. The following Table gives a synoptic overview of the six levels within the cognitive domain, from the lowest level to the highest level [8].

TABLE 2. COGNITIVE DOMAINS ACCORDING TO BLOOM'S TAXONOMY

Knowledge	define, list, name, order, recognize, relate, recall, repeat
Comprehension	classify, discuss, explain, identify, indicate, report, review, select
Application	apply, choose, demonstrate, sketch, solve, use, write
Analysis	analyze, calculate, compare, contrast, discriminate, examine, experiment
Synthesis	assemble, construct, create, design, develop, formulate, prepare, propose, write
Evaluation	assess, attach, choose, compare, predict, rate, select, evaluate

Assignment is a refreshingly simple method for collecting student work [7]. It is given out by the teacher who sets a deadline for the students to submit their work. Finally, the teacher grades the submitted work and it is usually followed by feedback. Generally speaking, the very fact that students have to carry out a certain written assignment develops their language skills, but in a much less interactive way than it is the case with other Moodle activities, especially when it is set up as a Peer-Reviewed Assignment, where students participate in the role of teachers by giving their input in the work of their colleagues by correcting their mistakes. According to Bloom's taxonomy, the cognitive domains employed by the Assignment activity are Comprehension, Application, Analysis, Synthesis, and Evaluation.

The second most used Moodle activity at the University North is the Database, which provides a tool for collaborative development within the course [7]. Basically, everyone enrolled in the course can share data with each other and use that data for learning. The reason why the Database module is a great tool for teachers of ESP lies in the fact that there is no limit to its potential uses – it can be used to create glossaries, catalogues, taxonomies, registrations, maps, anything students can fill in to form data [7], and consequently, make use of their previous language knowledge and further develop their new knowledge. The cognitive domains awoken by this activity according to Bloom's taxonomy include Knowledge, Application, Analysis, Synthesis and Evaluation.

Finally, the third most used Moodle activity at the University North is the Forum, which is a powerful communication tool within a Moodle course, because it is a primary tool for online communication [7]. It can be said that it establishes the social component of the course. Students can communicate with the teacher and, what is even more important in terms of language acquisition, they can communicate with each other – they can ask each other questions and answer them [9] and thus get the help they need when dealing with the course's content. The reason why Forum is an important asset in ESP courses lies in the fact that by giving students the option to discuss certain ideas with other students in their second language, in this case English, the teacher enables them to thoroughly think of what they wish to express and they can then take time to write down their thoughts, without the feeling of being pressured, which often happens in face-to-face communication. Communication on the Forum is asynchronous [7], allowing them to open a dictionary or a glossary, find various options for expressing their thoughts, which is also a means of developing their skills and knowledge pertaining both to grammar and vocabulary. According to Bloom's taxonomy, the cognitive domains employed by the Forum are Comprehension, Application, Synthesis and Evaluation.

However, the three LMS activities connected to the ESP vocabulary acquisition that we mentioned in the introduction – Glossary, Hot Potatoes, Wiki – will be discussed in more detail in the continuation of the paper.

As it has already been stated numerous times before, part of becoming an expert in any field is learning the vocabulary used by practitioners [7]. By being active in a certain field of interest, you not only use the already existing vocabulary, but you come up with new terms and concepts, actively creating a new language. In order to feel as a member of the chosen community and to be given the chance to further develop the knowledge acquired during the days at the university, one of the conditions is to become acquainted with that language. This is precisely where Glossary comes in hand. Although it may appear at first as a fancy word list, it is a powerful tool for learning [7].The teachers have at their hands a variety of features to develop shared vocabulary lists which can then be further edited and enriched. One other important feature of the Glossary is that it offers the opportunity to link every word entry to the text it first appeared in during the course, i.e. the students are given both the word and its context, which is the best way for learning and adopting new vocabulary. The cognitive domains involved in this Moodle activity include Knowledge, Application, Analysis, Synthesis, and Evaluation.

Since assessment is one of the most important features of the learning process, both for the teacher and the students, tests have been introduced as the main means of assessing the students' knowledge. However, due to the Hot Potatoes activity, things can be spiced up a bit. It is one of the most complex activities in the Moodle system, requiring a lot of time and effort. It covers the testing of basically all main elements of a language, from grammar and vocabulary to reading and listening [8]. Teachers can

create quizzes with different question types, randomly generate quizzes from pools of questions, allow students to re-take the quizzes multiple times and then have the computer score everything [7], which is another bonus as immediate feedback is given to the students. The Hot Potatoes activity requires a lot of energy from the teacher in the creation process, but it also requires a lot from the students, starting from their own attention, active recognition and use of the knowledge they acquired during the duration of the course. Hence, the five cognitive domains that are involved in this activity are Knowledge, Comprehension, Application, Analysis and Synthesis.

Last but not least, the Moodle activity we have deemed as important in the ESP vocabulary acquisition is the Wiki. As its very name suggests, it is built along the lines of Wikipedia, i.e. it is a collection of collaboratively authored web pages [7]. Students are the ones who actively create and edit the web pages. To be more precise, the activity functions by allowing the students to edit the already existing page or to add more pages to it by creating links to new pages that do not exist yet [7]. Moreover, wikis are a very powerful tool because they also work on the social component of the course, teaching the students how to work together in the creation of new content, leaning onto both their own knowledge and the knowledge of their colleagues. Hence, they not only expand their own knowledge, but actively learn from others and through it, adopt the skills of working in a team. They also adopt a new set of valuable information shared with them by their colleagues. The cognitive domains that are employed by this Moodle activity are Application, Analysis, Synthesis, and Evaluation.

III. MOODLE ACTIVITIES AND STUDENT FEEDBACK

After gathering information on the most frequently used Moodle activities at the University North, closer attention was paid to the improvements that could be made by introducing new activities. Numerous studies [5, 7, 8, 9, 10] on the use of Moodle activities have been carried out, but since this paper is primarily concerned with the acquisition of ESP vocabulary, we have narrowed down our research to the case studies dealing with the implementation and application of the Glossary, Hot Potatoes and Wiki activities, which we, as it has already been stated before, see as beneficial in the context of ESP vocabulary acquisition.

It is important to note that in the context of language courses for specific purposes, the use of groupware activities such as Glossaries and Wikis has enabled teachers to design a learning environment which allows students to asynchronously participate in collaborative tasks, sharing or jointly constructing their knowledge of specialized lexis or relevant content [2]. Hence, Glossaries are one of the best methods for a joint construction of databases which are then useful for the students both in their final exam preparations and in their future work as autonomous professionals.

A case study in terms of creating and using the Glossary for the purposes of ESP vocabulary acquisition was carried out at the Universidad de Navarra. The basic idea underlying the creation of an ESP glossary was that writing entries would help students in the revision of their knowledge of the concepts and terminology for their final exam [11]. Another important idea behind the creation was that they would also practice giving explanations of key concepts in their second language, which is a skill important for their future professional progress [11]. However, the activity was also perceived by the authors as an important feature of the social component of Moodle, i.e. instilling the sense of team work in the students' behavioral pattern. Once the students carried out their task until the end, reaching their final goal of creating an ESP glossary which would help them in their preparation for the final exam, the authors asked them for their feedback both regarding the entire creative process and the final impact they felt the Glossary had on their ESP vocabulary acquisition. The majority of the students gave a positive feedback. They felt that the task had been useful in helping them to consolidate their knowledge of vocabulary and their understanding of difficult concepts, and that the final product had helped them to study for their exam [11]. It enriched their vocabulary, which we see as the main goal behind this activity in terms of ESP learning. Moreover, some students even commented that they had enjoyed using the Moodle activity, i.e. that they felt satisfied as it helped them create a final product which was useful not only to them, but to the class as a whole [11]. Their feeling of contentment strongly emphasizes the social component of the Glossary activity, which helps the students feel as part of the collective. However, there were certain traits of the whole process which the students perceived as negative and which should be taken into account by the teachers. Despite the clear structure of the task and the timescale in which it was expected that the Glossary be completed, some students expressed uncertainty about the quality of the colleagues' entries, which highlights the need for a firmly fixed deadline and explicit criteria for when teacher intervention is necessary in the evaluation of student contribution to the Glossary [11]. Therefore, it is important to note that it seems necessary that the final contribution to the Glossary be done by the teacher, i.e. the teacher should perform the final corrections to the terms, because that action serves as a guarantee that students will completely trust the Glossary and use it as a valuable tool for their final exam preparations [11]. Based on this case study, it can be concluded that the Glossary activity could function as a complementary part of face-to-face lectures when it comes to the ESP vocabulary acquisition. By setting up the activity within a set deadline, students are forced to carry out timely research in the target language and then use the target language in writing and later on in the adoption of terms in the target language. That complex process covers the five cognitive domains according to Bloom's taxonomy that we mentioned above – Knowledge, Application, Analysis, Synthesis, and Evaluation. It should be noted that this type of active learning approach complies with the project work envisaged in the Bologna framework for undergraduate degrees [11].

When it comes to Hot Potatoes, more and more teachers are becoming aware of the advantages this activity may have on the acquisition of ESP. However, as we have already mentioned, this is one of the most

complex features of Moodle and it requires a lot of effort from the teacher in creating it. The Hot Potatoes activity is especially suited to work with cloze and multiple choice exercises to practice grammar and vocabulary, i.e. practically all activities pertaining to the Use of English can be carried out with the help of this activity [4]. What it is also important to mention, a gamified approach can be implemented, which stimulates a greater number of students to actively participate in the activity. The majority of case studies approach the Hot Potatoes activity from the teacher's point of view. However, this is not unusual because in its essence, the effectiveness of the activity does indeed depend on the use the teacher manages to make of it. A case study carried out at the Payam Noor University showed that one of the main benefits of the Hot Potatoes activity is the tremendous increase in the extent of exposure to and interaction with the target language outside the classroom environment [6]. This activity successfully prompts students to pay attention both to the content they are reading and to the language they are adopting, which awakens the various cognitive domains of Bloom's taxonomy mentioned in the text above. The case study comes to the logical conclusion that if the Hot Potatoes activity is successfully combined with appropriate content and motivated learners, ESP learning will be highly facilitated [6]. The main issue of the activity in terms of vocabulary acquisition lies in the fact that the program is limited to a one-way production, i.e. teachers produce tests which students then solve, as opposed to the Glossary and Wiki activity, which directly and interactively engage the students in terms of language production. Since the emphasis is primarily on the teachers and their acquisition of the activity's technical aspects, there is a lack of case studies dealing with the students' perception of the activity and their feedback on it. The idea suggested by many researchers is that the future editions of the activity should try to focus on an additional possibility of learners' independent use of this activity, which would be greatly beneficial to the ESP vocabulary acquisition.

As far as the Wiki activity goes, the process is in fact very similar to the Glossary activity. Emphasis is yet again on the social component of Moodle, i.e. Wiki is a collaborative activity which functions only if all students are included in the creation process. A case study carried out at the Balıkesir University concluded that the Wiki activity plays a major role across the entire spectrum of the Use of English. Wikis encourage learners to enhance inquiry learning and critical thinking; but most importantly, Wikis facilitate basic language skills and grammar and vocabulary knowledge in both integrated and isolated manners [12]. However, student participation yet again proved to be a slight issue, which brings us to the conclusion that teachers simply have to assume the role of moderators by overseeing the entire process and intervening at the end of it by checking whether everything was done correctly in terms of grammar and vocabulary use, since that gives students a certain sense of trust in the final product. Teachers should also set a firm deadline to prevent certain students from not doing their job in time and hence failing the class as a whole. Wikis are a learner-centered environment in which learners construct their knowledge with the help of their colleagues and teachers as facilitators [12].

As it can be seen from the case studies and student feedback, Moodle activities are an essential component of the ESP learning process. Moodle is a very powerful technological tool which can, if approached correctly, be of great value to language teachers. As important as face-to-face lectures are, the blended learning method offers many new possibilities in the development of the students' skills and knowledge. However, it should be noted that the role of the teacher is indispensable [8], whether in terms of creating an interesting Hot Potatoes quiz or simply in terms of moderating the Glossary activity. Student feedback also gives teachers a very important and valuable insight into their perception of various activities when it comes to the ESP vocabulary acquisition. At the beginning of our study, we believed that the Glossary, Hot Potatoes and Wiki activities would be the best ones when it comes to ESP vocabulary acquisition. According to case studies, that was first and foremost the case with the Glossary activity, while the Hot Potatoes and Wiki activities, while indeed helping the students with their vocabulary acquisition to an extent, also have certain setbacks which influence both the final product and the students' attitude towards the activity. Teachers must be very careful when it comes to their role in the entire process, because as autonomous as students are in their use of Moodle activities, certain boundaries must be set, especially the ones pertaining to the timeframe in which the students have to finish their tasks since the entire class depends on every individual in the process. Moreover, teachers must be aware of the importance of interactivity, which is one of the crucial factors in ESP acquisition.

IV. Conclusion

In the ever-expanding competitive market, in order to become an invaluable asset in the chosen profession, students must, apart from the knowledge they acquire of their profession during their university days, render their knowledge of the English language, or to be more precise, of the English used for Specific Purposes. During their formal education, their teachers take on the role of introducing them to the ESP language learning world, and it is of vital importance that teachers be aware of the role vocabulary plays in this process. At the University North, which consists mostly of departments belonging to the area of Technical Sciences, teachers use Moodle as a supplement to face-to-face lectures. Apart from the standard Moodle activities such as the Assignment, Database and Forum, ESP teachers at the University North wish to expand the number of Moodle activities by using the activities such as the Glossary, Hot Potatoes and Wiki. When examining the case studies already conducted in terms of the three mentioned activities and ESP acquisition, our belief that the introduction of new activities would help students in their ESP vocabulary acquisition proved to be correct, with a slight exception in the case of the Hot Potatoes activity. The mentioned activities give teachers a great possibility to help their students become better at ESP learning, all the while being on a par with the swift ICT advances in the world of higher education.

In this light, this paper can be perceived as a framework for carrying out a case study of implementing the above-mentioned Moodle activities in ESP courses at the University North, where many engineering departments operate.

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ICT competences assessment through ICT escape room

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Abstract - To assess the ICT competences most frequently tests or work assignments are used. Tests are more reliable because they are conducted in the controlled environment, but they are also time limited and stressful and consequently not entirely encouraging surrounding for competences' assessment. Work assignments are usually more time consuming, done outside the controlled environment, hence less reliable. Initial intention of our team was to prepare alternative type of tests of the IT competences using the concept of escape rooms. In our experiment, person or two cooperate solving IT problems to gain "freedom" at the end, i.e. to unlock the escape room. In this environment, the stress is inherent but with fun components. Participants do not feel the context as a test environment and the stress of failure is less evident. Each participant in the experiment can learn his or her IT weak points. It takes around one hour to find the way out of the room and another half for discussion. Participants are asked to complete the survey before the entrance into the IT escape room and this survey is later used in the discussion, which is the base for the qualitative analysis. One of the conclusions from our analysis is that it is not easy to prepare the suitable assignments and clues to solve them. Additionally, we discovered that there are problems of understanding of the IT terminology hence the help clues, which are perfectly understandable to the ICT specialist, are generally not suitable for experiment's participants.

Keywords: Education, IT, Competences, Assessment, Escape room

1 INTRODUCTION

We can observe in Slovenia and other EU countries that use of ICT in education lacks behind the use of ICT among the general population. What we have observed in the past few decades, and consider it as transient phenomenon, have become an undeniable fact. Teachers report that despite kids have ICT equipment they do not use it for the educational purposes. There are two possible reasons for this:

1. they do not know how to use it or/and
2. schools do not have resources (tools nor knowledge).

It is even worst; schools have ICT equipment, but it is rarely used. Available ICT equipment is not enough; competent teacher should be the one to use ICT equipment effective and didactically suitable. The odd thing is that even after extensive training [1] teachers' behavior did not change significantly. Teachers show they are capable to use the ICT equipment on the training but not in the classroom. Between 2017 and 2018 Ministry of Education funded a project where all Slovenian teacher training study programs participated [2] and where current study was conducted.

We started researching the competences in education in 2008 with the project "Development of natural science competences" [3]. Since then we develop and test procedures further; we gained significant insight into competence assessment; but we still lack the reliability of the competence assessment. We can prepare the test to grade the knowledge or skills, but competences are still more or less soft assessed and influenced by observer or individual who performs self-assessment. In the past years, we have cooperated with the colleagues from natural science department who addressed the problem of use of ICT in education and study different outcomes. They focused on the use of ICT in lab work and the influence of ICT used in education to the students of educational study programs. [4] [5] [6] [7] [8]; and use of ICT as simulation tools to gather the insight to the natural phenomena that are hard to analyze during the experimental exercises (lab work) [9].

One relatively new method of educational gaming involves adapting the popular entertainment activity of the "escape room". Escape rooms are "*live-action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to accomplish a specific goal (usually escaping from the room) in a limited amount of time.*" [10]. Educational escape rooms generally operate in the same manner, but the clues, puzzles, and solutions pertain to specific learning objectives. From an instructional standpoint, escape room games are collaborative, task-centered, time-based, and provide immediate feedback, which make them an attractive consideration for in-class learning activities [11].

We wanted to make informal test where participants would be intrinsically motivated, where they would feel the need to find the solution of problems based on the clues. Such environment would be much more suitable for competence assessment than assignment where individual just follow predefined sets of action and solve the problem. With this in mind, we have decided to design an ICT escape room and test it among our colleagues and students.

2 ICT ESCAPE ROOM DESIGN

In the design of the ICT escape room, we wanted to design tasks that are common in the classroom where ICT is available. We have analyzed the most common problems teachers experience in the classrooms. We have verified the selected topics with school ICT professionals. In the ICT assignments, we have prepared the scenario, which would lead the participants to the final task – finding the key to get out of the room. Our goal was to include hardware, software, and communication topics. In our scenario most of the participants would get to the end, though they find different routes through our ICT maze. Time requirement for participants to solve all different puzzles in the ICT escape room should be 45 minutes, however it generally required a little more time. One hour solving time was our limit and then we stopped the processes. On Figure 1 we present outline of our scenario with tasks and riddles that participants had to solve it.

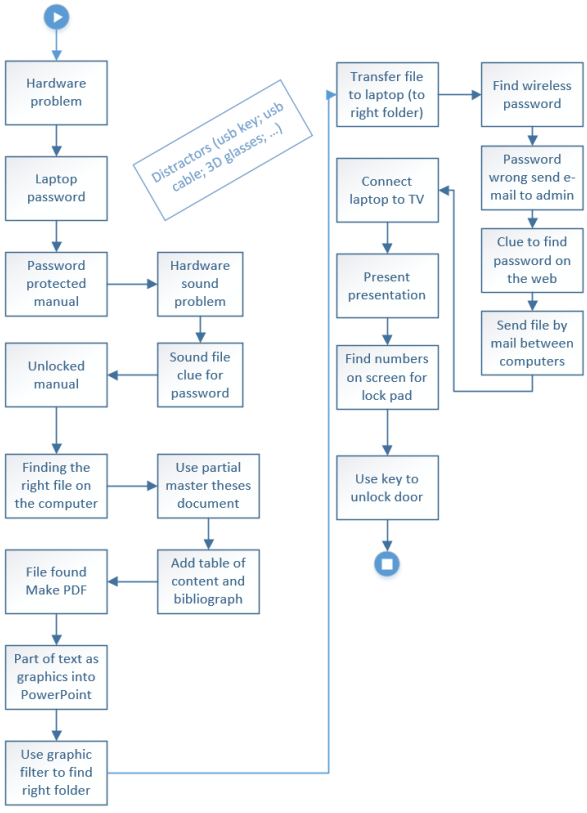

Figure 1: Graphics scenario for ICT escape room

ICT escape room does not need big space; small corner in the classroom is enough, as shown on Figure 2. We designed the room to be very similar to the usual setting in the classroom. There are two computers, one stationary PC and one laptop. PC has connection to the internet using Ethernet cable but no wireless capability. Laptop on other hand has disabled Ethernet port and it is not connected to the internet but has wireless capability. There is also wireless router on the table and around the computer corner there are scattered some objects (on the wall; on computer screen; in the name of the files …) with previously mentioned clues and distractors (3D glasses, broken USB key, etc.) that are there to confuse participants but don't have any role in the scenario.



Figure 2: A 3m x 3m setting is enough to prepare ICT escape room

Clues can be found around the setting as well on the computers, participants just need to look carefully. Two clues are presented on Figure 3.



Figure 3: Different clues are displayed around the working area

Next, we describe different topics that we included in our ICT escape room.

A. Background story for the ICT escape room design

Every escape room needs a background story, which gives context. Participant(s) (up to three) who enter the ICT escape room get the initial story that gives him or them a clue how to start. During the process of solving the puzzles in the ICT escape-room, new stories with the

clues are uncovered. Uncovering new clues determine the stages where the participant(s) are in the scenario (see Figure 1).

B. Hardware topics

Most common problems that teachers encounter in the classrooms are related to the power plugs. We have prepared the computer and unplugged it from the power line (as students sometimes do to teachers). The first task that the participants need to solve is to find the power cord and plug it to the stationary computer to power it up.

Powering the laptop up, the second problem arises; the laptop is protected with the password. In general, this is the situation in most of the classrooms and the password is somewhere to be found. In our case, the password for laptop is displayed on the background image of the stationary computer. If participant wants to enter arbitrary password on the laptop, the hint points him to the stationary computer.

At the end of scenario, we have additional hardware task where participants need to connect laptop to the TV and set up the projection.

C. Software topics

Software topics are divided into the two subtopics. One requires setting up computer and the other is office tools oriented. In the setting up participants are required to find password for password-protected file. On the laptop the speakers are turned to low volume and sound files default open setting is set to open sound files with wrong program.

Office tools phase consists of more tasks, find right file to open in word processing application, where they need to prepare:

1. table of content and
2. insert bibliography and
3. count words in document;
4. convert the text to pdf,
5. capture screen of the pdf file and
6. insert the captured image into presentation application on specific slide in the background of all other objects on this slide.

D. Communication topics

At the beginning, only the stationary computer has internet access. To find the key of the room the participants need to transfer file from stationary computer to the laptop. There are different clues on how to setup connection on the laptop. Automatic mail response system from system administrator gives clue where to find wireless password. To make system more realistic the Ethernet (wired) connection on the laptop is disabled. This often happens when user does not have administrative privileges on the computer where they supposed to have presentation. Provided USB key is intentionally broken, therefore, they need to find the way to transfer file from one computer to another using email or any other means (file transfer, Dropbox, etc.).

E. Help clues

The participants may ask for help if they feel incapable to find a solution. However, we provide help on our own if we see that participants are stuck in the perpetual loop. We have prepared help in different parts of the process and are generally in the form - read text carefully; examine something; see what is written somewhere...

3 COMPETENCES AND ICT ESCAPE ROOM

In the beginning of the ICT escape room design, we knew that practical constraint would limit us in the testing of the potential competences. Searching the solid background for ICT competences, we decided to use DigComp 2.1: The Digital Competence Framework for Citizens [12]. On the other hand, we wanted to test competences needed in the most common ICT situations that can occur in the classroom. Time constraints and practical value of the ICT escape room prevented us to test all competences and levels from DigComp 2.1. In general, our competence test covers all 5 topics:

- Competence area 1: information and data literacy;
- Competence area 2: communication and collaboration;
- Competence area 3: digital content creation;
- Competence area 4: safety;
- Competence area 5: problem solving

According to the DigComp 2.1 we could test previously mentioned competences on eight proficiency levels, but it could not be done within the desired time constraints.

4 ANALYSIS

In the context of the analysis and evaluation of the ICT escape room we included 24 subjects who volunteered to participate in the initial or upgraded scenario version of the ICT escape room. The participants were between 17 and 53 years old, (M = 33.83; SD = 9.87), half of them being males (50.0 %). In the first scenario version (the initial phase), three advanced ICT users participated in the single-user context. In the second scenario version (the upgraded phase), 21 participants with various levels of ICT expertise participated in the group context. The objective of the initial phase was to gain the first insights into the ICT escape room dynamics, concretely, to test the separate segments of the scenario and possibly to improve them. The objective of the upgraded phase was to gain as much as possible feedback information from the users in the fixed scenario context of the ICT escape room. In both phases participants at the beginning, i. e. before entering the room, filled short evaluation questionnaire concerning some basic information about respondents' ICT use, attitudes towards ICT and self-evaluation of ICT competencies (some of the scales were adapted and elaborated from the instruments in [13] [14] [15];. Then they entered the ICT escape room. After finishing the ICT escape room, test subjects participated in the short (evaluation) interview and filled the questionnaire with the self-evaluation of ICT competencies again. The dynamics in the ICT escape

room was monitored by two to three observers who intervened in the process in the case of explicit demand for help of the participants or in the case of the perpetual loop of the participants. In the upgraded phase, the observers also used short screening scheme of the ICT escape room scenario to gain approximate information about the duration of separate segments, the order of the segments, number of potential clues, and evaluation of the performance of separate segments in the scenario. With the strict consent of the participants (those who signed the informed consent form), the dynamics in the ICT escape room was recorded on camera for the analysis and evaluation purpose only.

In the initial phase, three males participated who were above intermediate or advanced ICT literate. The process in the ICT escape room lasted from 38 to 50 minutes (45 minutes in average), with several interventions (clues) mostly regarding the text in the instructions and segments in the scenario related to content creation in the office tools environment. All participants in this phase evaluated their experience in the ICT escape room as positive. Based on the observation of the process in the ICT escape room and feedback information in this phase we made some changes. We slightly modified the instructions and clues for the average ICT user who have problems with the proper understanding of ICT terms to better understand what he/she needs to do but we did not make any drastic intervention into the initial scenario. The difference between the version of the ICT escape room scenario in the initial phase and the version of the scenario in the upgraded phase was thus marginal. The outcome of the initial phase was elaborated and finalized scenario, tested in the next phase of analysis and evaluation.

The analysis and evaluation in the upgraded phase were more thorough and exact since we had a fixed scenario of the ICT escape room and screening scheme. Also, potentially we gained more information since the participants worked in a group of two (dyads) and in one session in a group of three.

On average the session lasted approximately 54 minutes (range from the app. 39 to the app. 64 minutes), with one dyad not resolving the scenario in one hour and an additional extra five minutes.

There was variability in a number of help clues, ranging from 1 to 25, with median 5.

From the perspective of the segments in the scenario, the steps from hardware problem to finding the right file on the computer, addressing the digital competency of (ICT) problem solving, lasted app. 8 minutes (range from 4 to 13 minutes).

The steps from use partial master theses document to use graphic filter to find right folder, addressing the digital competency of digital content creation, lasted app. 27 minutes (range from 12 to 40 minutes)

The steps from transfer file to laptop (to right folder), to transfer file between computers, addressing digital competencies of communication and collaboration and information and data literacy, lasted approx. 11 minutes (range from 7 to 16 minutes).

The most time consuming were steps addressing digital content creation (in office tools environment). This phase also required the most help clues from the observers and with more moderate estimates of the performance from the perspective of participants.

Generally, the participants evaluated the experience of the ICT escape room positively, with an average of 4.45 on the 5-point scale where 5 is the best score.

In the scale of self-evaluation of ICT competencies, the scores on the 5-point scale before entering the ICT escape room and the scores after the finish in the phase of evaluation were generally comparable. Three exceptions were detected:

1. There was a significant difference in the scores for competency of resolving ICT problems before entering the ICT escape room (M=3.23; SD=1.02) and scores after the finish of the ICT escape room (M=3.95; SD=0.90); t(21)=-3.46, p=0.002;
2. There was a significant difference in the scores for competency of use of office tools before entering the ICT escape room (M=4.27; SD=0.55) and scores after the finish of the ICT escape room (M=3.73; SD=1.08); t(21)=2.32, p=0.030;
3. There was significant difference in the scores for competency of production of project work before entering the ICT escape room (M=4.23; SD=0.75) and scores after the finish of the ICT escape room (M=3.86; SD=0.77); t(21)=2.94, p=0.008.

Participants emphasized as positive the selection and nature of the tasks or problems in the scenario. They have positively related the scenario to the real-life experiences with ICT. The same positive experience was expressed in the context of gaming and pleasure.

The most negative experiences of the participants were related to the (self-)criticism about the text of the instructions; specifically, about their limited concentration regarding the exact content and meaning of the instructions.

The most useful suggestion from the evaluation phase is related to the digital competency of safety. This competence assessment was not initially planned to be in the scenario of the ICT escape room. Since some of the participants mentioned it in the interview, we added the possibility to evaluate this competency to the ICT escape room, and especially in the phase of evaluation of the ICT escape room experience (interview). Thus, it is possible to track personal digital footprints in the context of participants being in the ICT escape room, and in the phase of interview highlighting this important aspect of ICT use.

5 CONCLUSION

Competences assessment is not as simple as knowledge assessment. It generally requires assessment of knowledge, (transferable) skills, and (personal) attitude. The ICT is used in everyday life and in the education as well. What is the effective use of ICT in

education is a debatable question. Kids often use their ICT gadgets as their body extension for communication and fun. The possession of the ICT gadget does not imply they will be used properly in the education. Teaches need to be ICT competent to teach kids how to use ICT in education. In the course of our project, where we wanted to discover why teachers do not use schools' available ICT effectively, we have find out various reasons. Even if teachers have successfully completed ICT courses they generally acquire knowledge but not competences to use the knowledge effectively. As one of the way to test the ICT competences in "fun" way we prepared the ICT escape room. Our intention was to get the insight to the ICT competences of most common situation that may occur in the schools' environment. We prepared the scenario to test hardware, software, and communication skills of the participants. In course of planned 45 minutes the participants solve different ICT problems to find the exit of the ICT escape room. Most participants needed around one hour to complete all required tasks. Analysis has shown that test subjects generally assess their ICT competences higher in some topics which proved them wrong in the ICT escape room. The most significant finding would be:

- People are lazy (superficial) readers
- ICT terms are not properly understood (this is the problem of education)
- Preparing the ICT room is fun but preparing the proper clues (instructions) is much harder task.
- ICT escape room is fun and highly graded among test subjects.

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Experiences from Digital Learning Analytics in Finland and Sweden: A Collaborative Approach

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***Abstract*—Digital learning management systems (LMS) are revolutionizing learning in many areas, including computer science education (CSE). They are capable of tracking learners' characteristics, such as prior knowledge, and other learning habits, and may offer more personalized learning or guidance on useful learning practices. LMSs collect large amounts of data. Proper processing of such collected data can offer valuable insights about the learning process, support for higher quality education, insights on why some students drop out of courses, and so on. In this paper, we briefly review and discuss the global trends in digital learning and learning lnalytics (LA), specifically from the viewpoint of two LMS systems and related LA research, one in Finland and one in Sweden. In this paper, we address the context-, and course-specific nature of LA by developing the idea of cross-country and cross-systems learning analytics. Second, we consider our research especially from an educational perspective to identify the most beneficial practices for teachers and students. Third, we discuss, based on findings from our projects, future avenues for research.**

***Index Terms*—learning analytics, digital learning**

I. Introduction

Digital learning management systems (LMS) are revolutionizing learning in many areas. In computing, a vast array of learning management systems (LMS) are being used in teaching many topics, especially programming, in schools and universities, globally (eg. [1]). Modern LMS systems are often web-based, and they are labeled as adaptive, semi-intelligent, offering a range of learning content and supportive tools and services for learning content creation and management. LMS systems can track learners' characteristics, such as prior knowledge [2], and other learning habits, and may offer more personalised learning [3] or guidance on learning practices that are beneficial for personalization. These modern approaches are already having major implications to education.

Learning management systems collect a lot of data, which is being analyzed by research under the titles of learning analytics (LA) or educational data mining (EDM) [1], [4]. Proper processing of such collected data can offer valuable insights about the learning process, support for increasing learners' success, insights on learner's dropping out, and so on. In addition to many opportunities of LA, there are challenges, too. Among the challenges is that a large amount of LA and EDM research in CSE has focused on simple metrics analysis and has been conducted in the context of a single institution or a single course (eg. [1]). Other challenges are how to use the collected data in the most beneficial ways, as well as ethical issues. A review, in 2014, concluded that: *"To date, the complementary disciplines of learning analytics and educational data mining have focused predominantly on analyzing data systematically gathered in educational settings, which at the tertiary level includes factors of prior academic performance, demographic data, such as age and gender, and data gathered by logs recording student behaviour in online learning environments."* [4]. Moreover, it has been argued that important variables, such as ability, personality, motivation, self-regulation—while being well-proven predictors of academic achievement—are not much included in learning analytics [4]. In CSE, much of the analytics research is still done in the contexts of single courses and institutions (eg. [1]), lacking a holistic and generalisable approach to research.

In this paper we discuss the global trends in digital learning and LA from the viewpoint of two research groups on learning analytics, one in Sweden and one in Finland. With this paper, we have the following aims. This article aims to find answers to the following questions.

1) What are the most beneficial practices for teachers and learners in digital learning resulting from our research?
2) What are the most promising ongoing research approaches in our research efforts in learning analytics?

The rest of the paper is organized as follows. In Section II the background of digital learning in computer science (CS) is presented and our two educational systems are briefly described. Section III discusses the learning analytics research in our systems. Discussion about further possibilities for joint work and cooperation and influence of emergent development that e-learning offers to different educational stakeholders is given in Section IV. Section IV-D concludes the paper.

II. Background: Digital Learning in CS

A. Digital Learning Overview (Stockholm)

The case study from Stockholm focuses on the department of Computer and Systems Sciences (DSV) at Stockholm university and its learning management system iLearn, which is an instantiation of the commercial tool Moodle, and the thesis management system SciPro [5].

iLearn is used at DSV to manage the course contents and student-teacher interactions in the courses offered to students.

As the unit that is responsible to support the university teachers to use digital tools in education, DSV manages all the online and on-campus courses in iLearn. DSV, at the moment, offers at least three Masters programs completely in online fashion. There are a significant number of students enrolled in 29 distance courses. In addition, there are 18 other bachelors and masters programs using iLearn to manage contents, submit assignments, peer collaboration, group activities as well as digital examination. Courses in iLearn are structured to follow a carefully chosen pedagogy, which is well-grounded in learning theories, and well tested evaluations (eg. [6], [7]).

SciPro is a system that is developed by DSV for managing students at bachelors and masters levels with a main purpose of finding relevant supervisors for students' thesis projects based on interests of the supervisors and the needs of the students [8]. SciPro supports communication during many levels in the thesis process. SciPro answers to the needs to increase quality of thesis projects, and the rights of students to receive proper feedback in reasonable time [9]. SciPro facilitates peer communication during peer review process [10]–[12], student-supervisor communication [6], and efficient thesis writing [13]–[15]. SciPro brings flexibility to meetings between students, supervisors, and examiners to plan, discuss and exchange information efficiently [6], [10]. The quality control of theses is automatically done in SciPro with integrated plagiarism control [16], [17]. The use of SciPro has significantly increased performance in thesis writing [6].

B. Digital Learning Overview (ViLLE)

The development of ViLLE started in 2004 at the Department of Information Technology, University of Turku, Finland. The first edition was mostly a program visualisation tool. Over the course of time, through massive development efforts, ViLLE has grown into a full scale learning tool, with extensive digital tools for learning, tools for learning material creation, and tools for learning analytics (see [18, pp. 17–34]).

Through the development lifecycle of ViLLE, research has increasingly become one pillar for development. This means that the functionalities and pedagogical approaches are evaluated through research. Through these efforts, a number of features that are beneficial for learning have been identified, which include automatic assessment, immediate feedback, support for a range of exercise types, and teaching modes such as pair programming [19], [20]. Positive results for learning and teaching have been demonstrated in numerous introductory computer science and basic mathematics courses both in university and high school courses [18], [20].

ViLLE has gained a lot of popularity in Finland [20]. Finnish school teachers, all of whom hold a higher university degree (master's level) in education, are autonomous in selecting learning tools of their preference, which means that teachers must perceive digital learning as significantly beneficial in order for them to use it. In schools, ViLLE is currently being used in teaching of a wide range of topics. ViLLE is actively used in a large number of courses at schools, universities, and polytechnics institutes in Finland. In universities, ViLLE is being used in various computer science courses [20], [21]. Using ViLLE as compared to traditional instruction has improved learning outcomes in programming courses in high school [18, 39–41] and in various CS courses at university [18, 41–42], [18], [22], [23].

III. Thematic Overview of Research

A. Learning analytics research (Stockholm)

The learning analytics group at DSV with its extensive networks with research organisations, industry, and society, conduct research both with its digital platforms (iLearn and SciPro), but also extensively with respect to other cases and systems nationally and internationally. The research is grounded in learning theories and aims in using learning analytics and artificial intelligence in enhancing education. Together with the researchers and other stakeholders who share the interest in tracing learning, understanding learning, and improving learning with the support of LA and AI, DSV's LA research broadly covers advances in learning analytics and artificial intelligence for education, including but not limited to the topics of tools and methodologies for LA for education, applications of LA for education in real-world settings, and, theoretical perspectives on LA for education. More specifically, our research focuses on the following themes, covering education from primary school to higher education.

1) Learners' activity, interactivity, engagement and motivation: Learning management systems (LMS) harbor a lot of data, but until recently that data has been a largely unused source of information for pedagogical decision making. Relying on the log data in LMS for decision making on the other hand is challenging due to the variations of the information richness of this data. Understanding learning engagement as part of learning activities in online courses is one of our research tracks [5], [24]–[26]. For example, in one masters course for research methods in computer science [7] a clear difference between the click logs of high and low performing students is shown (see Figure 1).

Fig. 1. Average clicks of excellent, good, fair and failed students.

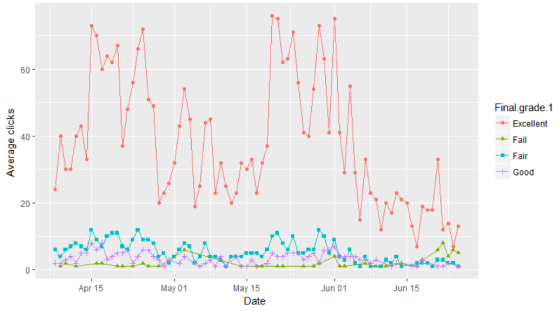
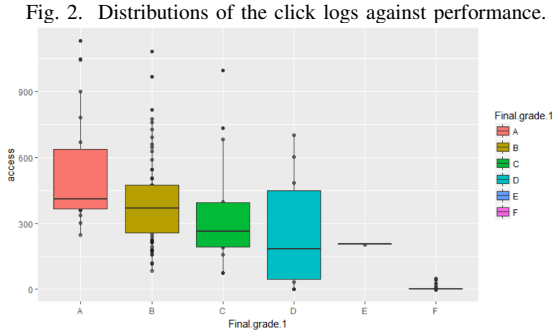


Figure 2 shows that there are significant differences of behavioural patterns of high achieving and low achieving students. For instance, students who fail to complete the course have the minimal logins in the LMS in the beginning of the course. Such indications perhaps could be an alarm for the teacher for early interventions on the course for reducing the

Fig. 2. Distributions of the click logs against performance.



failure rate. Our further research on the matter [26]–[28] have shown particular applications of log data to measure learning scenarios, such as lifelong learning, self-regulated learning and collaborative learning.

2) Evaluate, inform and develop current teaching practices and learning designs: Another important line of research has been support in thesis process with increasing communication and peer learning [6], [24]–[26]. This line of research has investigated how to design the thesis process to support increased communication and peer learning [6], how students' temporal behaviors in digital learning platforms can predict performance and learning and form the basis for formative feedback [24], how learning analytics can be used to better understand and through feedback to support collaborative learning [25], and, how the engagement in the LMS throughout a span of a professional development course explains the throughput of the course [26].

3) Technical applications: machine learning, data mining, predictive analytics, social network analysis and network modelling: All the LA studies conducted at DSV follow at least one of these techniques. The use of complex machine learning techniques for building predictive models that explain the performance of prospective students based on data of previous courses has been demonstrated in studies [27], [29], [30]. In [29] flipped classroom contexts to predict low and high-performing students in a part to provide automatic formative feedback using machine-learning methods is discussed. With a pre-hypothesis that social network analysis may be of significant value in studying online collaborative learning, in one research [27] student collaboration in a digital learning platform was investigated. The results show that social network analysis can enhance the understanding of the collaborative process, predict the under-achievers and uncover the dynamics of students' interactions [27]. The results further show that some students took teacher or instructor roles in the collaboration process, and that social network analysis was powerful in classifying students according to their achievements [27].

4) Improve feedback practices and support personalized learning: Analysis of behavioral patterns of students can inform pedagogical and institutional decisions [30]. On the level of classroom, patterns in learners' behavior reflected in the data can inform the feedback teachers provide to learners, this feedback, in turn, can inform a conscious effort in learners to improve their studying habits and learning strategies. Our studies in this line have shown that systematic employment of formative feedback can support self-regulated learning [24]. Also, we are planning a research study to build on our previous work by extending self-regulation through formative feedback mechanisms. The plan is to explore possibilities of gaining insights through adopting a systemic and holistic approach, i.e. through collecting and analyzing data from multiple sources that reflect learning that takes place within as well as outside digital learning platforms.

5) Modelling learners interactivity in learning and teaching in blended environments: Almost all the third cycle courses at DSV are offered in blended fashion where, the content and some learning activates are taking place at a digital environment complemented by face to face teaching sessions. LMS record a large amount of data, i.e. traces of learning processes, which allows to investigate the learning processes in-depth. However, such approach has a major deficiency that it does not count on the behaviours outside the learning environment and focus exclusively on one data source (that of LMS), thus, contextual factors are not considered [31]. The focus on a single data source is especially problematic when trying to understand learning processes that take place in blended learning environments, i.e. in courses that combine offline and online learning, where the processes in both environments are intertwined and affect one another, including on the aspect of regulation of learning. The assumption that learning occurs within the learning platforms only has been pointed out as the main reason for LA research findings to lack in generalizability and transferability [31]. Thus, we argue that an analytical and methodological shift is needed, from the digital platform as the unit of analysis, which is the current practice, to the blended learning environment as the primary unit of analysis.

B. Learning analytics research (Turku)

TABLE I
THREE CLASSES OF LEARNING ANALYTICS IN VILLE

(1) Experimental (pre-post) for comparing features and pedagogies
Research that uses experimental pre-post research designs, which looks at the most efficient features or pegagogies in developing ViLLE. The mostly used dependent variables are learning performance measured by course grades and assignment scores.
(2) Learning metrics (live learning data and achievements)
Research that uses variables such as assignment submission times, prior skills, numbers of assignment submissions, log data, attendance data in learning sessions, attendance data in groupwork sessions, and patterns of code writing behavior in programming courses. Possible associations such as causalities are investigated by using statistical methods.
(3) Psychometrics
This class includes research that uses psychometric measurement instruments to classify learners' behavior, motivation, problem solving abilities, attitudes, mindsets, or orientations to learning, and finds statistical associations with the measurements and other variables such as learning performance.

This section gives an overview about the learning analytics research conducted around the ViLLE. That research can

be roughly divided to three classes: 1) experimental pre-post setups, 2) analysing technical and log data, and 3) psychometrics. These three classes are summarised in Table I, and explained in detail in the related forthcoming three subsections.

1) Experimental Research for Comparing Learning Performance: ViLLE is the result of 15 years of development. One of the cornerstones of success is that the functionalities and pedagogies are evaluated through research methodology [18]–[20]. Thus, this class of research forms one of the founding pillars of the development work, and includes research that evaluates courses and features. Examples of evaluation research include looking at the impact of visualisation exercises in high school programming [18, pp 35–39], looking at programming courses at university level [18, 41–42], and at university level for computer science minors [18, 43–44], and computer science majors [18], [23, 45–47], as well as object oriented programming courses [18, 48–49], and introduction to computer science courses [22]. This class of research has helped to distill the most beneficial features in ViLLE, such as active learning and continuous assessment, heterogeneous exercise types, electronic examing [32], tutorial-based learning, and continuous feedback [18]. Perhaps most importantly, it has given evidence about the positive impact of digital learning for learning outcomes on a range of courses and topics. The research methods in this class are mostly pretest-posttest experimental setups, which use the pedagogical approach (such as tutorial-based learning versus traditional instruction) as the independent variable.

2) Learning Metrics: This class of research contains research that investigates statistical associations in the domain of a number of variables, which can be divided to live learning data and achievement data. The data includes variables, such as submission exercise times, number of exercise submissions, log data, and attendance data. Examples of research designs include looking at associations between students' time usage and their course grades [21], [33], issues in regards of collaboration patterns seen in log data [34]–[36], finding associations in students' previous knowledge and skills—as measured by course grades in previous courses—and course performance [2], and misconceptions in programming tasks by looking at the exercise completion patterns [2]. The data used in this class can be considered mostly as "technical". The research methods include a range of measures of statistical association, depending on case.

3) Psychometrics: This class of research includes the use of well-tested and validated psychometrics instruments in order to gain deeper understanding about the various processes of learning. For example, while research in Class 1 (comparing pedagogies) has proven that a number of ViLLE-based pedagogical approaches outperform other, "traditional" approaches to instruction, it is currently not well understood why this is. The more deeper psychometric understanding about learning can provide important insights about a number of issues, such as learning deficits, special needs, talent, and groupwork. An overview of the research in ViLLE-project that falls under this class is summarised in Table II, which divides the research into completed, in progress, and future research.

TABLE II
PSYCHOMETRICS RESEARCH IN VILLE

Instrument	Data	State
Completed or near completion		
PSI [37]	UTU/AOP students	Accepted [38]
	UTU/TKP1 students	Under review
	Intro and AOP	Manuscript in preparation
NALMQ [39]	High School Math ($n = 300$)	MSc thesis under review
	Programming	Manuscript in preparation
MAKEKO [40]	Math 3rd graders ($n = 27$)	Published [41]
Mindset [42], [43]	1st year CS students ($n = 86$)	First findings [44]
In progress		
Mindset [42], [43]	2nd year CS students	Data being collected
	High school math pupils	Data being collected
SMQ [45]	Science students UTU	Planning phase
Mood Ring Data	AOP students (UTU)	Planning phase
Psychometrics pool for future research by construct category		
Motivation research intrinsic motivation, expectancy motivation, goal-orientation motivation, self-determination, **Learning orientations**, **Self-theories** self-regulation, mindset. **Special needs and learning deficits Temperament**, **Cognitive abilities Groupwork and social measures** collective intelligence, social intelligence, systems intelligence, social belonging, **Creativity** (*references omitted for saving space)*		

Table II shows the current psychometrics research in ViLL. In regards of Problem Solving Inventory (PSI) [37], it has been investigated in the contexts of University of Turku courses on introductory programming and basic course in algorithms. The current results show that PSI scores can be used to predict students' final exam performance, to a certain extent [38]. Also, it has been shown that by using a PSI-based machine learning model, it was possible to predict the learning performance in a test set by the accuracy of 80.01%. PSI was also tested in identifying students at risk of dropping out. Other research has used the The Nature of Attitudes Towards Learning Mathematics Questionnaire (NALMQ) [39], and the MAKEKO [40], which is a well established Finnish test for identifying students' threshold concepts in mathematics as part of learning analytics within ViLLE [41]. In regards of Mindset [43], research is underway [44].

As can be seen from Table II, the psychometrics research in ViLLE team is currently still at an early stage. Psychometrics measures and constructs with proven potential are listed in the future research-section of Table II. This list provides measures that are well-tested and many of which have proven power to predict factors such as academic achievement. Research based on the listed measures is currently being planned.

4) Conclusions: This section provided an overview of learning analytics research in ViLLE. During the extensive development process of ViLLE, spanning over 15 years, learning analytics research has started with comparing features and pedagogies in ViLLE by experimental settings (Class 1) towards analysis of a variety of technical and log data (Class 2), and is now expanding also to psychometrics research (Class 3). The current research in regards of psychometrics is relatively small in scale, considering the possibilities provided by extensive research in psychometrics, and the extensive pos-

sibilities that digital learning and the ViLLE system provides for data collection.

IV. Discussion and Conclusions

This section discusses the most important findings from our research. We align our discussions with the questions that we set in the introduction of this article.

A. Concrete benefits of digital learning

First, significant increases in learning outcomes in various courses have resulted from introduction of digital learning to teaching. Second, proven benefits to recognise students in risk of dropping out have resulted in new models of student counselling, with proven positive effects to students' learning outcomes. Third, the introduction of the LMS systems have resulted in significant benefits to teachers, and development of new pedagogical models such as tutorial-based learning, and peer-based instruction. Fourth, identification of students' learning styles and preferences in learning has helped to individualise the learning paths of students.

B. Most promising research approaches

LA research require a major shift from one dimensional single unit case study into a holistic approach that allow capturing and triangulation of data of teaching and learning derived by several sources. The necessary first step would be to cover both the physical and digital environments where learning occur. What data to be curated, and how, are the exact next steps to be performed. Understanding the indicators for learning in regards of benchmarking and recognizing LA are of crucial importance. Important avenues for future research also include school computing education [46], computational thinking, and bringing innovation-friendly teaching [47] into digital learning.

C. Challenges in research on digital learning

In our digital world, learning is not happening in an isolated unit. Inter-dependencies of many factors influence the end results of learning. The big question is now, which data is best in explaining learning, and how highly contextualised LA models can be generalised to allow wider applicability.

Also, there is a very thin line between use of learner data for supporting learning and use of the same data for surveillance purposes. Building the trust between the data owners and data users is challenging. Privacy has become more important than ever before since the new GDPR strengthens the ownership of data. If LA is to become a useful endeavour, richness of the data is the key. The debate about how to conquer this challenge is ongoing, but yet to reach into its success.

The new rules for data protection imposed by the European Union (GDPR) have given people rights to control who they expose their personal data to. The essential consequences and implications of such implementations of data regulations are that the stakeholders in education can, at any point be opted out from allowing LA on their data. We are interested in exploring the perceptions of students, teachers, schools and universities, parents and the society on use of data about learning and the environment where learning occurs.

D. Conclusions

In this article we have reviewed the central results from development and research within two digital learning systems that are extensively used in digital education. The positive impact of digital learning, automatic assessment, continuous feedback, visualisation, and other features have been shown, and the introduction of digital learning systems to education has been clearly shown to be a good idea. By looking at the research of two widely used systems in two different countries, we are building the possibility for inter-system collaboration and research where features and approaches are simultaneously tested within more than one system. By doing this, we are building grounds for a European network of learning analytics in CSE research, where approaches can be tested and data can be collected from several contexts, significantly strengthening the research results. In the long term, we believe that this approach will lead to increased opportunities for comparing and testing various new pedagogies and approaches, collecting and comparing data obtained from different institutions, making it possible to replicate and conduct experiments in two or more contexts, increasing the validity of the results.

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Project Teaching in Computer Subjects

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***Abstract* - The research of the attitude towards the project teaching was conducted among students (N = 140). With the help of this analysis it is possible to determine in which way the project form of teaching helps to students in master the teaching content. The project teaching conducted at the Electrotechnical School is based on the correlation between various subjects, encouraging students to attain a higher level of knowledge, motivating them for research by providing practical examples, having clearly defined rules and steps to be developed.**

After completing their project tasks, the students presented their results in front of the class. They are asked to study additional content on the Internet and thus use the computer for positive and useful purposes. Afterwards, students gave their views and opinions about project tasks. We found that they reacted positively to the project tasks, and that they prefered to work in smaller groups (up to 3 students) or independently.

Keywords - project, teaching, research, student outcomes, competences, presentation, evaluation, teamwork, vocational teaching

I. INTRODUCTION

The main motivation for conducting an anonymous survey was the evaluation of the work done so far and the finding of new teaching methods with the aim of improving students' competences. After the project tasks were completed, the students answered questions related to them.

What did we ask students by an anonymous poll?

The anonymous survey contained four main groups of questions related to:

- adoption of the outcomes - how writing project tasks affects the adoption of outcomes and teaching content
- motivation - are the project tasks motivating students and how they affect interpersonal relationships
- structure of the project task - whether the project tasks were clearly defined, whether the students responded to the manner in which they were set and whether they were of adequate weight and complexity
- team work - are they preferring to create project assignments independently or in a group

The students responded to each question by an estimate of 1 to 5. Scale description:

1- I do not agree
2 - mostly disagree
3 - I do not know
4 - mostly agree
5 - I completely agree

II. PROJECT ASSIGNMENTS

Project assignments were designed in such a way that they linked textbook lessons to practical examples. For the quality of project work, students should invest extra effort, and the scope of the task was such that it was necessary to work in multiple stages. Some tasks were designed to work in a team and some individually.

The students answered the questions after they had made several project assignments in the subject of Algorithms and Programming and from Computer Networks.

Each project task contains clearly defined guidelines to which it is to be made, the date and time of submission and the means of submission.

A. An example of project assignments from Algorithms and Programming

Project assignment - security on the Internet (each student works independently)

The aim of this project task is to protect student safety on the Internet and social networks. The task was to write a program that will let students know how secure are their passwords used for social networks. The students wrote the code in the programming language C (correlation between programming and civic education).

B. Example of Project Tasks from Computer Networks

Project assignment - development of project documentation (team work)

The team of computer network specialists should prepare the project documentation for the computer network of the organization "3. c. LLC" which consists of

the following organizational units: research, procurement, production, sales, human resources, finance and accounting.

The aim of the project task is to produce documentation that should include:

- The IP address of the device
- logical scheme and network simulation in Packet Tracer
- device arrangement in the program
- prices of devices and equipment for such a network

III. RESEARCH RESULTS

A. *Adoption of the outcome*

In this category we asked students did the project tasks encourage their ingenuity, and did they help them in achieving a higher level of knowledge. The results are presented in Figure 1, which shows that most students (61 %) believe that by designing the project tasks they gained a higher level of knowledge (33 % answered with 4, 28 % answered with 5).

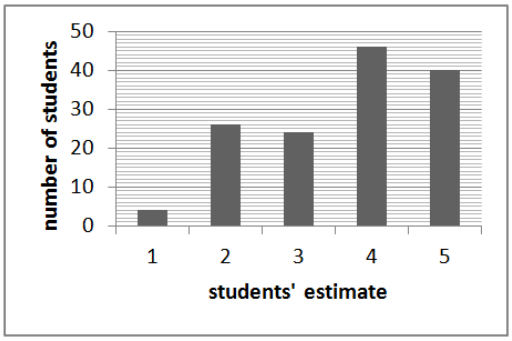

Figure 1. Student assessment of whether the design of project tasks has a positive impact on their level of knowledge

When asked if project topics were previously covered by class lessons, they responded as it is shown in Figure 2. The results showed that the pupils applied the teaching materials they met on the course in project assignments (38 % answered with 4, 44 % answered with 5).

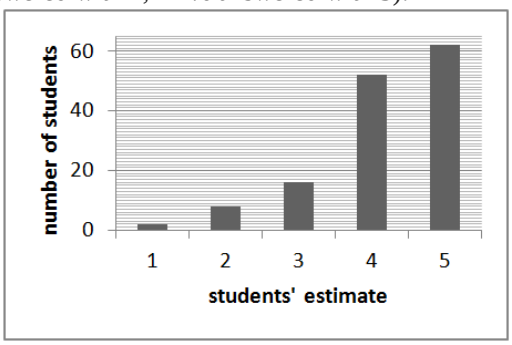

Figure 2. Students' estimates how much their curriculum content in the school helped in the design of project tasks

B. *Motivation*

Asked how project tasks affect motivation to master new teaching contents, the students responded as shown in Figure 3. Students agreed with the statement that project tasks motivate students to work and learn (only 28 % disagreed, and answered with 1 or 2).

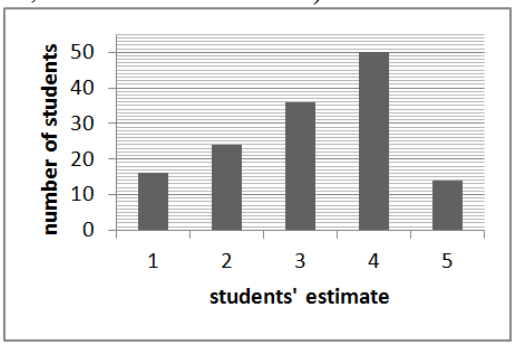

Figure 3. Positive project assignments affect student motivation to master new teaching contents

When asked whether students think that project tasks encourage mutual communication between students, the evaluation was as shown in Figure 4. The evaluation is very positive and it shows how these types of tasks achieve a higher level of communication and pupils develop ways of adopting civic education concepts (e.g. co-operation, accountability for task accuracy and compliance with deadlines).

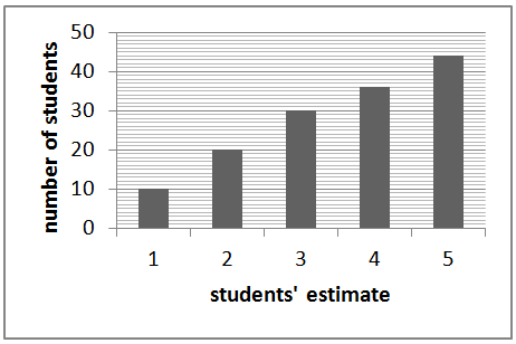

Figure 4. Student assessment, whether the project tasks develop mutual interconnection between students

C. *Structure of project assignment*

On the assertion that the project tasks were clearly defined and that the instructions were accurate enough to answer the questions asked by the students, the results are shown in Figure 5. Students overwhelmingly agreed that the project tasks were clearly defined - 77 % answered with 4 or 5.

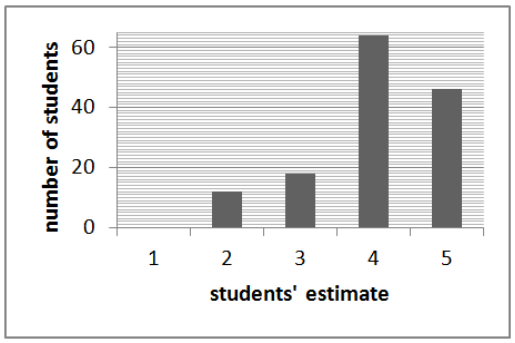

Figure 5. Student assessment of whether the project tasks were clearly defined

On the question whether the evaluation of project tasks was clearly defined and whether the grades the students had clearly described their efforts, the students responded as shown in Figure 6.

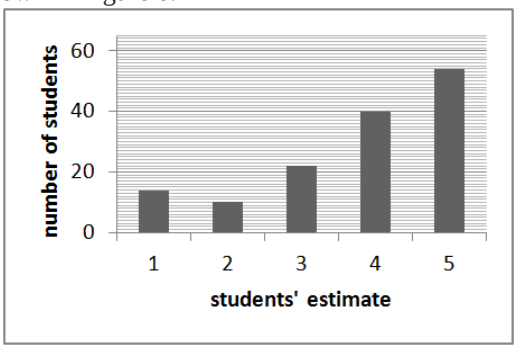

Figure 6. Student assessment that their work is evaluated according to clearly defined rules

On the complexity of the project tasks, the students said that the projects were of adequate complexity, giving feedback on how all the tasks were done (Figure 7).

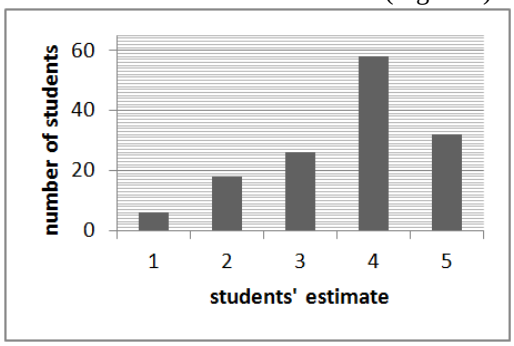

Figure 7. Student assessment of the claim that the project tasks were of adequate complexity

These questions were set up to enable the teacher to evaluate "what combination of teaching methods should be applied and whether these methods meet student learning abilities, learning conditions and available resources to support the learning process" [1][2].

D. Team work

In this set of questions we wanted to find out from the students whether they prefer more individual work or group work. The results are shown in Figures 8.a, 8.b and 8.c.

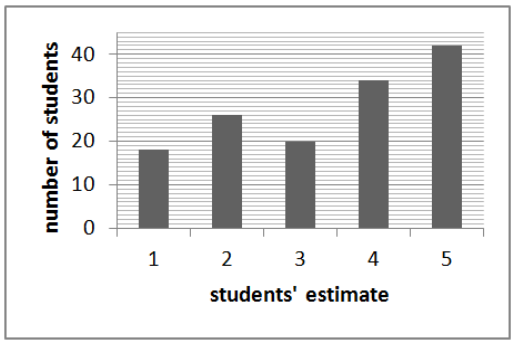

Figure 8.a. I like to design the project tasks independently

From Figure 8.a it can be concluded that most students (54 %) prefer to work individually and do not necessarily like working in a team.

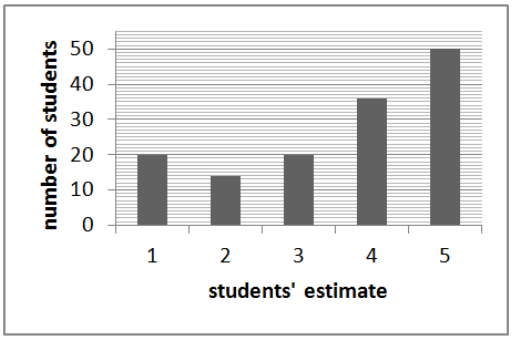

Figure 8.b. I like to design project tasks in a group of 2-3 students

From Figure 8.b it can be seen that the majority of students (61 %) agrees the ratio of 2-3 pupils per team is optimal.

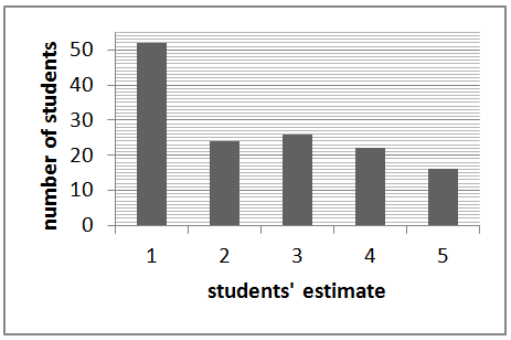

Figure 8.c. I like to design project tasks in a group of 4-5 students

Through this questionnaire the students expressed the attitude that they do not like when a larger number of students make a group that needs to create a project assignment.

IV. CONCLUSION

As a result of this research, it was shown that students achieve higher levels of competence by writing project assignments. The results of the testing and the checking of the knowledge after the project tasks are better and the average grade rating is higher by 20% with no negative scores.

After making a project assignment, the students feel more satisfied, and the process of designing the project raises students' motivation for learning. The topics that students deal with are from everyday life and are closely related to practice. Apart from a higher level of achievement, students also have good competencies in interpersonal relationships. This result is also linked to clearly defined project tasks motivating students. When designing some types of project tasks, students prefer to work in a maximum of three-member teams, while they prefer to work independently when solving individual tasks.

With these surveys, we wanted to emphasize that the main subjects in the teaching process are students and teachers [3] and we wanted to achieve communication that will teach us how to feel when learning new teaching contents through project teaching methods and thus help to master new teaching content.

Project teaching on the basis of these results shows positive results for students, which is a positive feedback, and this type of teaching should be applied as far as possible in computer-related subjects.

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Dynamic Machine Translation of Croatian Academic Web Sites

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***Abstract* - Web sites internationalization of Croatian web sites is a problem remained from the beginnings of web. In most cases, only some general information that are rarely changed are available in foreign languages, and the reason for that is the lack of human resources to make translations, as well as the need of software adaptations to support multilingualism. This paper analyses some lexical characteristics of the selected Croatian academic web sites, compared with some other, like daily newspapers and culinary web sites in order to find out their suitability for machine translation. The findings are compared to the actual state of our dynamic translation system for web contents, named as Domain Translator.**

Key words - web sites translation, machine translation, Domain Translator

I. INTRODUCTION

Comparing today's Croatian academic web with the web of 15 or 20 years ago, we'll find a remarkable improvement in the design, interactivity achieved by different technologies and even the regularity of content updates. On the other hand, little has changed in the availability of web contents in foreign languages, primarily English. The main reason for this is the lack of human resources. This includes software developers to adapt the software to support multilingualism, but also employing the language specialists to make translations on daily basis. This is difficult to reach, especially within the academic community, and for that reason the majority of academic institutions offer only a subset of their web contents available in foreign languages, usually some general information and the information that is rarely changed. This can hardly satisfy the needs of foreign students that need some information and services like news, schedule of the lectures, Learning Management System, notifications of student office, web services of library and applications for final and graduate papers.

All these problems point to some solution based on the machine translation. This paper presents some initial lexical assumptions and prerequisites for building of such translator, as well as some tests performed on the prototype of such translator, named as Domain Translator (DT) [1] that is based on the phrase-based algorithm introduced in [2].

The first assumption starts from the fact that some specific lexical domain, covered by some web site, will be much smaller in relation to the whole lexical domain of Croatian language. This will be elaborated in Chapter 3, which gives the results of our research of the size of some Croatian web domains, mostly academic, expressed in number of words and phrases. Smaller lexical domain means its easier coverage by the translator's database of lexical artifacts like words and phrases.

The second assumption is that we need only a one direction of translation (e.g. from Croatian to English) in order to present the web content in a foreign language. According to the related researches (Chapter 2) and our own tests (Chapter 4) the expected results of translation from a language that use more lexical forms (like cases, genders, different conjugations etc.) into a language that uses less lexical forms (e.g. from Croatian to English) will be much better than vice-versa.

Tested DT[1] was in a form of Chrome browser extension, while there is also a possibility of its embedding into the web site.

II. RELATED WORK

In the paper were used two metrics for assessment of the quality of machine translation, BLEU (BiLingual Evaluation Understudy) [4] and NIST (National Institute of Standards and Technology) [5]. Both methods use the referent translation which is compared to the machine translation giving a score, where higher score means better translation. The difference between these two methods is that BLEU uses plain n-grams of both texts in order to compare them while NIST gives weights to n-grams, assuming that some of them are more important for the accuracy of machine translation than the others.

[1]http://gpml.foi.hr/ (group Translators)

Since Domain Translator is a one direction translator that translates web contents from Croatian to English, it's important to show that this direction of translation is much more promising than vice versa. Different authors have shown in their experiments that the accuracy of translation depends on the translation direction. In general, it's much more efficient to translate the text from language with lot of word inflexions (e.g. resulting from gender, case or number) to a language with less inflexions, like English. In that sense, Koehn and Schroeder [3] have tested their translation system on several language pairs, in both directions, using BLEU and NIST scores. The results show that translation to English gives better results than the translation in opposite direction. This difference expressed in BLEU score is the biggest for English-Czech language pair (22,68 to 12,34) and the smallest for English-Spanish language pair (33,26 to 32,55 and 34,17 to 33,59 for different test sets).

Similar results were obtained by Arčan et al. [6]. They have tested their translation system named Asistent on different language pairs including English-Croatian and vice versa using data set from OPUS web site [7]. It can be seen that the result for Croatian to English translation was better than vice versa (48,07 to 42,15). These results were confirmed in our study (as shown in Chapter 4).

Toral et al. [8] performed a research in which the translation errors have been analyzed. The domain size was 1,000 sentences. Those sentences were translated both by a professional translator and by amateur translators. The tests were directed towards translation direction and their results were put against the commercial systems available online by Yandex, Microsoft and Google. It can be seen from the results that the translation that goes into English has much better results in relation to translation into the most of other languages.

Toral et al. [9, 10] had another research where they gathered parallel data from 20 tourism web domains on which their system was trained and afterwards tested on three tourism sites. The training sets contained between 19,100 sentence pairs and 27,274 sentence pairs which depended on the test set and configuration of the crawlers used to gather data. The conclusion was that crowd sourcing should be used to translate small amounts of text (100 sentences) and web crawling for large data sets (millions of sentences). Their own translator outperformed Microsoft Bing by 7.94 points in terms of BLEU for Croatian-to-English and by 2,17 points for English-to-Croatian.

Seljan et al. [11] presented their results of machine translating for non-closely related language pairs (English-Croatian) and for closely-related pair (Russian-Croatian). The research included 400 sentences and two systems for translation (Google Translate and Yandex Translate). The results were mixed between fluency and adequacy of the translations, where Yandex won in fluency tests and Google in adequacy.

Another prerequisite for efficient translation is the Domain Adaptation (DA). DA represents, according to Koehn and Schroeder [3], combining a large amount of training data (usually from general language domain) with a much smaller amount of in-domain training data in order to optimize translation performances on that particular lexical domain. The complexity of DA mostly relies on the complexity of lexical domains, which can be expressed in the number of used lexical artifacts like words and phrases. For that reason, a research on Croatian web domains was done (Chapter 3).

Pecina et al [12] accessed the problem of DA by exploiting the domain data acquired by the domain-focused crawling systems. The authors have gathered a huge amount of data for English, French and Greek language. For example, just for English, the number of gathered sites has exceeded 145, with over 90.000 pages viewed and for those over 28.000 pages was stored after initial cleaning of the near-duplicates. For English language there were 1.088.660 paragraphs after initial cleaning (5.841.059 in total) of which the unique paragraphs were 693.971 with 1.700.436 sentences. Their results show that their previous work was once again confirmed on the topics of tuning and training the systems as well as for language model adaptation. Adaptation of translation models (using 7.000 – 20.000 acquired sentence pairs) increased the BLEU scores by 4,56 points absolute compared to the general-domain systems. These results were confirmed in the research performed within the scope of this paper for Domain Translator, with similar results (Chapter 5).

III. CROATIAN WEB SITES

The research encompasses 21 Croatian web sites according to their size in number of words and phrases of two words. Most of the sites are academic, together with two daily newspapers and two that are dedicated to culinary. Table 1 shows the dependency of the number of extracted words to the number of observed web pages. (Appendix: Table 1)

It can be seen in Table 1 that the trend of increasing of the number of words mostly stagnate for the majority of the academic web domains at the number of 2560 web documents (pages). On the other hand, this trend continues to significantly rise for daily newspapers (Jutarnji list and Večernji list).

Table 2 shows the actual coverage of the observed web domains by the Domain Translator on the level of single words. The referent language

corpus[2] includes about 624000 Croatian words (contains all inflexion forms of the words).

The difference between total coverage of some lexical domain and the weighted coverage arises from the different frequencies of particular words occurrence that varies from only one occasion to several tens of thousands for conjunctions and words used in web site navigation, titles and other web site elements. (Appendix: Table 2)

Table 3 shows the actual coverage of the observed web domains by two-word phrases. The specificity of the phrases is that some of them could be redundant, i.e. translation of separate words gives the same result as the translation of the phrase.

For this reason, an estimate value was calculated, so Table 3 shows the coverage of phrases in an absolute amount (like Table 2) but also the estimated coverage. The estimation was done by using of the dictionary of English phrases containing 1,13 million of two-word phrases. Croatian phrases were translated using the DT database on a word to word level. If the obtained translation exists in the English dictionary, then the phrase is observed as being redundant. (Appendix: Table 3)

IV. TRANSLATION DIRECTION

Our research was done in order to support the assumption that it is much more effective to translate from Croatian to English than vice versa. For this reason we used a sample of 20 abstracts from the CASE 2018 conference[3], because they exist in both Croatian and English. The experiment was conducted using Google and Bing Translator and the results[4] are given in Table 4. (Appendix: Table 4)

As can be seen in Table 4, the BLEU scores of both translators were significantly better for Croatian to English translation than vice-versa (Google: 36,62 to 19,77 and Bing: 32,93 to 18,81).

V. TESTING OF THE DEVELOPED TRANSLATOR PROTOTYPE

In order to test DT, the same sample of 20 abstracts from the previous experiment was used. The lexical base of the DT included about 75000 phrases 1-5 words in length. The results are given in Table 5. The column DA (0) represents the BLUE scores for Domain translator before the Domain Adaptation (DA); DA (1) contains the results after filling the translation database with single words that previously remained untranslated; and column DA (2) contains the results after full DA process (entering words and phrases 2-5 words in length).

As shown in table 5, the initial result of DT (BLEU score of 18,85 in average) is somewhat weaker in relation to Google and Bing (36,62 and 32,93; as shown in Table 4), but, after two phases of DA can be significantly improved (44,48 in the example).

VI. CONCLUSIONS

The paper deals with some assumptions for building of a machine translation based solutions for the problem of presenting the contents of Croatian academic websites in foreign languages, primarily in English.

The first assumption is that the lexical size of some particular web site will be much smaller in relation to the whole lexical domain of Croatian language. This was shown in Chapter 3 that gives the results of our research on 21 Croatian web sites, mostly academic. The results also show that these web domains can be successfully covered by a translator database of lexical artifacts (words and phrases).

The second assumption was that the translator will be much more efficient in translation from a language that use more lexical forms (like cases, genders, different conjugations etc.) into a language that uses less lexical forms (e.g. from Croatian to English) than vice versa. This was supported by the related work research, but also by our own research, as shown in Chapter 4.

Finally, the prototype of the translator, named as Domain Translator, was tested in order to compare its results with the results of Google and Bing translators (Chapter 5). The results were initially weaker in relation to Google and Bing, but significantly improved after two phases of domain adaptation.

For the future work is planned to make a deeper insight into the lexical state of Croatian web sites by expanding the research in order to find some of their another features like degree of mutual overlapping of the lexical domains, the ratio of specific names, foreign language words etc.

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APPENDIX

TABLE 1. NUMBER OF WORDS IN RELATION TO THE NUMBER OF OBSERVED WEB PAGES

	Number of web pages					
Web sites	**160**	**320**	**640**	**1280**	**2560**	**5120**
Faculty of Agriculture	5931	10631	13035	13412	**17589**	
Coolinarika	13332	17335	23066	34327	**47845**	
Faculty of Economics Osijek	6420	7775	10456	14301	**20032**	
Faculty of Economics Rijeka	8398	10294	13825	17153	**17500**	
Faculty of Economics Zagreb	4485	6571	9583	13772	**16379**	
Faculty of Philosophy Zagreb	11756	14769	18427	22889	**30311**	
FOI Varaždin	6038	11033	13006	13323	**14795**	18342
FOI Varaždin - teaching	5239	8642	14743	18614	**18942**	
Faculty of PoliticalSciences Zagreb	6644	7290	10669	13503	**19265**	
Faculty of Civil Engineering Zagreb	3200	4882	6140	11147	**16418**	
Music School Varaždin	3405	4115	4461	4909	**5831**	
Jutarnji list	17601	25380	33920	58017	**75928**	102321
CatholicFaculty of Theology Zagreb	10354	11159	13538	14553	**14587**	
Faculty of Food Technology Zagreb	5314	6535	9104	16966	**18151**	
Faculty of Science Zagreb	8072	11437	17031	19923	**22031**	
Faculty of Law Zagreb	12851	16003	18008	21123	**26221**	
Faculty of Metallurgy	6335	6808	6979	8398	**8115**	
University North	4462	5954	9197	16942	**21834**	
Večernji list	12109	15010	23205	37796	**56078**	78489
Gastro 24 sata	7373	10029	14391	19155	**24007**	
FER Zagreb	7829	12298	18960	28407	**29332**	
All domains together					**150140**	

TABLE 2. ACTUAL COVERAGE OF SINGLE WORDS BY THE DOMAIN TRANSLATOR DATABASE

Web sites	Single words	In DT database	Total weight	Weight of DT words	Total coverage%	Weighted coverage%
Faculty of Agriculture	17589	12545	502022	478347	71,32	95,28
Coolinarika	47845	18543	2396259	2259544	38,76	94,29
Faculty of Economics Osijek	20032	15197	4801881	4789946	75,86	99,75
Faculty of Economics Rijeka	17500	13537	1997323	1944887	77,35	97,37
Faculty of Economics Zagreb	16379	13122	2595628	2585619	80,11	99,61
Faculty of Philosophy Zagreb	30311	18690	3993037	3959396	61,66	99,16
FOI Varaždin	14795	13140	704801	702580	88,81	99,68
FOI Varaždin - teaching	18942	15398	3217865	3194499	81,29	99,27
Faculty of Political Sciences Zagreb	19265	13883	708310	692728	72,06	97,80
Faculty of Civil Engineering Zagreb	16418	11481	380429	366936	69,93	96,45
Music School Varaždin	5831	4780	1219551	1214824	81,98	99,61
Jutarnji list	75928	29253	2589102	2415361	38,53	93,29
CatholicFaculty of Theology Zagreb	14587	10271	1399581	1379093	70,41	98,54
Faculty of Food Technology Zagreb	18151	12413	912347	892204	68,39	97,79
Faculty of Science Zagreb	22031	14021	842080	816762	63,64	96,99
Faculty of Law Zagreb	26221	16888	1296232	1264748	64,41	97,57
Faculty of Metallurgy	8115	7019	5123982	5118611	86,49	99,90
University North	21834	16443	3364784	3350465	75,31	99,57
Večernji list	56078	23681	1251306	1169058	42,23	93,43
Gastro 24 sata	24007	11722	709732	663193	48,83	93,44
FER Zagreb	29332	17851	1493353	1435626	60,86	96,13
All domains together	**150140**	**40396**	**74584175**	**73589599**	**26,91**	**98,67**

TABLE 3. ACTUAL COVERAGE OF TWO-WORDS PHRASES BY THE DOMAIN TRANSLATOR DATABASE

Web sites	Phrases of 2-words	Phrases In DT	Coverage In DT %	Weight In DT %	In English dictionary	Estimated coverage %
Faculty of Agriculture	16449	1274	7,75	**26,43**	4080	**46,16**
Coolinarika	71878	1706	2,37	**26,64**	14130	**46,35**
Faculty of Economics Osijek	21840	1969	9,02	**47,67**	6763	**62,77**
Faculty of Economics Rijeka	44091	2236	5,07	**21,55**	11138	**41,73**
Faculty of Economics Zagreb	27798	1954	7,03	**42,23**	7472	**60,31**
Faculty of Philosophy Zagreb	36470	2249	6,17	**41,34**	9550	**54,72**
FOI Varaždin	16997	2322	13,66	**46,20**	6254	**66,32**
FOI Varaždin - teaching	61178	2416	3,95	**27,64**	12758	**46,61**
Faculty of Political Sciences Zagreb	29407	1749	5,95	**21,71**	7775	**42,03**
Faculty of Civil Engineering Zagreb	17512	1243	7,10	**20,61**	4151	**40,69**
Music School Varaždin	5534	491	8,87	**44,77**	1412	**52,69**
Jutarnji list	97617	2771	2,84	**20,47**	24340	**41,77**
CatholicFaculty of Theology Zagreb	20806	1388	6,67	**36,69**	5114	**52,57**
Faculty of Food Technology Zagreb	18650	1237	6,63	**25,79**	4762	**55,79**
Faculty of Science Zagreb	22609	1412	6,25	**24,08**	5318	**45,22**
Faculty of Law Zagreb	46760	2083	4,45	**17,80**	11313	**37,11**
Faculty of Metallurgy	10612	1120	10,55	**32,49**	3107	**48,42**
University North	35937	2091	5,82	**46,57**	9164	**57,92**
Večernji list	54316	2106	3,88	**23,62**	15273	**47,62**
Gastro 24 sata	29689	1007	3,39	**17,11**	6852	**41,58**
FER Zagreb	43800	1739	3,97	**21,36**	8312	**38,76**
All domains together	**557252**	**7763**	**1,39**	**33,93**	**90344**	**51,57**

TABLE 4. BLEU SCORES FOR TWO DIRECTIONS OF TRANSLATION

Document	Number of words (Croatian original)	Croatian to English		English to Croatian	
		Bing	Google	Bing	Google
1	106	44,49	33,65	20,11	22,67
2	226	41,94	44,35	27,23	26,38
3	200	27,28	21,67	8,13	10,79
4	191	43,80	43,97	18,79	21,56
5	117	5,37	5,90	1,71	3,64
6	180	26,71	21,96	13,79	14,34
7	160	34,83	39,10	25,39	27,97
8	183	47,07	47,15	28,46	27,95
9	224	24,74	28,05	26,23	30,41
10	97	49,02	56,03	33,01	22,48
11	116	27,90	30,20	19,50	11,42
12	47	24,65	31,09	12,84	11,60
13	159	16,57	18,62	12,53	16,06
14	51	35,86	45,96	22,69	25,65
15	49	39,29	50,40	13,42	7,97
16	204	12,40	10,55	5,36	5,00
17	67	44,57	38,98	27,05	30,66
18	98	24,42	27,53	16,73	15,50
19	77	65,58	98,13	36,50	43,25
20	153	22,17	39,17	6,72	20,09
Average	**135,25**	**32,93**	**36,62**	**18,81**	**19,77**

TABLE 5. BLEU SCORES FOR DOMAIN TRANSLATOR, BEFORE AND AFTER DOMAIN ADAPTATION

Document	Number of words*	Unknown words %	Phrases (0) %	BLEU DA (0)	BLEU DA (1)	BLEU DA (2)	Phrases (2) %
1	106	12,62	13,59	13,20	15,23	56,22	64,08
2	226	8,89	20,00	18,97	21,29	35,63	39,56
3	200	10,10	23,08	13,36	14,21	31,39	45,67
4	191	7,41	18,52	18,48	19,23	48,93	48,94
5	117	3,60	19,82	3,51	3,64	23,60	46,28
6	180	5,35	22,46	22,76	22,76	38,83	47,75
7	160	10,83	20,38	21,27	22,71	37,42	50,32
8	183	3,35	17,88	25,52	26,76	43,85	40,41
9	224	8,53	23,22	20,44	22,40	31,53	37,26
10	97	3,19	18,09	17,96	19,24	42,68	44,23
11	116	5,22	20,87	18,92	19,88	48,25	67,83
12	47	10,26	28,21	3,47	3,73	66,60	89,74
13	159	5,10	20,41	14,05	14,08	18,18	42,64
14	51	8,70	8,70	31,36	40,93	100,00	58,93
15	49	1,59	14,29	21,94	21,94	70,02	73,02
16	204	5,03	18,09	12,41	12,76	26,46	44,22
17	67	0,00	15,52	34,07	34,07	58,25	44,83
18	98	0,98	21,57	12,16	12,16	22,74	36,27
19	77	5,41	21,62	34,47	33,44	55,68	52,00
20	153	6,94	22,92	18,67	22,80	33,40	45,45
Average	**135,25**	**5,81**	**19,77**	**18,85**	**20,16**	**44,48**	**50,97**

*original documents in Croatian

Teachers' Perceptions of Digital Learning Path in Mathematics, Languages and Programming

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***Abstract* - ViLLE is an exercise-based digital learning platform designed and implemented at University of Turku. The digital learning path in ViLLE is a pedagogic methodology of utilizing educational technology effectively in classroom: with learning path, one mathematics, language or programming lesson in a week is transformed into digital learning experience. The learning path in ViLLE is already used in one third of Finnish schools. In this article, we present the results of surveying teachers' perceptions about the usage of learning path, it's pedagogic value and their ideas of improving the environment and the learning experience. 280 teachers answered to the survey. Majority of the teachers were very happy with the environment and more than 95 % of them were willing to use it in the future as well. Still, some critique and suggestions for improvement were also presented. In addition to detailed analysis of the results, we also present possible changes into pedagogy based on these suggestions.**

Keywords – teacher feedback; technology enhaned learning

I. INTRODUCTION

Digital solutions have become very common in schools. There are many different applications, games, devices and platforms available for multiple purposes. We have previously studied the adaptation of digital learning paths in mathematics learning in various quantitative studies with focus on students' learning performance and arithmetic fluency. However, teachers' perceptions about using the learning path are not previously emphasized in reporting. In this article, we present a survey about the pedagogical usage of the learning path that was answered by 280 teachers. The goal of the survey was to find out how teachers have adapted the learning paths into their classrooms.

The rest of the article is structured as follows. First, we present some studies related to our research. Next, the concept of the digital learning paths is presented along with teachers' workflow on using it. In the next sections, the research setup and the results are presented. Finally, we discuss the result and their implications.

II. RELATED WORK

There are various studies underlining the impact of digital learning tools in mathematics (see for example the meta studies of [1, 2], languages [3, 4] and programming [5]. However, the pedagogical skills for utilizing the technology properly might sometimes be overlooked. [6] presents a technology-enhanced pedagogical content knowledge, where teacher students' pedagogical adaptation of technology was studied in five cases. Moreover, Niess [7] continues to present TPACK - a dynamic framework that describes "teachers' knowledge required for designing, implementing, and evaluating curriculum and instruction with technology" and a strategy for deciding on when, where and how to use domain-specific knowledge.

Teachers' adaptation to technology might not be an easy task, especially for teachers with years of experience of teaching without technology. Still, the early career teachers might struggle with use of technology as well. Moursund et al. [8] found out that even before the turn of the millennium, technology infrastructure in classrooms was growing rapidly. However, according to [9], the teachers still find the availability of technology as the greatest barrier for technology usage in classroom. Likewise, [10] state that the biggest barrier is the ineffective field experience. The meta-analysis of [11] concludes, that the relationship between technology and pedagogical beliefs is a complex issue, and needs a multi-dimensional approach and knowledge of the school context to be understood.

In addition to technology usage, the questions in the survey covered gamification [12], differentiation (see for example [13, 14], homework [15] and collaboration [16, 17, 18, 19].

III. DIGITAL LEARNING PATHS

Digital content requires carefully planned adaptation [20] to be effective and motivating. We have previously described the planning and implementation of digital learning path for mathematics, languages and programming [21]. Currently, more than 7,000 teachers and 190,000 students use the digital learning path (DLP). In fact, more than one third of all schools in Finland have at least one teacher using DLP in their teaching. The DLP is implemented by using ViLLE - a collaborative, exercise-based learning tool [22] with more than 150 different exercise types and full support for gamification and comprehensive learning analytics.

The basic principle behind the digital learning paths is one digital lesson every week. In this lesson, the students typically solve 20 to 30 automatically assessed exercises about the topic at hand. Most of the exercises are initialized with random values and all of them provide instant feedback when completed. Teacher can differentiate the content and provide either warm-up or bonus exercises to students with too much or too little challenge. The teachers can utilize the built-in real-time learning analytics, which include for example an

automatic detection of students' misconceptions in different mathematical topics [23].

The teachers' workflow with digital learning paths starts with selecting the suitable content for the class. The DLP follow Finnish curriculum in mathematics and in Finnish language, and the content adapts to all workbooks the teachers may use. Before the lesson starts, the teacher needs to open the suitable digital lesson in the tool. Moreover, the teacher needs to decide for example on the following issues:

- Whether the material is worked on as alone or in collaboration with another student? Digital collaboration has been proven as beneficial for learning in many studies [16, 17, 18, 19]. On the other hand, collaboration has potential drawbacks, such as the concept of free-riders and the problems in group selection (see for example [24]).
- Whether to utilize differentiation for some students or not. In the platform used, it is possible to provide warm-up exercises for students who are struggling with the basic content. Moreover, bonus exercises can be provided for students who are not challenged enough.
- The differentiation can also be done by modifying the digital trophies provided. The platform utilized gamification for example by providing students virtual trophies on their achievements while doing the exercises. Typically, bronze trophy is awarded for completing half of the required exercises, and silver, gold and diamond trophies when more or all exercises are completed. The teacher can modify the score limits for all of the trophies for individual students, meaning that the number of points needed for bronze trophy might be different to all students in class.
- Whether the DLP is only used at school or in home as well? Typically, teachers give the exercises not completed during the lesson as homework in traditional lessons, so why not require the completion of digital exercises at home as well? The problem, if any, might be the unequal digital competences of parents and insufficient devices at home.

In addition, the teachers need to do other pedagogical decisions on using the tool, including for example how often the digital learning paths should be used. The effectiveness of the learning paths have been previously studied in various setups (see [25, 26, 27, 28, 29]) and the results show, that the DLP can be highly effective to students' performance and arithmetic fluency. In this article, we however concentrate on teachers' pedagogical approaches while using the digital learning paths with their students.

IV. Research Setup

The survey was conducted on April in 2018. We used Google Forms as a survey platform. The survey was sent as an email attached to newsletter to all teachers using our learning path materials during that time. A reminder to answer the survey was sent six days later to expert teachers (N=143). We reminded the expert teachers to remind also their colleagues in their school. There were altogether 2032 recipients and 630 opened the email (31%). We got 280 answers (13.8%). The teachers range from first grade teachers to ninth grade IT or mathematics teachers. This information was only collected, if the teacher gave feedback on content. This was optional.

The goal of the survey was to find out how teachers use ViLLE, which features they use the most frequently and get feedback from mathematics, Finnish language and programming contents. We also asked in which direction the teachers hope ViLLE would develop. Contents of the survey are discussed in more detail in next chapter.

A. *Survey*

The survey was created on Google Forms. We informed teachers it would take 5-10 minutes to answer the questionnaire. Three types of questions were used in the survey. We had predefined options where answerer chooses the most suitable option. Typically, these questions were accompanied with open field to give more detailed answer, if necessary. Some questions concerning the quality of content or support were asked in 5 step likert scale.

Due to low rate of responses in Finnish language (14.6%) and programming (8.8%) we concentrate more on the results for the non-optional topics of the survey. All teacher's answers were handled in non-optional questions. Content related survey answers were handled by the content team who made decisions how to change the content according to teachers' wishes.

V. Results

The results section is divided further into four sections. First, we introduce how teachers use ViLLE and how experienced they are. Second, we report how teachers use the differentiation tools provided by ViLLE. Third we concentrate on the feedback from Mathematics content. Languages and programming were left outside of the reporting due the low number of answers. Finally, we report results on support, general user experience and willingness to continue using ViLLE. We also introduce some of the open feedback.

A. *General usage and teacher experience*

First, we wanted to find out how experienced the respondents were (Figure 1). All 280 respondents answered this question.

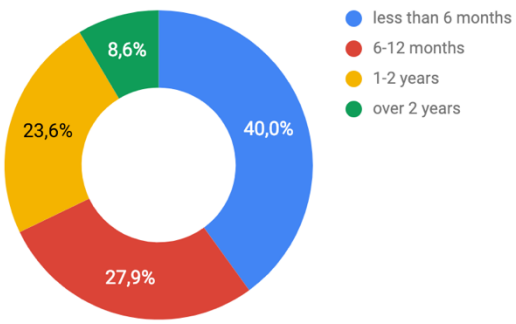

Figure 1 Teachers' experience

Most of the answers came from new users however but there are almost as many 6-12 months experienced as there was 1-2 years experienced users.

We asked teachers to choose from given options how often they usually work with ViLLE (Figure 2). We got 280 answers to this question. We also got 121 open questions to describe in more detail how teachers work with ViLLE.

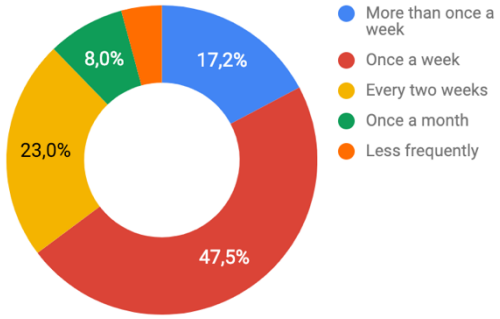

Figure 2 Frequence of using ViLLE with students

When we add together usage tendencies from every two weeks to more frequent, it covers 87.7% of all usage. In open answers many of the teacher describe that if there is an exam coming they might use ViLLE more frequently to rehearse. The frequency also varies depending on the topics student currently learn. Many also mention that the frequency depend on the availability of IT-devices.

Figure 3 shows the relation between how long teachers' have used ViLLE and how often they work with the platform.

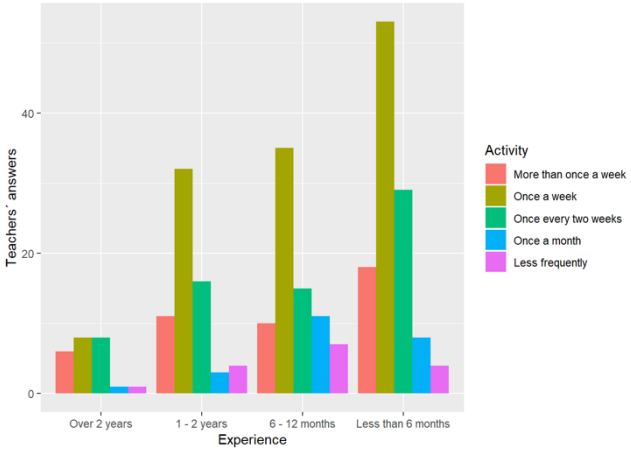

Figure 3 Teacher's experience and frequency of usage

The more experienced the users are the more frequently they use ViLLE. The number of ViLLE teachers has increased rapidly, hence it's natural that most of the respondents are new users.

We recommend teachers to give homework from ViLLE. We asked how often they give homework to students (Figure 4). Also, in this question we got 280 answers.

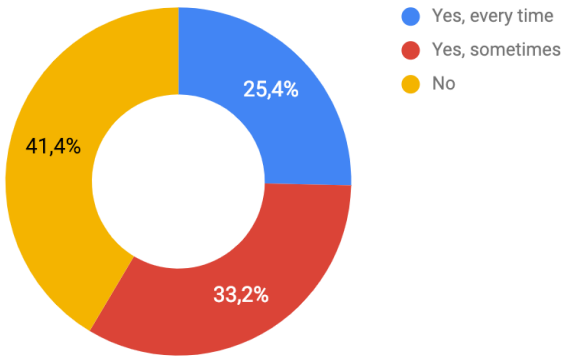

Figure 4 How often teachers assign homework

Over half of the respondents assign homework from ViLLE at least sometimes. We got 101 open answers giving more specific answer or explanation to this question. Many answers complain that not all students have necessary skills or devices at home to do homework and thus it's not mandatory. One teacher answered that he/se did not realise this possibility before and will definitely try it later.

Figure 5 shows the relation between assigning homework and how experienced the teacher is. The less experienced the teacher the less like they will assign homework from ViLLE.

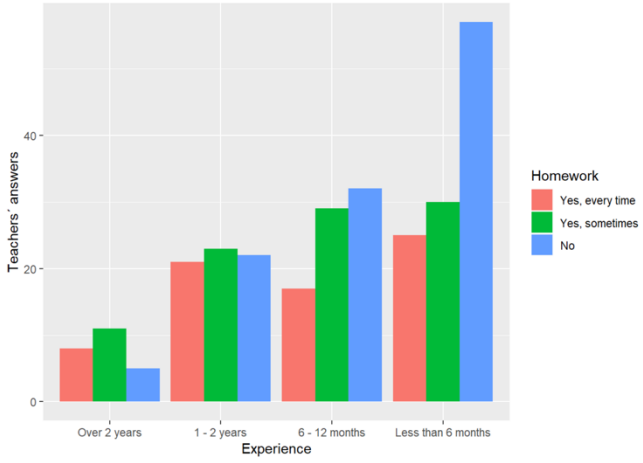

Figure 5 How often teachers assign homework in relation to how long teacher has used ViLLE.

The Figure 5 shows well the natural tendency, that teachers with more experience and confidence are more willing to assign homework than relatively new users.

B. Differentiation

In Figure 6 we can observe the tendency of giving specific goals for students by customizing the trophy limits for the whole class or for individual students. We got 280 answers to the multiple-choice question.

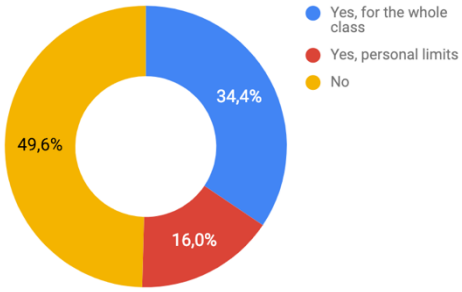

Figure 6 Have the teacher changed the trophy levels for students.

We got 51 open answers to this question. In many answers, teachers have decreased the limits to motivate students. Also, many answers state that the respondent haven't had time or knowledge to do this.

Another way to differentiate is to assign students to preliminary group or bonus group. 280 teachers answered as follows (Figure 7).

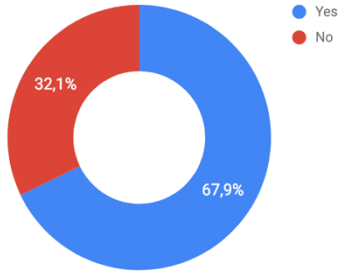

Figure 7 Has the teacher used preliminary or bonus groups to differentiate

Two thirds of teachers have used either preliminary or bonus groups to differentiate students. We also got 40 open answers. Many of them state that preliminary exercises help low achieving students with their motivation.

There is an option for students to work in pairs. However, teachers must enable this feature. We asked how many have tried this feature (Figure 8). We got 280 answers for this question.

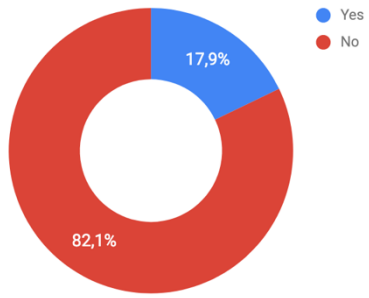

Figure 8 Has the teacher tried the pair work option

Only a small portion of teachers have tried the pair work feature. In 29 open answers giving more specific answer, many teachers tell that they have completely forgotten about the feature or they don't know how to use it. Some teacher did tell, that they use pair work only, when there are not enough devices available for the whole class.

C. *Mathematics content*

We asked all teacher, if they would like to give as feedback on mathematics content. We got total 88 answers, where 87 (31%) answered all the questions. First, we asked teachers to choose which grade (or grades) their feedback concerns (Figure 9).

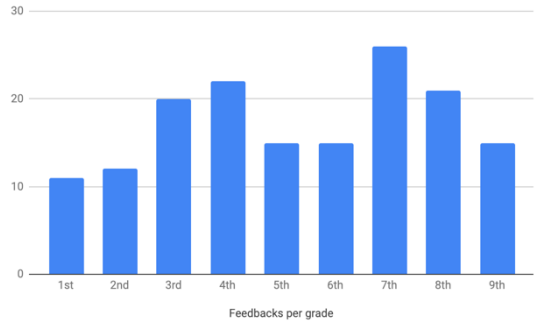

Figure 9 Distribution of feedback among grades

The 1st grade got the lowest number of feedback (11) and 7th grade the most (26). We asked if the number of exercises were suitable and if the difficulty level of the exercises was suitable. Teachers gave answers from scale 1 to 5. The optimal answer was 3. For number of exercises the number one indicated too few exercises and number 5 too many. For difficulty level the number one was too easy and number five too difficult. Teachers' answers are shown in Figure 11. We divided the grades in primary grades (1-6) and junior high grades (7-9).

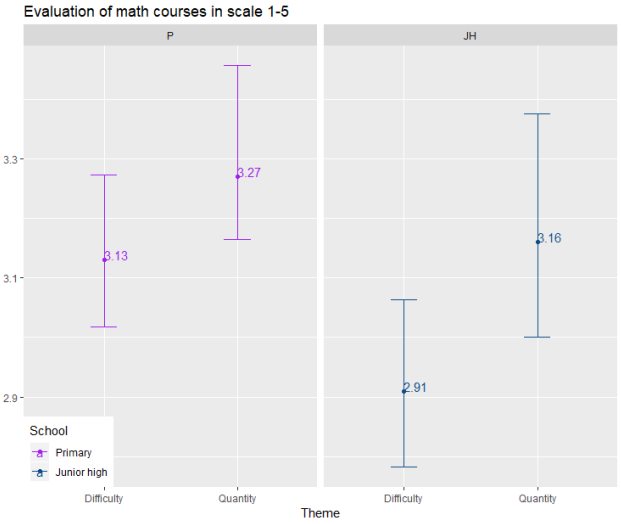

Figure 10 Teachers' perceptions on the difficulty level of the exercises and number of exercises

We asked whether the number of exercises provided each round (or lesson) was suitable. Most teachers evaluated that the number of exercises was suitable but in primary grades there is a slight tendency towards "too many" and in junior high for "too little". The general difficulty level of exercises was asked in a similar manner as the number of exercises in each lesson. Only a few answers were given to "somewhat easy" or "somewhat difficult" in both primary grades and junior high grades the tendency is towards the difficult side.

D. *Support and Training*

We wanted to know how well teachers respond to our trainings and if the support is adequate. Our support team provides support via email and phone during office hours. Expert teachers are available at schools to give help and support.

Figure 11 shows how well teachers feel they know how to use ViLLE in general on scale from 1 to 5. All teachers answered this question.

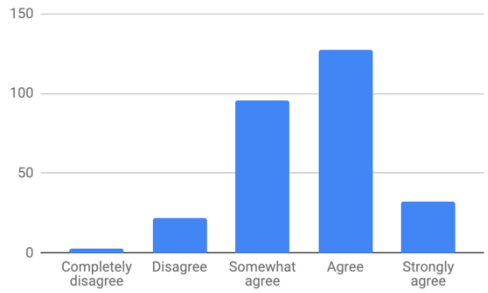

Figure 11 Teachers own opinion how well they know how to use ViLLE

Over 91% of the teachers answered somewhat agree or better.

Support was divided into two questions. Figure 12 shows how well ViLLE Team managed to provide support to teachers and the support provided by colleagues. All teachers answered both questions. We also got 78 open answers that explained teachers' answers in more detail.

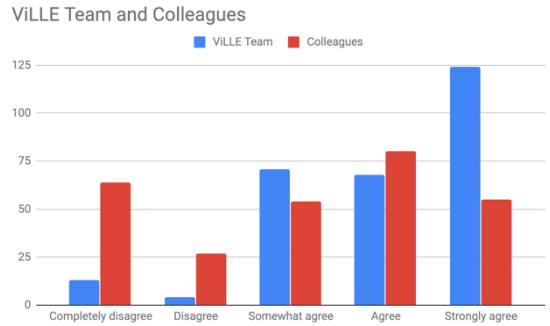

Figure 12 Did teachers get help from ViLLE Team when in need?

We were able to reach 94% teachers answering "Somewhat agree" or better when asked, if they received help from ViLLE Team when in need.

From open answers we see that many teachers are currently only ViLLE teachers in their school. Others praise that they have a very skilled colleague who is ready to help if there are any problems. Many respondents also state, that they haven't contacted our team.

Finally, we asked teacher whether they are willing to continue using ViLLE during the next academic year. Again all 280 respondents gave an answer to this question. 98.9% Answered positively that they are going to keep using ViLLE during the next academic year. Only 3 teachers told, that they were not going to continue. We got 52 open answers to this question. One of the respondents retired and one was unsure where he/she would be working the next year. The third one told that he/she would have continued if the class would have remained the same. Now there is no time to familiarize students with ViLLE. Four teachers complained about slowness or insufficient device resources at school.

In other answers teachers praised the platform: "I could not even imagine teaching without ViLLE. Totally fantastic platform. Thank you for your work", "Definitely the best digital learning environment I have tried. Students have been really excited and motivated. Even sixth-graders are waiting to get new trophies to their board of honor. For teacher it is fast enough and easy to use. Lessons can be opened ad-hoc, which is really important for itinerant special education teacher.". The comments are freely translated from Finnish.

VI. DISCUSSION

We are thrilled to get feedback from teachers who use our platform regularly to bring versatility and get more date on students learning processes. It's important for us to be able to meet the needs of teachers. The teacher community is quite active and we receive feedback on daily basis. In the spring of 2018 we collected feedback from our users.

The overall result of the survey was very positive. It might be due the fact that teachers who are more satisfied and active are also more active participating in surveys. This might affect especially the high (98.7%) result on teachers who are very positive on continuing using ViLLE the next academic year as well. This shows that we have answered the needs of the teachers and they keep using the platform. Based on the survey, it's hard to judge the individual features that make teachers so satisfied. Generally, the satisfaction seems to rise from multiple small details. The high number of new users in contrast to more experienced users is explained by the fact that the number of users is growing rapidly and there just are more new users than more experienced users [22].

The survey shows that teachers who have used ViLLE longer tend to use it more regularly and are also more likely to assign homework for students. Using a new platform requires certain amount of confidence. It is natural that the more confident the teacher is the usage also gets more regular and versatile.

Based on the numeric evaluation of mathematics content the number of exercises and the difficulty level of the exercises were suitable. Teachers gave answers from scale 1 to 5. The optimal answer would be 3. For number of exercises the number one indicated too few exercises and number 5 too many. For difficulty level the number one was too easy and number five too difficult. However, the open answers helped us find some topics that teachers found troubling. For example, many 2nd grade teachers mentioned clock exercises having analog and digital times mixed, which caused problems during lessons. We were able to reorganize the content for better suitability.

The confidence of using ViLLE reported by teachers is relatively high. This indicates that the level of training is sufficient at least to give the basics knowledge how to use ViLLE. However, from the open questions we learned that even though differentiation and other advanced features

are introduced in training and in support material, there were many teachers who did not know about these possibilities. We can use this information to even further emphasis on these features but we can also assume, that there is a need for rehearsal trainings as well.

Our support team got many praises from open feedback. Also, the results of the survey show high satisfaction for getting help from our team. There is still clearly room for improvement when 13 teachers completely disagree. In the open feedback some teachers had clarified the "completely disagree" and "Somewhat agree" answers by stating, that they had not needed any help. The same trend is shown also in the answers getting help from other colleagues except many teachers stated that they are still the only ViLLE-teachers in their school. We were still happy to see that many mentioned that the more experienced ViLLE-users from their school provide support when needed.

To conclude, the given feedback shows that even with comprehensive training there are still topics that some teachers fail to master. This does however not necessarily hinder the user experience or reflect negatively. Also support after training plays an important role for user satisfaction.

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A Framework for Measurement of Interactivity of Digital Learning Resources

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***Abstract* - The Digital Education Action plan, adopted by the European Commission is setting out a strategy to help EU Member States meet the challenges and opportunities of education in the digital age. Action 9, which covers the third priority of the plan is intended to measure the progress in the use of digital technologies in school education. Measuring the progress itself requires establishment of measurable criteria. When we consider digital education, the digital learning content becomes one of the crucial components of the educational process. At the same time the growth of the interactive technologies transforms the digital generation to a generation demanding a highly interactive experience in the classroom. The research presented in this paper identifies a necessity to be established a detailed specification of criteria measuring the interactivity of digital learning content in order to assure a learning process adequate to the learners needs, attitudes and expectations. An abstract concept of learner-content interaction in a digital context is provided and a framework of identifiers, measuring the interactivity of various formats of digital learning content is proposed.**

Keywords – digital learning; digital learning resources; interactivity; measuring interactivity; framework of interactivity indicators

I. INTRODUCTION

With the introduction of digital education as a method (equally technological, as well as didactical) into the classroom, the question has been discussed for twenty years, as to what characteristics and specifications it should come equipped with. In its dominating aspect, the digital education, to current date, is reviewed mainly from its pedagogical and psychological sides, rather than its technological counterpart, which circles around the logistical function of it. The technology of virtualization the didactical tools in the digital education is, by rule, exploited in the educational process, but in its entirety, it is not studied in detail as it will be presented, further down this publication. The research shows, that when determining the interactivity of a system, different specific non-metrics are used (such as degree/level), nominal (interaction, social presence, remote presentation, etc.) [36] or ordinal scales (low, medium, high, very high, etc.). In order to be more efficient the approach to investigating the interactivity of digital learning resources, in the present publication is discussed a definition, a conceptualization and a formal representation of educational interaction in terms of technological context as well as a framework of metrics, which empirical values can be used during the assessment of interactivity is provided.

II. REVIEW OF RESEARCH

The fundamental theories of Psychology over the influence of the environment differentiate several levels – processes of perception and spatial knowledge, management of social and personal space, interaction with the environment [1]. The key fragment of these theories is the influence a person has over the environment and space, including social space and of course the response reaction to the person himself, in other words the reflection, as well as psychological reflection to the person's own actions. This fundamental background gives a reason to accept an analogy between a person's interactions in a real environment and a user interactions in a digital environment and space as well as an analogy between the reflection in the real and digital environment.

Reviewing the interactivity, the author of [2] brings out its main advantage when applying in the context of cognitive process. The study identifies its key features such as levels and degrees, concluding, that the higher degrees of interactivity improve the processing of knowledge as a whole, perfect the process of knowledge internalization, reduce the influence of non-interactive content, optimize the time of interaction, relatively to the time spent within the whole system (e.g. a website) in which the interactivity is being applied.

In [3] is presented a study, covering the research of interactivity for a period from 1986 to 2006. The authors identify three factors, defining interactivity: speed of digital content manipulation, range and compliance of controls. As an approach to measure interactivity is used a specification of categories defining its levels and degrees. In [4] are defined interactivity types and their levels in a hybrid learning environment, summarizing, that the interactions are interlaced and there is a dependency between the perception of knowledge and the level of interactivity.

A review [5], based on a broad overview of sources (184) analyzes the interaction between four underlying processes (imagery thinking, spatial presence, co-presence and flow) unleashed by interactivity and builds a comprehensive conceptual model of the direct and

indirect effects of interactivity, including actual continuous behavior. This research overviews some definitions of interactivity, considering it as a degree, with which the user can change the form and content of digital resources. The research differentiates two base approaches in considering interactivity – technological and sensory approach. From a technological point of view, the focus is set to attributes as number and type of interactive elements. A concept is built, over the statement that interactivity defines the structural capacity of virtual reality, thus reflecting its functionality and construction. Basic interactivity characteristics as feedback in real-time and user control over the environment. It is argued that in an interactive learning process, interactivity plays a significant role by expanding learning and enhancing the learner's abilities [20].

Another study [6], on the basis of a technology model of perception (Technology Acceptance Model / TAM) [7], investigates three inner factors (perceived ease of use, perceived usefulness, behavioral intention) and two outer factors (system interactivity and technical maintenance), which can affect a given learning management system (LMS). The study brings a statistical data analysis and states several hypotheses about the influence of these factors including interactivity over the digital educational systems.

In addition to the wide spectrum of interactivity definitions, [8] offers an integrated model of multimedia interactivity. This model takes into account psychological factors like emotion and motivation, in a common constructive entity. This generalization, however, would imply some inaccuracies in the model. Motivation should be examined as an inner state of the individual, dictating the decision for performing a willful act, as reasons for this statement could be find in [9], whereas emotion is a resultant state, consequence [10]. A specific accent in the publication is the premise that the interactivity in digital education is presented as a reciprocal activity between the learner and a digital educational system, inside of which the learner's action depends on the system's action and vice versa. This could, in any case, bring a certain confusion, since the theory of reciprocity [11] examines two of its types - homomorphic and heteromorphic. The thesis about reciprocal interactivity [10] is possibly based on its homomorphic type, but this is not explicitly stated. Although, if the assumption is accepted as true, then a series of questions would have to follow up, regarding the probability of a heteromorphistic reciprocity emerging and being taken as a zero in the multimedia interactivity and its application during the educational process. Inside the same material, the focus over quantification of the interactivity is placed under critique. But in the opposite case, non-implementation of quantitative criteria in estimating the interactivity does not help to clarify more specifically its role in the educational process.

The examined in [15] conceptual model of interactivity, comprising communication context, user perception and technological component, including properties like speed, range, time flexibility and sensory component, should be noted, that corresponding to the present research could be defined additional property as range of interactive actions, which the system offers to the user. This detail could also be taken as a starting point for the formulation of measurable criteria for estimating the interactivity.

In the analysis of the technology of evaluation of interactivity, the rules, by which this evaluation may be carried out, should be taken into account. The development methodology differentiates two basic types of rules – prescriptive rules and descriptive rules. As [12] summarizes, the prescriptive rules are validated by an official body and they must be compulsorily complied with, while descriptive rules are based on following the experience and observance over the accepted practice or how the subject understands the phenomenon or process (interactivity), which must be evaluated (measured). In a technological perspective, however, prescriptive rules should be imperatively applied.

As a basic approach to evaluating the interactivity [2, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24] sets of descriptive rules, implemented by using nominal or ordinate scales of non-dimensional values are usually applied.

From the presented so far, as well as the reviewed timespan (1986 – 2017), during which the digital education expands [24, 25, 26] on a large scale and is becoming part of the educational process, the following conclusions can be made:

Conclusion №1: In the reviewed sources most of the researches are focused to non-technological aspects of the interactivity in digital systems. The characteristics of interactivity are registered by using of non-metric variables, nominal or ordinal scales, based on subjective perceptions and sensations;

Conclusion №2: There are not available measurable objective indicators and parameters of the interactivity;

Conclusion №3: The higher level of interactivity of the digital learning content is a prerequisite to higher quality of the educational process;

Conclusion №4: The interactivity is in a direct dependence of the level of technological advancement.

III. PREREQUISITES

According to global market researchers, 30 to 50 percent of the world's population uses smart mobile devices [27, 28] and for the period 2014-2017 5.7 billion of them were sold [29]. This human-oriented intelligent environment, comprised of 56% mobile and 44% desktop devices [30], is transforming the digital generation to a generation, operating in highly interactive environment, whose communication capabilities and perception channels evolve. The modern business virtual environments provoke the emotional perceptions of the users, stimulating at first place the emotional response of the human brain [31], as the cognitive process and the analysis of motives remain on a second place.

To current date the offered digital content integrates a wide spectrum of interactivity forms, based on functionalities, supported by the operational systems.

And even though the leading providers of interactive digital content are commercial players, the educational institutions and organizations are taking their steps towards adapting educational systems to the attitudes, expectations and needs of digital generation.

IV. SUBJECT DOMAIN

When we consider digital education, the digital learning content becomes one of the crucial components of the educational process. The digital learning content has specific functionalities, depending on the platforms and tools used for its producing, but the most important characteristic of this content is the one, based on human - computer interaction. In this work the technological aspects of the interaction between the learner and digital learning content are discussed and some directions as well as a proposal for establishment of a framework of norms and requirements for preparation of such a content are given.

Establishment of a standard is the last step of a given stage of a certain technological development. In 2002 IEEE accepted the IEEE 1484.12.1-2002 Learning Object Metadata Standard [32], which purpose is defining the norms and requirements to the metadata, specifying the structure of reusable learning objects in the learning management systems. This was a step to the right direction which gave a good start to the introduction of digital learning content in the classroom, but to this point the research has been focused mostly to the pedagogical aspects of learner-content interaction. The LOM Standard itself envelopes two interactivity issues – instance 5.1, defining the type of interactivity and instance 5.3, defining the level of interactivity. As an affirmation of the first conclusion given above, in LOM Standard the interactivity is placed in the Educational category, this way focusing only to its pedagogical aspects.

The absence of measurable indicators of learning content's interactivity does not assure such a quality of the learning process, adequate to the attitudes, needs and expectations of a generation demanding a highly interactive experience in the classroom.

The behavioral model, formed in a highly interactive environment is expecting a similar functionality and interaction in each other form of digital content delivery including in the classroom. And when the reality do not correspond to the learners' expectations factors as motivation, attention, interest, emotional engagement and concentration are decreasing their values thus leading to lowering the effectiveness of education.

The assumption about evolving of a highly interactive generation as a result of innovations in digital technology is grounded in the multimodal nature of the human brain and the multichannel sensor system of the human body [33, 34].

From a technological point of view the interactivity is considered as a key feature of API's concept reflecting the model of user interaction with the digital systems. In addition, neuroscience has revealed changes in neural pathways and synapses due to changes in behavior, environment, neural processes, thinking and emotions. The structure of the brain changes and the brain's cognitive functioning shifts in response to regular, intensive use of technology resulting in development of new cognitive talents that better suit an intensive digital lifestyle [35, 36].

The authors of [35] differentiate three levels of attention, upgrading the existing attention model in terms of users' ability to focus when operating in a digital high-tech environment. The research offers the conclusion that the user attention is influenced significantly by the way the digital technologies are being used in the daily routine and an evolution of the attention skills is ongoing. The results show that the digital savviness dictates whether the people are more likely to employ selective or alternating attention to navigate/make the most out of multi-screen environments [35].

At the same time assuming the cognitive process as a process comprising activities that unfold over time [37] when considering it in the context of human-computer interaction it could be interpreted as a set of distributed over the time actions, performed by the user.

V. A FRAMEWORK FOR MEASURING INTERACTIVITY

The above presented results give a reason to assert that if the digital learner is explicitly operating in a highly interactive environment in each routine, then when this learner is participating in an educational process he or she is more likely to:

- form a cognitive activity, based on multiple information flows delivered through multichannel interactive environment;
- solve problems by use of digital devices with highly interactive functionalities;
- demonstrate a common model of behavior when interacting with each one digital device incorporated in the classroom.

This work proposes an approach to formalize the digital learning content as a complex structure of integrated components of various data types, each of them having a predefined set of interactivities. The idea of forming separate sets of interactivities for each data type in a digital learning resource is based on the concept about the multichannel perceptions of digital learners.

A core part of the approach is defining several sets of interactivities and their abstract representation but before formalizing the interactivities of the digital learning content is necessary to be defined the educational interaction emerging in educational process running in a digital context.

A. Educational interaction in a digital context

Further in the article when referring the educational interaction in a digital context we will mean *an interaction, requiring and provoking a response reaction which generates a measurable result in a cognitive process running in a digital environment.*

On Figure 1 are represented the interactivity layers in an educational application. Each educational interaction is considered as an interactive layer over the API layer

implementing the system functionalities accomplishing the user-system interaction.

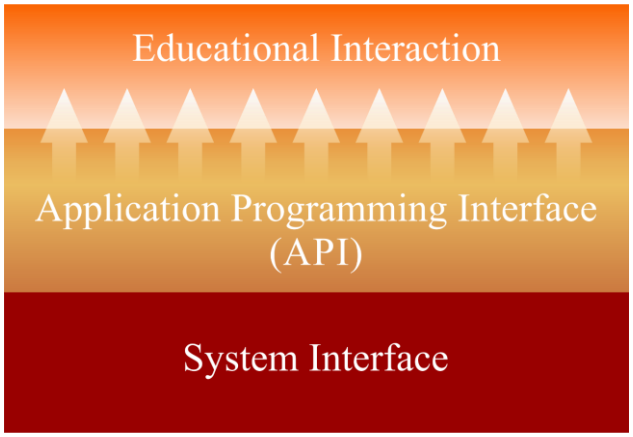

Figure 1. Interactivity layers in an educational application

In a previous work [38] the authors have proposed a pattern of a learning resource with interactive rich content, which defines a finite set of basic data types $DT \supseteq \{V, T, A, D\}$ where V denotes a finite subset of visual data types, A denotes a finite subset of audio data types, T denotes a finite subset of textual data types and D denotes a finite state of specific user defined data types:

$$V = \{v_i, v_2, v_3, .. v_l\}$$
$$T = \{t_1, t_2, t_3, .. t_m\}$$
$$A = \{a_1, a_2, a_3, .. a_n\}$$
$$D = \{d_1, d_2, d_3, .. d_k\}$$

To each element belonging to these sets is related an object which is an instance of the corresponding data type:

$$\forall(x: V) O_{v_x}$$
$$\forall(x: T) O_{t_x}$$
$$\forall(x: A) O_{a_x}$$
$$\forall(x: D) O_{d_x}$$

Each one of the objects should provide to the user a set of possible interactions:

$$E_V = \{e_{v_1}, e_{v_2}, e_{v_3}, .. e_{v_l}\} \; as \; for \; \forall(x: O_v) E_{v_x}$$
$$E_T = \{e_{t1}, e_{t2}, e_{t3}, .. e_{tm}\} \; as \; for \; \forall(x: O_t) E_{t_x}$$
$$E_A = \{e_{a1}, e_{a2}, e_{a3}, .. e_{an}\} \; as \; for \; \forall(x: O_a) E_{a_x}$$
$$E_D = \{e_{d1}, e_{d2}, e_{d3}, .. e_{dk}\} \; as \; for \; \forall(x: O_d) E_{d_x}$$

The abstract concept of the educational interaction with a digital learning resource is based on a lower level interaction, defined by the software environment. We propose the digital learning content to be considered as a composite, consisting of independent **modules**, formed by **resources** which are built by **objects**. The **objects** are the smallest distinct entities of the learning content and deliver the defined above data types in an appropriate form for interaction with the learner. Figure 2 shows the abstract conceptualization of the educational interaction.

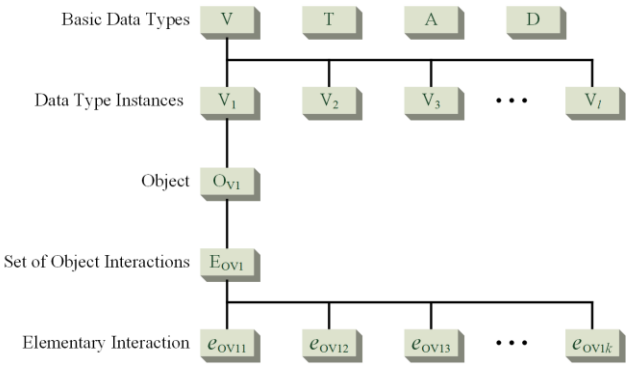

Figure 2. Abstract conceptualization of the educational interaction

As an example will be given the digital learning content included in the course "General Geomorphology". A module "Atlas of a Landscape Ecology" is a part of the content and it has a resource "Geographic Map" associated with it. The resource could contain objects - digital instances of the defined data types – e.g. image, text, audio, video, simulation, etc. Various components could be reused and assembled in different objects for specific purposes – lectures, labs, tests, educational games, etc. as the leading principle is that each module, resource and object should have its own interactivity.

The proposed conceptualization is applicable in various digital tools, supporting the delivery of knowledge, acquiring skills, knowledge testing, application of knowledge and practicing skills as well as in educational games.

By nature the educational interaction is an abstract concept, but since it is based on APIs and system interfaces it means that some of the ideas of object oriented modelling are applicable for its specification. To each educational interaction could be associated attributes, as shown below.

B. Attributes of the educational interaction

1. Initiator. By default the initiator is the teacher, but there is a possibility the functions of the teacher to be performed by artificial intelligence.
2. Interaction of each object of a certain data type:

$$E_{DT} = \{E_V, E_T, E_A, E_D\}.$$

3. Response form:

$$R_{typeV} = \{type1, type2, type3 \; ... typeL\}$$
$$R_{typeT} = \{type1, type2, type3 \; ... typeM\}$$
$$R_{typeA} = \{type1, type2, type3 \; ... typeN\}$$
$$R_{typeD} = \{type1, type2, type3 \; ... typeK\}$$

4. Quantity of interactions for

$$\{E_V, E_T, E_A, E_D\}$$

a) Quantity for each subset of

$$\{E_V\}, \{E_T\}, \{E_A\}, \{E_D\}$$

$$N_{v_i} = \sum_{j=0}^{n} E_{v_i j}$$

$$N_{t_i} = \sum_{j=0}^{n} E_{t_i j}$$

$$N_{a_i} = \sum_{j=0}^{n} E_{a_i j}$$

$$N_{d_i} = \sum_{j=0}^{n} E_{d_i j}$$

б) Quantity for the subsets

$$\{N_V, N_T, N_A, N_D\}$$

$$N_V \in N = \{N_{v_1}, N_{v_2}, N_{v_3}..N_{v_l}\}$$

$$N_T \in N = \{N_{t_1}, N_{t_2}, N_{t_3}..N_{t_l}\}$$

$$N_A \in N = \{N_{a_1}, N_{a_2}, N_a..N_a\}$$

$$N_D \in N = \{N_{d_1}, N_{d_2}, N_{d_3}..N_{d_l}\}$$

5. Sensitivity level – a set of learner's senses, engaged in the interaction with the digital learning content

$$S = \{S_1, S_2, S_3..S_p\}$$

The educational interaction could have a horizontal or vertical structure. When the structure is a horizontal one, the objects of a same type have identical interactivity. With a vertical structure, the interactivity of the parent resource should have attributes, applicable only to its inheriting objects. In the given above example the interactivity of the "Atlas" module could be operable only if it is provided to its inheriting resources and objects by the lowest system interface – e.g. scaling, transparency, positioning, drag and drop etc.

In order to be measured the interactivity, the given above attributes, should be accessible at a programming level and to be delivered to the teacher in an appropriate format. Their measured values could be used as a framework of didactical criteria assessing the educational interaction.

Below is proposed an exemplary framework of measurable criteria in form of weight coefficients which could be used for quantitative estimation of the interactivity of digital learning resources (Table I, II, III).

TABLE I Low Level of Interactivity

Level L	***Low Level of Interactivity***		***Weight***
Impact on	Object 3D Translation	XY position	2
		Z order	2
	Object Attributes	Alpha channel	2
		Color	1
		Size	1
		Shape	2
		Amount	2
	Hyperlink	Textual	1
		Visual	2
	Document Manipulation	Page up	1
		Page down	1
		Scroll	1
		Cross reference	2
	Hint	Textual	2
		Visual	2

TABLE II Middle Level of Interactivity

Level M	***Middle Level of Interactivity***		***Weight***
Impact on	Visual	Image	10
		Video	20
		Animation	30
	Audio	Sound	10
		Speech	10
		Music	20
	UI Components	Desktop	20
		Mobile	30

TABLE III High Level of Interactivity

Level H	***High Level of Interactivity***		***Weight***
Impact on	Tactile	Augmented Reality	50
		Virtual reality	50
	Haptic	Contactless	50
		Contact	50
	Sensors	Wired	40
		Wireless	40
	Neural computer	Contactless	60
		Contact	60

As an exemplary application of the framework will be given interactivity measurement of a learning resource containing text, hints, hyperlinks, video and user controls (Table IV).

TABLE IV Exemplary Application

Interactivity L		***Weight***
Object 3D Translation	XY position	2
	Z order	2
Hyperlink	Textual	1
Document Manipulation	Page up	1
	Page down	1
	Scroll	1
	Cross reference	2
Hint	Textual	2
	Total:	**12**
Interactivity M		***Weight***
Visual	Image	10
	Video	20
Audio	Sound	10
UI Components	Desktop	20
	Total:	**60**

As a system metadata for the interactivity level of the resource, the following exemplary data format could be used: <interactivity><L-12><M-60><H-0>.

VI. CONCLUSION

With the proposed above approach to assessing (measuring) the interactivity of the digital learning content it is possible to be found solutions to issues related to:

- motivation, attention, interest, emotional commitment and concentration of the learners in the educational process;
- effectiveness of the educational process;
- the intelligent approach to selection of digital forms for knowledge provision;
- reducing the negative influence of the generation gap between the teacher and learner in the educational process.

There are series of experimental studies envisaged to collect empirical data for future analysis.

The proposed framework wouldn't find its introduction and development in the educational process without the active involvement and collaboration between software developers, educational institutions and academic community. Teachers should not be placed in the position to self-develop digital learning resources that meet the requirements and criteria for interactivity proposed in this article. This, in many cases, would lead to negative results.

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Decision Support in a Telecommunications Engineering E-Learning Platform

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***Abstract* - This contribution presents the development of a decision support system to be used by telecommunications engineering students in selecting a suitable frequency filter design tool. System design follows the expert system paradigm and implements multi-criteria decision modelling using the Decision Matrix method, and combines set theory based option filtering with the MAUT method for option ranking. The expert system inference engine is rule based, while the knowledge base is designed as a Decision Matrix and implemented in a relational database. The user interface is to offer two types of user experience for beginners and advanced users. The system is developed as an integrated part of a telecommunications engineering online learning system, and is designed to be open-ended to incorporate additional filter design tools and decision criteria.**

Keywords – telecommunications; e-learning; filter design; decision support; multi criteria decision analysis; expert system

I. INTRODUCTION: FILTER TOOL SELECTION AS A DECISION PROBLEM

The selection of an appropriate filter design tool in telecommunications engineering projects requires considerable knowledge of the range of available tools, their characteristics and relevant criteria for the required filter type. Such expert knowledge is typically acquired through engineering experience.

In order to facilitate the learning process and the selection of the filter design tool for experienced and inexperienced users, we have decided to construct an expert system (ES) - a decision support tool that would incorporate the knowledge base of experienced telecommunications engineers and researchers and could be integrated within the online learning system under development by the Faculty of Telecommunications, Technical University of Sofia (TUS) and described in [1], [2], [3] and [4]. The goals of this system's development is to integrate available online tools solving different computer-aided design tasks and combining tools for complex task solving. Filter design tools are integrated in the online learning system after verification, estimation, classification and characterization.

A survey of the filter design tools was performed to gather the potential tool selection criteria, and the relevant selection criteria were then selected by the engineering team and collected in a table containing the criteria types, their names, description, and possible values. The list of approximately sixty filter design tools characteristics was reduced into a set of eighteen selection criteria, e.g. frequency range, approximations model, roll-off slope, sensitivity, noise, etc. and grouped into criteria types [4].

As there are several criteria present in the filter design tool selection problem, we have examined several Multi Criteria Modelling Analysis (MCDA) methodologies in the development process and implemented a combination of a Decision Matrix (DM) and MAUT method for option filtering and ranking.

In this contribution we present the original decision problem, the decision support tool development, and the decision modelling methodology used within our collaboration project with TUS. Our joint development goal is a working, interactive web-based filter design tool selection system.

II. METHODOLOGY: MULTICRITERIA DECISION MODELLING AND EXPERT SYSTEMS

Several decision modelling methods were examined in the development of the presented solution. A good overview of MCDA methodologies and tools is presented in (Bohanec, 2006) and (Kolios, et al., 2016). According to (Kahraman & Kaya, 2010), successful selection of the most appropriate multi-criteria methodology should consider a range of different perspectives in order to comprehend all sides of the problem and, when necessary, consider inter-connections among the criteria. MCDA methods need to structure the decision procedure, to demonstrate the trade-off among the criteria, to assist decision-makers to reflect upon, articulate and apply worthy judgments related to satisfactory trade-offs, resulting in suggestions when considering alternatives, to estimate risk and uncertainty more consistently and reasonably, to simplify negotiation and to keep a record of how decisions are made.

According to [5], an ES can be defined as: a program that attempts to mimic human expertise by applying inference methods to a specific body of knowledge. Bohanec and Rajkovič [6] describe ESs as intelligent information system that behave, in a certain sense, as a human expert in the application domain. According to [6], ESs are typically composed of two modules: (1) a knowledge base and (2) an inference engine. The knowledge base contains the knowledge about a particular problem domain. The most common methods of knowledge [6] are production (if-then) rules, semantic nets and frames. In addition, these formalisms are usually

capable of dealing with imprecision, uncertainty, and qualitative (nonnumeric) nature of the expert knowledge.

Grosan and Abraham [7] describe rule-based systems (also known as production systems or ESs) are the simplest form of artificial intelligence. A rule based system uses rules as the knowledge representation for knowledge coded into the system. Instead of representing knowledge in a declarative, static way as a set of things which are true, rule-based system represent knowledge in terms of a set of rules that tells what to do or what to conclude in different situations. Rule-based ESs [8] are used as a way to store and manipulate knowledge to interpret information in a useful way. They are often used in artificial intelligence applications and research. A classic example of a rule-based system is the domain-specific ES that uses rules to make deductions or choices. Rule-based systems have been used to automate problem-solving know-how, provide a means for capturing and refining human expertise since the 1980s [8].

The decision-matrix method, also known as the Pugh method and Pugh Concept Selection [12], is a quantitative technique used to rank the multidimensional options of an option set, frequently used in engineering, and applicable to other multi-criteria ranking or selection decision. The DM consists of a set of criteria, usually displayed in rows, and a set of options, usually displayed in columns. The relation between a criterion and an option is entered in the intersecting cells, and can represent the presence or absence of a quality described by the criterion, or a qualitative or quantitative value of the option for the criterion. In case of quantitative values, the DM can be used as a quantitative MCDA model, however its structure imposes the limitation to a single level of criteria, i.e. hierarchical MCDA models cannot be formulated as a DM.

The solution presented in this contribution is related to the system described by [13], as a prototype ES that helps software project managers and software engineers in selecting the appropriate software development methodology, and to the system described by [14], who present a rule based recommendation system that can be helpful to software developers in selecting the most appropriate SDLC model to be used for the development of a software product and to the solution presented by [15] whose paper presents an ES based rapid prototyping (RP) system selection program incorporating the data on 39 commercially available RP systems, and finally [16], who describe a decision support system using qualitative and quantitative criteria in multicriteria decision tree for project planning support.

A. Multi-Attribute Decision Analysis

One of the widely used approaches to decision support is multi-attribute decision analysis (MCDA) ([17] and [18] in [6]). The main concept of MCDA is the decomposition of a decision problem into smaller, simpler sub problems with the decomposition repeated until each elementary sub problem can be represented as a single value, which are referred to as attributes, parameters or criteria.

The resulting decision problem structure can be represented as the tree of attributes *X* as shown in Fig. 1. Each option *O* is modelled as a vector of values *x* of the corresponding attributes. The vectors are then evaluated by a utility function *F*. This function is defined by the decision maker(s) and represents their goals. When applied upon a particular option O_k, the function *F* yields a utility $Y_k = F(O)$. Options can be ranked according to *Y* and usually the best option is chosen (decision is completed). In the multi-attribute paradigm, the decision makers' knowledge about a particular decision problem is therefore described by attributes *X* and a utility function *F* while the options are represented as vectors (where the *i*-th component is represented by a variable x_i). [6]

The utility function for option Ok for the multi criteria decision model shown in Fig. 1 would therefore be written as $F(O_k)= F(x_{k1},x_{k2},x_{k3},\cdots,x_{kn})$, with option *k* represented as $O_k = (x_{k1},x_{k2},x_{k3},\cdots,x_{kn})$.

As the attributes often represent different measures (e.g. weight, price), the attributes' values are projected on a unified scale (e.g. [0, 100]) via attribute utility functions u. The utility function structure depends on the structure of the tree of attributes. Utility function for a single-level tree could be sum of individual attribute utilities u e.g.:

$$F(O_k) = \sum_{j=1}^{n} u_j(x_{kj}). \tag{1}$$

MCDA models often include weights to model the varying significance of different attributes. The value function for a single-level (non-hierarchical) MCDA model could then be written as the MAU (multi attribute utility) function as it is known from the MAUT method [17]:

$$F(O_k) = MAU(O_k) = \sum_{j=1}^{n} w_j u_j(x_{kj}) \tag{2}$$

where w_j describes the significance (weight) of attribute *j*.

A typical decision problem in the application of MCDA involves a static decision problem, i.e. decision makers follow a static set of goals, which are translated into a hierarchical structure of criteria and their weights, and then implemented as a utility function.

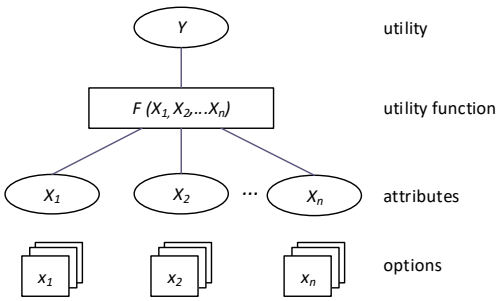

Figure 1: Tree of attributes in a MCDA model [6]

The resulting multicriteria model has a static structure, a static set of quantitative or qualitative criteria and static criteria weights. In the application of such a model, each options is evaluated by entering the value of its individual

criteria into the model, and a singular value representing the option utility is calculated. After analysis of results, the option with the highest utility value is then typically selected. The filter design tool selection problem (and engineering tool selection problems in general) however importantly differs because:

- the decision goals differ depending on the engineering problem that the tool is to be used on;
- due to variable goals, the criteria weights vary as well;
- some of the criteria can be exclusive due mandatory requirements for the engineering tool. These criteria have binary values (feature is present/not present); and
- weights have a discrete set of values: mandatory, desired, and irrelevant.

In such a problem, the evaluation of the exclusive criteria produces a set of viable options, which have to be then ranked according to the utility function calculated from the non-exclusive criteria. These specific qualities of the examined decision problem make the use of methods such as AHP [19], MAUT [17], or DEXi [6] impractical, as each use of the model requires changes to the multicriteria model as opposed to entering new options and their criteria values. Alternative methods, previously used in engineering, such as the DM or Pugh method [12] are better suited to this type of problem, and were used as a basis for the development of the solution – a rule-based ES. Adaptations of the DM system were however required in order to allow the development of a responsive, web-based ES.

B. Decision Modelling

Fig. 2Figure 2 shows the original filter design tool selection problem as an influence diagram [9], [11]. We start with the engineering problem which requires the use of a filter design tool, and from which we can assemble a list of requirements. Based on the available tools (software packages), which represent the options, and our requirements we can conduct the tool selection process. The decision process requires explicit definition of the decision criteria and their selection. The results of the tool selection process is a ranked list of feasible options. In order to model the decision process shown in Fig. 2Figure 2, we had to define the selection criteria. A survey of filter design tools was performed to gather the potential tool selection criteria. The relevant criteria were then selected by the engineering team and collected in a table containing the criteria types, their names, description, and possible values. The process is displayed in the influence diagram in Fig. 3. By consulting with the engineering experts and researchers which have provided the list of available options and their characteristics and defined the filter design goals, we were able to reduce the list of approximately 60 filter design tools characteristics into a set of 18 selection criteria, grouped into criteria types.

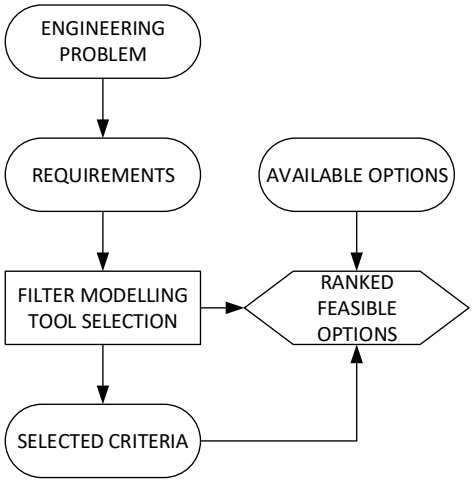

Figure 2: Influence diagram for the filter design tool selection problem

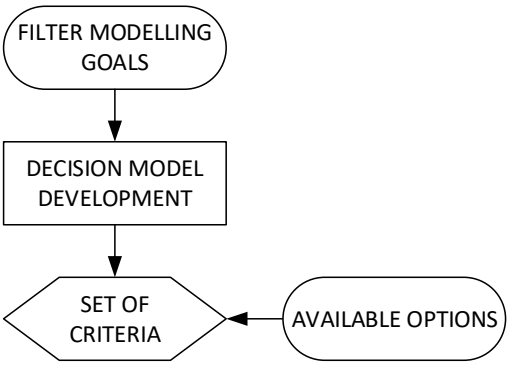

Figure 3: Influence diagram for the decision modelling problem

III. RESULTS: EXPERT SYSTEM DESIGN

A. Criteria and Weights

Due to problem specifics described in Chapter 2 we have decided to define a discrete, qualitative set of values for the weights: *mandatory*, *desired* (but optional), and *irrelevant*, that the user selects from when using the system. A *mandatory* value for a criteria will have the system to evaluate only the options where the feature is present. A *desired* value for a criteria will have the system add a number of points, depending on criteria weight, to the score of an evaluation option with the feature. Finally, *irrelevant* value for a criteria will have the system not evaluate the options for this criteria at all.

To shortly describe the operation of the proposed system, the evaluation of the *mandatory* criteria produces a set of viable options, which then have to be ranked according to the utility function calculated from the *desired* criteria.

As the importance of criteria depends on user goals, the criteria weights *(wi)* are not constants, but depend on user input, and can be therefore described as *wi = f(input)*.

User does not input weights directly, but chooses each criterion to be either:

- *mandatory*, or
- *desired*, with priority levels 1 (highest), 2 (medium), and 3 (lowest).

Priority levels are converted into weight values using the equation:

$$w_j = \begin{cases} \frac{3}{6}, \text{ if input(j) = 1} \\ \frac{2}{6}, \text{ if input(j) = 2} \\ \frac{1}{6}, \text{ if input(j) = 3} \end{cases} \quad (3)$$

, thus ensuring the conformity with the MCDA convention [20] of $\sum_{j=1}^{n} w_j = 1$.

The evaluation criteria are grouped into criteria types, with the following types currently used: *Filter types offered; Frequency range offered; Sharp roll-off slope possible; Cascading possible; Phase compensation offered; Ripple; Group Delay; Power consumption; Sensitivity; Noise level; Cost; Size*. For example, the *"Filter types offered"* criteria type contains the criteria *Low-pass; High-Pass; Band-Pass; Band-Stop; All-pass.*

Value domains for the criteria range from *Boolean* (e.g. the Low-pass criteria per option can be true or false), *discrete* (with separate tables defining allowed criteria values, allowing the use of qualitative criteria) and quantitative (*integer* or *real*, e.g. the Cost criteria).

B. Decision Matrix and the MAUT Utility Function

Using the defined set of criteria and the filter design tool data we have designed a table to be used as the Decision Matrix (DM). Table 1 shows a fraction of the DM, displaying its structure. We chose not to include the whole table due to space restrictions. Rows are used to list the criteria types and individual criteria, while columns are used to indicate the presence or absence of filter design features per tool. Criteria value of »1« represents the presence of the feature described by the Evaluation Criteria while the value of »0« represents the absence of the feature. The DM in the presented form allows the algorithmic evaluation of individual options including the use of weights, given as »Criteria Priority«.

The DM is implemented as table within a relational database, containing the data on options with each row/entry representing a single option, and columns/attributes containing the criteria values. The implementation of the DM in a relational database simplifies decision model maintenance by avoiding code-level changes and accelerates system operation via implementation of a part of the option evaluation via database server-side execution in SQL code.

Option evaluation is conducted using set theory and relational algebra based instructions to execute a set of rules for filter design tool selection. User requirement entries/replies to questions are used to generate the sets of suitable options per criteria, and the SQL intersect operation is used to combine these sets and thus generate the composite set of suitable options.

In the foreseen use case, the user is presented with a sequence of questions aiming at filtering the set of viable filter design tools. Every question allows the user to define a feature (criteria) as either mandatory, desired, or irrelevant, and selecting the criteria priority, thus setting the criteria weight.

TABLE I. DECISION MATRIX STRUCTURE

Criteria Type	Criteria Priority	Evaluation Criteria	Options						
			AADE	LCFD	FilterCAD	FilterLab	WBFD	AFW	PAC-Designer
Frequency range/ Filter elements	*f*(input)	1Hz-12MHz (active filters)	0	0	0	0	1	1	0
	…	….	…	…	…	…	…	…	…

The criteria set as mandatory by the user are used to construct the set of viable options, i.e. tools that offer all mandatory features. To accelerate the filtering of viable options we have decided to move the filtering processing to the database side.

First the set of viable options VO is generated by producing an intersection of the sets of options O that satisfy individual mandatory criteria, written using relational algebra and set theory as:

$$VO = \bigcap_{i=1}^{n} \prod_{OptionId} \sigma_{X_i=True}(O) \quad (4)$$

with *VO* representing the set of viable options, X_i with indexes $i = 1…n$ representing the mandatory criteria specified by the user, and $\sigma_{Xi} = True$ representing the selection operation in relational algebra.

The options O_k in the viable set VO are then evaluated and ranked according to the desired criteria using MAUT [20] equation for the utility function *F(Ok)*:

$$F(O_k) = \sum_{j=1}^{n} w_j u_j(x_{kj}) \quad (5)$$

where $w_j = 1$ and $u_j(x_{kj}) = \begin{cases} 1, \text{ if } x_{kj} = True \\ 0, \text{ if } x_{kj} = False \end{cases}$.

Consequently the viable options are to be displayed to the user in descending order according to their final score, i.e. utility, facilitating the selection of the Analogue Filter design tool in online learning system.

C. Expert System Implementation

ESs are usually developed using specialized ES software packages known as ES shells, e.g. DEXi [21]. As this ES is to be integrated within an Online assisted platform for Computer-aided design in communications being developed at the Faculty of Telecommunications, Technical University of Sofia, we have decided to implement it as a web based application using PHP and a MySQL relational database.

The ES has the three usual [6] components:

- a knowledge base, implemented as a set of tables in MySQL database containing the data on the available filter design tools as a set of criteria and their discrete values;
- an inference engine, implemented in PHP and a MySQL relational database code containing the rules for filter design tool selection based on user input;
- a user interface with two alternative user experiences: the classic ES interface implemented as a set of web pages containing the set of questions and options for the user and an alternative display for advanced users, containing all criteria on a single screen, allowing the selection of features via checkboxes and radio buttons.

The knowledge base contains the following tables:

- the options table: a table containing the data on options with each row/entry representing a single option, and columns/attributes containing the criteria values (thus implementing the DM),
- criteria value tables: a set of tables containing discrete values for each criteria, where necessary. Quantitative and Boolean type criteria do not require criteria value tables;
- criteria weight tables: a set of tables containing the weight for each criteria. As mentioned in chapter 4.2, we have decided to set all weights to the integer value of 1 (one).

The implementation of the knowledge base in a relational database simplifies knowledge base maintenance by avoiding code-level changes and accelerates system operation via implementation of a part of the inference engine via database server-side execution in SQL code.

D. Inference Engine Operation

After determining the list of viable options, each option (tool) is given a final score by adding all its points. Consequently the suggested options are ranked and displayed to the user in descending order according to their final score. Scoring detail is displayed to the user as a part of the explanation subsystem (justifier) of the system.

First the set of viable options is generating by producing an intersection of the sets of options that satisfy individual mandatory criteria using relational algebra (see Equation 4).

The options in the viable set are then evaluated and ranked according to the desired criteria using Equation 5.

To illustrate the operation of the inference engine we present a simplified example, where the user has specified that the sought tool should offer the following options (listed criteria values should be *True*):

- *Mandatory:*
  - *Filter types offered:*
    - *"Low-pass"*
    - *"High-pass"*
- *Optional:*
  - *Cascading possible*
  - *Cost: <100 EUR*

In implementation the list of specified mandatory criteria is traversed in PHP code and a set of SQL queries producing the sets as SQL views is generated. SQL code is passed to the database management system and a dataset containing the viable options and their criteria values is returned.

The generated SQL code for the given example would be:

```
CREATE VIEW ViableOptions
AS
    SELECT OptionId
        FROM Options
        WHERE LowPass = True
    INTERSECT
    SELECT OptionId
        FROM Options
        WHERE HighPass = True
```

The evaluation of desired criteria as per equation (8) would be then implemented as a set of rules as in the following pseudo-code example:

```
IF: UserInput(CascadingPossible) = "Desired"
THEN
    IF Option(CascadingPossible) = True
    THEN: OptionScore = OptionScore + 1
```

IV. CONCLUSION

Based on the study performed in the paper a MCDA based decision support system is to be developed to support the Analogue Filter design tool in online learning system. The approach will be extended to design in different categories of circuits and systems where a set of online CAD tools with high degree of equivalence is available. The boom of online tools led to development of portals or pools of online tools as for example Martindale's Center [22], but in those pools, tools are neither estimated nor characterized and there is not an interactive mode proposed for users. The novelty in the approach proposed in the paper is based on the estimates and characterization passports of online tools in the online learning system which are implemented further for automated support of designers in tool selection and development of interactive mode for users.

The following step is the development of a rule-based ES to be integrated in the telecommunications engineering online learning system, and used as a decision aid selecting the appropriate filter design tool. It is to be open-ended and able to incorporate additional filter design tools and decision criteria. The planned development will include design of the data model for the knowledge base, the design

of user interface and coding of the user interface and inference engine using web technologies (PHP, JavaScript).

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Enhancement of students' skills via project-based learning

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***Abstract* - The increase in employment, productivity and social cohesion are pillars of the smart growth of the European Union. Specialized agendas and action plans (Digital Agenda, Education and Learning, E-skills and Employment) were designed to support these objectives. To increase the employment of European Union citizens, the part of the above-mentioned agenda is focused on the employment of the young people, especially recent graduates. Excessively theoretical approach to educate youth was identified amongst the major problems in the educational system. The educational system should empower the students to acquire practical experience, which represents the advantage when applying for a job, or choose to develop their own business. Moreover, making graduates able to implement their knowledge, skills and experience to solve practical problems via project-based learning to enhance their motivation and involvement in the educational process. The paper describes the setup of the newly developed course, its content, evaluation by students and lecturers, achieved results and concept describing our future work related to Europe2020 objectives.**

Keywords – project based learning; on-line marketing; education-practice collaboration; entrepreneurship; startups;

I. INTRODUCTION

Development of the new business units is the driver of economic growth of the country [22]. However, when browsing the study plans of universities with the major in economics, business and management in Slovakia, the content of their courses tends to transform the students to become ideal employees, not ideal employers. Moreover, Harris [24] consider the education to be the structured misrepresentation of reality, and many times, students have no opportunity to gain practical knowledge by executing real-world business tasks. On the contrary, the word "startup" is one of the most significant buzzwords in the sphere of business. During university studies is the ideal time for students to start their own venture, as they (1) have more certainty in their lives provided by their families ("the pillow") in case of failure; (2) have an ideal opportunity to learn practical skills that can help them later in their career, even when they finish running their own business; (3) can acquire great talent for their team (represented by their classmates) for smaller wages before these talents apply for a job in large corporations. Even in case their business fails, they can learn a lesson from this experience and build a new company (many successful entrepreneurs have a history of failures [32]). This motivated us to develop a-mixture-of-marketing-and-business course that helps students conduct business by actually conducting a business and motivate them to become an employer, not an employee.

II. THEORETICAL BACKGROUND

A. Entrepreneuership agenda in European Union

Unemployment is one of the crucial economic factors for the country. When it comes to young citizens, the rate is even higher, compared to the other groups of the citizens [34]. Typically, young people in their twenties, new graduates need to face the reality of finding the job. In EU (European Union), the youth unemployment rate reached 15.1% in 2018 [34]. In [34] entrepreneurship is defined as a transversal competence, which applies to all spheres of the life: from the nurturing personal development, to the actively participating in the society, to (re)entering the job market as an employee or as a self-employed person, and also to start-up ventures (cultural, social or commercial). From that point of view, the education of young generations towards entrepreneurship is important. In Europe2020 strategy, it was identified as one of the key elements to promote innovation, competitiveness and economic growth [12]. Entrepreneurship is 'an individual's ability to turn ideas into the action. It includes creativity, innovation and risk-taking, as well as the ability to plan and manage projects to achieve business objectives. [5] The development of the entrepreneurial skills at multinational level is covered by the New Skills Agenda for Europe [8], [13] by its particular area - The Entrepreneurship Competence Framework (EntreComp) [10], [9]. EntreComp conceptualizes entrepreneurship as a competence needed in XXI century (Figure 1). It covers the mixture of cognitive skills, social skills and relationship skills, technical skills and managerials skills, also defined as important by the other authors e.g. [7], [21].

B. Education towards innovative entrepreneuership

The entrepreneurial skills are crucial in the process of defining a new business idea and its implementation. It is important to know how to reduce the risk, seek for new sources of innovation, use creativity tools, and learn from the market [16].



Figure 1. Entrecomp Framework visualisation; source: [14]

Based on Institute of Entrepreneurship Development [18] it is necessary for the young people to possess entrepreneurial skills. The survey identified some of the main skills for successful entrepreneur:

- Management and leadership skills, that cover the ability to plan activities occurring in the organization, ability to coordinate and motivate human resources within the organization, ability to support cooperation, communication, etc.
- Networking and communication skills helping express ideas in clear and effective way and develop relationships with people within and outside the business.
- Planning a business plan and access to finance, which are extremely important factors to maintain the sustainability of the business.
- And finally - Digital marketing skills, that are considered as the key factor for boost competitiveness, productivity, innovation and professionalism. The crucial part is the knowledge about using digital tools and technology for surviving on the market and future growth of the business.

C. *Education of 21st Century and Project Based Learning method (PBL)*

At present, the "wireless" generation is the participant of the education. "Wireless" means, that this young generation is born into the age riddled with Information and Communication Technology (ICT), so for these people is natural to use ICT in every field of their lifes. Not excluding education. J. S. Brown [20] defined attitude of the digital youth to ICT as "something akin to oxygen". It's integral part of their social life. It causes shift in their perception of the education, life and behavior, and also in requirements of the educational process and contend design and development. In the article [19] main requirements on new learning design were introduced (Table 1):

TABLE I. REQUIREMENTS ON LEARNING DESIGN

Requirements	Learning design
Well-defined goals	Learning objectives are clear
Patience	Students may redo assignments repeatedly if necessary
Team play	Groups of students work together to complete and review tasks
Tracking	Students see progress at every level and as a whole
Change	Students divide large tasks to learn time management and to progress toward goal achievement
Immediate consequences	Teachers provide immediate/useful feedback and meaningful, formative and diagnostic assessments
Personalization	Students explore different roles, which are shaped by their interests, to discover strengths and achieve goals
Patterns	The learning environment makes sense

Source: [19]

The Gold Standard PBL (Figure 2) developed by [2] supports, besides of the above mentioned learning skills and improvement skills, also skills like research skills and inquiry skills, self-assessment and reflection skills, and critical thinking.

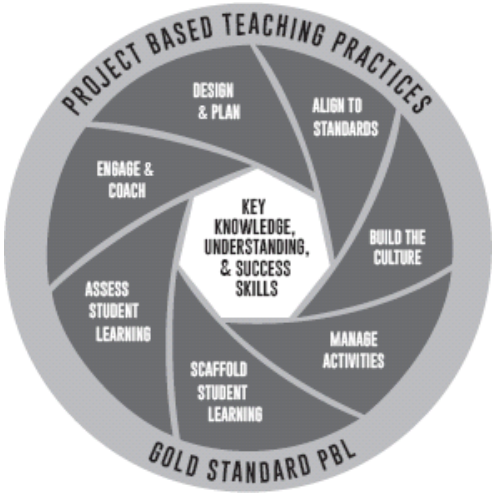

Figure 2. Gold Standard PBL elements; source: [2]

PBL offers to students the personalization of their learning [33]. It is active, student-directed learning. The basic principle of PBL requires students to work on a real-world and open-ended problem by solving projects over the specific period of time, while demonstrating their knowledge and skills. Finally, their solution/product/service is presented to a real audience. By using PBL, students can see on their own that obtained knowledge can be used in the practical reality [1].

By applying PBL, lecturer could create collaborative problem-solving groups, so students are more open to learning because of the same difficulties they must face. The learning may include aspects like the activation of the prior knowledge, recalling of the information and discussion increase in the group. These result in the students' interest in the educational process. [4], [17].

While planning the use of PBL method, it is important to take care of the following Essential Project Design Elements [2]:

- *Challenging Problem or Question*, because an engaging problem or question makes learning more meaningful for the student. At the same time, they have to apply their knowledge to find a solution to the problem.
- *Sustained Inquiry* – searching for appropriate information is more attractive and more interactive while using PBL, because students' results are constantly confronted by their colleagues or lecturers. They can mix traditional research methods with interviews with experts, service providers, future customers, etc. Students can fulfill the needs of potential product users.
- *Authenticity* – project can be authentic in term of solving the real-world problem by using real processes, tools and performance standards.
- *Student Voice and Choice* – student obtains only project definition. In order to complete the project, he/she can use methods by his/her choice. They can choose the resources and answers, tools and way of fulfilling the project objectives. It is up to them how they conduct and present their outcomes to public.
- *Reflection* helps students strengthen what they have learned and think about how it could be applied elsewhere, beyond the scope of the project.
- *Critique & Revision* teach students how to give and receive constructive feedback that could be supportive in further product improvement. It is important to involve classmates or people from practice, who have more experience and excitement.
- *Public Product* adds motivating power and encourages students to high-quality work. The motivation raises, if they have to present their results to an audience.

As a result, students develop deep context knowledge as well as critical thinking, creativity and communication skills in the context of doing an authentic, meaningful project. Project Based Learning unleashes a contagious, creative energy amongst the students and teachers. [27]

III. COURSE: MARKETING TOOLS FOR THE PRESENTATION AND EVALUATION OF BUSINESS IDEAS

According to Patel [31], 90% of startups fail. Giardino et al. [3] claims that acquisition of the first customer, delivery of customer value and targeting a niche market are amongst most frequent marketing issues of early-stage startups that cause them to fail. Da Silva et al. [15] add no market need (market validation), pricing/cost issues and ignoring customers to be another marketing issues of failing startups. Wang et al.'s [35] study proved, that customer acquisition, business model and product market fit are amongst most significant challenges of starting companies. These are all issues mainly connected to marketing. The purpose of the educational institutions should be providing a knowledge to their students so they can overcome these issues.

There have been several studies discussing the innovative ways of teaching marketing skills. Das [23] provided a methodology called Participatory Photo Novels. By creating a photo novel by students, teachers were able to generate a discussion in the marketing classroom and deliver new learnings to all participants of the class. Bove and Davies [26] assigned students to client-sponsored projects, and by conducting the analysis, they were supposed to deepen their knowledge in the field of marketing research. Overview conducted by Granitz and Pitt [30] was focused on teaching marketing using innovative technology. This overview contains several technology tools to teach marketing, however, instead of teaching students to learn modern marketing technology, they are taught traditional knowledge by using unusual tech tools. McCorkle et al. [6] claims that marketing students need more room for creativity. However, by taking a traditional way during the education, there are boundaries that limit the creativity, which is among the most required skills marketers possess.

Based on the introductory discourse and provided research in the field of marketing education, we decided to create a new concept of the university course that allows students to learn current marketing knowledge, combine it with the usage of the modern marketing and technology tools, and acquire practical skills by using the knowledge and tools in the real-life environment.

During the development of the innovative subject content, we took the net-generation requirements on the educational process into account, e.g. to allow students to be in control, to make their own choices, to interact in the groups and to take the risk and implement the PBL. PBL method, according to the above mentioned, allows to increase motivation, interest and involvement of students to the process of their education and at the same time enhance their practical skills implementation in the real-life problem solutions. We already have experience with using PBL method in the subjects carried out at our faculty, for example Informatics II [25], Electronic Finance Services [28], Economic Information Systems [29], etc.

The main objective of the course "Marketing tools for the presentation and evaluation of business ideas" is to provide basic knowledge in the field of information technologies, especially its utilization on marketing issues. During the course, students are confronted by practical problem of the product development, market fit, promotion and analytics, so it allows them to try what it means to start a company from scratch.

They are asked to come up with the product business idea and afterwards, check its viability and the response of the market directly. For that purpose, they obtain theoretical knowledge in the business models, objectives and KPIs, modern website design, data analysis and online marketing. Solving the practical problem, they are introduced to and gather practical skills by working with the applications such as WordPress, Google Analytics, Google Tag Manager, Google Trends, Google Market Finder, Google Ads, social networks, etc.

The course itself was divided into two parts – face to face (F2F) learning and self-studying and self-practicing. The F2F part is filled with lectures in business and marketing, and afterwards the appropriate tools are demonstrated. The achieved knowledge and skills are later applied by the students in their projects.

The content of the course covers following topics:

- Business Models and Key Performance Indicators,
- Content Management Systems and modern website design; basic graphical and content aspects of the product/service website,
- Marketing Research – validation of market potential, buyer persona research,
- Data Analysis – data collection, sources of marketing data, methods and tools of data analysis,
- Social Networks – how to set up product campaign based on the product/service,
- Content marketing – strategy and development,
- E-mail Marketing,
- Basics of the traditional and agile Project Management basics.

During the course, students worked in small teams (2-5 people). The team roles were set directly by students based on their skills and interests in particular activities. The course was evaluated in context of students' skills achievement proof – students presented their product, its market fit, business model and marketing strategy. Project was evaluated by lecturers and colleagues, while focusing on the following aspects: business model definition and its measurable objectives, website of the product/service, real-world use of online marketing tools, design and execution of the content marketing initiatives, identification of the relevant data and its analysis, and evaluation of the viability of the product/service in the market.

While developing the course organization and content, we focused on the development of particular group of the skills referred in the previous chapter, as we considered them to be the most important for new entrepreneurs and start-uppers, especially those ones defined in EtreComp parts "Ideas & Opportunities" and "Into Action".

IV. Results and Discussion

The course "Marketing tools for the presentation and evaluation of business ideas" is optional, so the number of the students enrolled is much lower compared to the obligatory courses. During the academic year 2017/2018, only 15 students participated on the course. They created 4 teams. The LMS Moodle was used to publish and manage the course materials, schedule and activities. The results of their work (Figure 3, Figure 4) are available at http://marketing.ekf.tuke.sk, because of their public visibility outside the secured access to LMS Moodle course.



Figure 3. Final website of the innovative dating service; source: http://marketing.ekf.tuke.sk/wifitouch

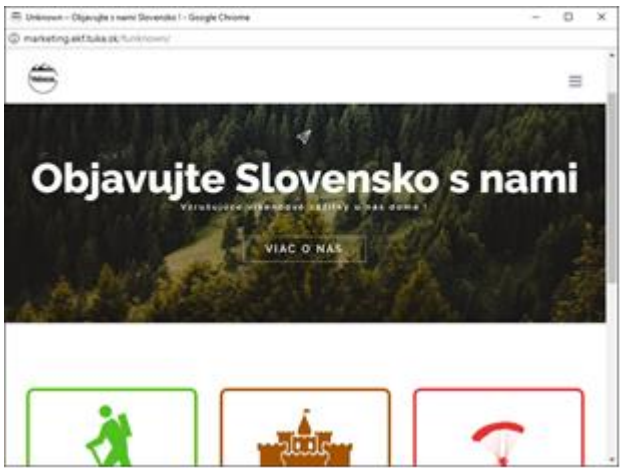

Figure 4. Final website of the travelling service; source: http://marketing.ekf.tuke.sk/funknown/

At the end of the course, the students' projects were evaluated from different points of view. Every team could reach the 100% rate in the total. The evaluation was concerned on:

- Formulation of the objectives and their achievement by the team,
- Website content, design and its functionality,
- The use of the web analytics tools to analyze data collected from website of the product/service,
- The use of the content marketing in order to develop new prospects and provide support in the decision-making of the customers,
- Viability conclusion, decision whether the product or service will be able to survive in the competitive marketplace.
- Presentation of the project and the results achieved by the whole team.

Only one of teams reached the results of 100%. However, results of the other teams were positive. The other teams reached the following results (Table 2):

TABLE II. AVERAGE VALUES REACHED BY WORKGROUPS FOR SPECIFIC PARTS OF THEIR PROJECT

Evaluated part of the project	Maximum value	Mean value reached by students
Formulation of objectives	10%	8.5%
Website design and functionality	15%	13.5%
Web analytics	15%	14%
Content marketing	15%	11.5%
Data Analysis	10%	9.75%
Viability conclusion	10%	10%
Presentation of the project	25%	25%

Source: own contribution

The most common problems were unclearly defined business goals, the level of the content marketing and set up Google Analytics that did not covered the company needs. That resulted in misinterpretation or lack of data collected from online channels.

In addition to the project development, all teams were challenged by necessity of achieving official Google certifications - Google Tag Manager Fundamentals and Google Analytics Fundamentals, by at least one member of the working team. More than half of students participating on the course obtained above-mentioned certificates. We consider it to be a success of the course.

As the course was in a pilot stage, we were focused on the evaluation of the content of the course, the difficulty level, communication, the project difficulty and approach used during the course. All students that attended the course filled the questionnaire at the end of the course. The results of the questionnaire could be summarized as follows:

- The content of the course met the students'expectations (47% of them agreed and 53% strongly agreed). They were informed about the content in advance via specialized document – course syllabus.
- 54% of respondents declared that the most interesting part of the course was website design and development. 13% of them chose the marketing and 33% had no favorite part of the course.
- 87% of students were satisfied by the course execution. They appreciated that there was no clear boundary between practical exercises and lecture. We run the course as the consultation meeting combined with lectures by the experts. The main emphasis was taken on the students' activity and their need to self-search and self-study. The remaining students missed the tutorials and cannot apply their own creativity, imagination and curiosity. In spite of this, students evaluated this course as very interesting and motivating towards studying.
- For 87% of the students considered the course moderately difficult, for the remaining 13%, the course was very difficult.
- One of the objectives of the subject was to showcase the practical information and examples as much as is possible. All students agreed with the statement that the obtained knowledge and skills are applicable in the real life. At the same time, they appreciated the outcome of the course and process of generation of the outcome because of the need to employ creativity and teamwork.

If we try to summarize the experience with the course execution and define the skills and the competencies achieved by the students, we are able to classify them as part of Ideas & Opportunities (especially creativity, vision, evaluation of ideas and sustainable thinking), Into Action (particularly learning through experience, working with others, planning and management) within the EtreComp Framework. From that point of view, the feedback results could be summarized as follows:

- 87% of the students confirmed the improvement of their managerial skills,
- 100% of the respondents agreed that participation in the course improved their understanding of the processes in the start-up company,
- 93% of all participants are able to assess the importance of their business idea. In [8], having a business idea and access to finance alongside having an appropriate business partner and the role model are amongst the most important factors when deciding to start a new business. In that context, students' practical experience with the projects should be considered as one of the most important outcomes of the course.

In general, we can conclude, that course invoked the high activity and the interest of students. Moreover, they also regularly discussed the various topics and issues on F2F lessons to find the solution or recommendation about their problems with project. What really interest us is the fact that despite of short time (three months interval), students managed to develop the product/service, to build up the website, to organize and to execute marketing campaign and to analyze achieved results and collected data.

V. CONCLUSION

The contemporary business sector is constantly changing, and becoming more complex and challenging. At the same time, business competition is inevitable and tough, with entrepreneurs being urged to adapt and react quickly to changes and constant developments.

From [11] follows, that 34% of self-employed people had followed an entrepreneurship course, because they feel lack of skills and experience needed for guarantee the sustainability of business in the labor market. However, less than half of EU citizens feel that their school education helped them understand the role of entrepreneurs in society (47%) or gave them the skills and the know-how to enable them to run a business (41%).

For that purpose, we decided to implement these missing skills into our education. By participating in our course, students could improve some of their competencies, such as "taking the initiative, planning and management, coping with uncertainty, ambiguity and risk; working with others; learning through experience", etc. listed in main EC document – EntreComp. At the same time, they

need to proof their ability to develop ideas and be creative and innovative, define the problems and find the solution. As was stated above, these seem to be crucial skills to be successful on the labor market if somebody decide to start-up own business.

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Modernizing Laboratories for New Courses in Automotive Software Engineering

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***Abstract* - Rapid expansion of information-communication technology (ICT) sector, although promising, does not have a satisfactory support in education which can adapt fast to trends and demands of the automotive industry. In addition, one of the leading European employers – the automotive industry, has included in its focus the software and embedded systems. With growing need for engineers with adequate skills, university roles are shifted to take active part in creating healthy business environment, but the needed skills are not sufficiently acquired at universities in the region. The Faculty of Technical Sciences in Novi Sad and Faculty of Electrical Engineering, Computer Science and Information Technology in Osijek have started the common project DRIVE as part of the IPA Cross-Border Programme, with the goal of equipping the laboratories and developing the course materials in the field of automotive software engineering. Four laboratories have been set up to support the project goals and accompanied materials, such as books and tutorials, will be created. The materials will be used in new and updated courses at the upper years of undergraduate studies and graduate studies. This paper gives an overview of the procured equipment and plans for establishment of new courses in automotive software engineering.**

Keywords - automotive, automotive software, cross-border cooperation, laboratories

I. INTRODUCTION

Rapid expansion of information and communication technology (ICT) sector, although promising, does not have a satisfactory business environment support that can adapt fast to trends and demands, for sustainable economic growth. In addition, one of the leading European employers, the automotive industry, has included in its focus the software and embedded systems. As a result, there is a growing need for engineers with adequate skills and ICT companies that can respond to the demand [1]-[2]. Simultaneously, the University roles are shifted to take active part in creating healthy business environment via technology transfer-oriented research, provision of services that utilize infrastructure, courses oriented to better employability of prospective students and trainings that support lifelong learning. Common problems in the targeted regions, such as workforce attrition caused by challenged economy, or low employability and income, can be solved faster and with higher efficiency if opportunities, such as for example the changes mentioned above, are timely recognized and seized.

In order to respond to the fast-growing needs of automotive industry and enhance the competitiveness of the region in education of future engineers specialized for automotive software and hardware, the new project idea was proposed. University of Novi Sad, Faculty of Technical Sciences (FTN), Serbia and Faculty of Electrical Engineering, Computer Science and Information Technology (FERIT) in Osijek, Croatia have joined in a cross-border cooperation project "Modernizing Laboratories for Innovative Technologies" (DRIVE) as part of the European Union's INTERREG IPA program. The aim of this project is to equip the two partner institutions with latest laboratory equipment for development of automotive software and develop the curriculum with study materials for graduate-level education of computer engineers to specialize them for engineering in automotive industry. The project has started on 15 July 2017 and it will last for 29 months, until 14 December 2019.

The project DRIVE will allow faster integration and economic development of the region and make the region more competitive and closer in development to the developed European regions. This will in turn decrease the difference between European regions. Engineering of embedded computer systems applied to automotive systems is a new field within the automotive industry and the engineers working in this field have less than 20 years of experience. Nevertheless, it is one of the fastest-growing fields with a high impact on economy in terms of the Gross Domestic Product (GDP) [3]. The industry faces challenges like updating the infrastructure for product development and hard-to-find people with desired information technology (IT) skills. The development suffers if the infrastructure does not keep pace with the market demands. Still, the infrastructure cannot be developed without skilled people. Skills are best acquired through formal studies, which stresses the importance of quality education programs.

The research leading to these results has received funding from the European Union's Interreg IPA CBC Croatia-Serbia Programme (2014-2020) under subsidy contract no. 2017HR-RS60.

In addition to increasing the competitiveness of the region, the project DRIVE aims to allow younger generations to study on state-of-the-art technologies and gain practical skills on modern laboratory equipment which will make them ready for work in the automotive industry. [4]-[5] One of the project outputs will be course materials, as well as a proposal for a complete curriculum suggested for education of the automotive software engineer profile. Published materials, such as books and laboratory manuals will be available to teachers, students and engineers. The project will organize workshops which will be attended by engineers who seek increase in knowledge and skills in automotive-related computer and software engineering topics.

The rest of the paper is organized as follows: section II gives an overview of the procured equipment and established laboratories; section III describes the curriculum for automotive software engineering and the courses being developed in the project and section IV provides the timeline of the project activities for the remainder of the project length, as well as conclusions.

II. PROCURED EQUIPMENT FOR LABORATORIES

One of the main goals of DRIVE project is to equip four laboratories on two locations, two in Novi Sad and two in Osijek, which will serve as laboratories for teaching laboratory activities in the courses within the automotive software engineering field. Laboratories will also serve to host workshops for engineers which the faculties FTN and FERIT will offer to institutions in the region.

At FTN the following two laboratories have been established:

- Laboratory for functionally safe automotive architecture and software design,
- Laboratory for hardware-in-the-loop testing, calibration and diagnostics.

At FERIT the following two laboratories have been established:

- Laboratory for design and testing of automotive-related software,
- Laboratory for image and video processing in automotive applications.

The laboratories are equipped with state-of-the-art equipment for development and verification of software for automotive systems, which consists of:

- equipment that supports automotive application development in Automotive Open System Architecture (AUTOSAR) for automotive electronic control units (ECU) and supporting software,
- advanced driver assistance system (ADAS) development boards and supporting software,
- equipment for automotive application testing based on hardware-in-the-loop (HiL) simulation.



Figure 1. Part of the equipment that supports the fundamental automotive application development based on AUTOSAR architecture

Equipment that supports the fundamental automotive application development (Fig. 1) is based on Automotive Open System Architecture (AUTOSAR). It consists of a hardware platform of the Electronic Control Unit (ECU) which allows development and verification of applications by completely simulating the ECU in the vehicle and the communication interfaces to the peripherals in the automotive computer system. The equipment is supported by a software whose academic licenses were purchased together with the equipment. The software contains tools for application development for AUTOSAR architecture, as well as tools for design, development, configuration and verification of automotive software applications.

Equipment that supports advanced automotive application development (Fig. 2) serves for design and verification of applications for Advanced Driver-Assistance Systems (ADAS). It consists of development boards with large number of camera interfaces as the main purpose of these applications is to analyze the data coming from several cameras placed on different parts of a vehicle. Development boards contain digital signal processors (DSP) which allow required image processing in real time. Another possible application of these development boards is in the development of algorithms based on artificial intelligence and deep learning which is heavily used nowadays to increase the level of autonomy of a vehicle.

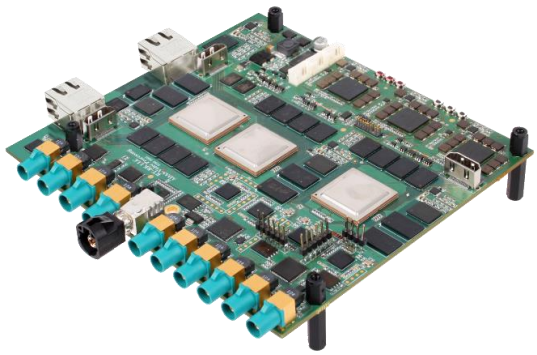

Figure 2. Development board for advanced driver-assistance system automotive application development

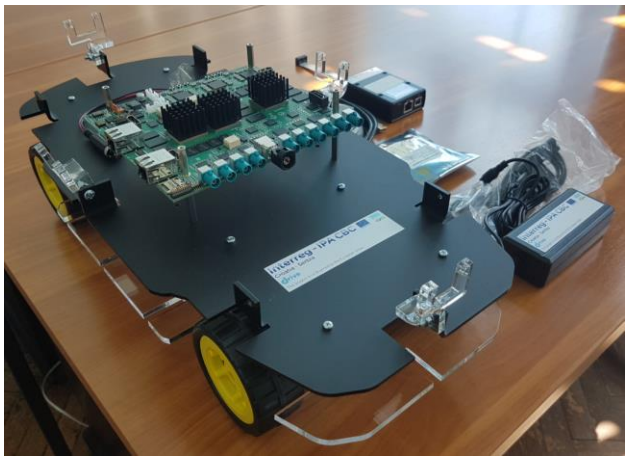

Figure 3. Development board with the automobile model ready for student use

The development boards were placed in an automobile model with placings for cameras, not only to protect the board and make it ready for student use in a laboratory, but also to allow application testing with the cameras and not only with the image files as inputs. Example of an automobile model equipped with the development board and camera placings is given in Fig. 3.

Previous equipment focuses on application design and development for various purposes in automotive systems. For the verification of applications, a separate set of equipment was procured, i.e. equipment for automotive application testing. This equipment is based on Hardware-in-the-Loop (HiL) testing and consists of a server system with: a computer for ECU testing, network modules, signal generator module, measurement module, power module, digital stimulus module, sensor module, input-output module and interface cards for network interfaces which are abundant in modern automotive systems: Controller Area Network (CAN), Local Interconnect Network (LIN) and FlexRay. Every workstation is equipped with the platform containing the ECU system and the computer with installed software for design, development, testing and analysis of networks and buses connected to an ECU in a vehicle, as well as the software for calibration, real-time measurement, bus analysis and analog signal measurement tool integration. Fig. 4 and fig. 5 show a server system and an example network interface module for FlexRay interface.

After procuring this equipment and establishing the four laboratories, FTN and FERIT have become, to the best of our knowledge, the most equipped higher education institutions in the region, considering the field of automotive software engineering and one of the most equipped higher-education institutions in Europe. These laboratories will allow education of students using the equipment which will make them job-ready as soon as they finish the studies.



Figure 4. Equipment for automotive application testing – server system



Figure 5. Equipment for automotive application testing – FlexRay interface network module

III. Curriculum for Automotive Software Engineering

After consulting the experts in automotive industry and researching the existing study programs in the information-communication technology (ICT) fields in automotive systems [6], the project partners have identified the study areas which are needed to educate an engineer specialized in software development for automotive systems.

Since the automobile is a complex system, traditional study programs in the domain of computer science and computer engineering do not give required level of specialized knowledge needed for software development in automotive industry as the processes in software development in this industry are very different from classical software development due to high level of reliability and safety which the software must satisfy.

To prepare the student for a career in automotive industry, the following is the list of topics identified as essential for study:

- software development processes for automotive industry;
- networking and protocols in automotive;
- engineering of safety-critical software systems;
- artificial intelligence and deep learning in automotive software systems;
- digital signal processing in automotive systems, with focus on image processing;
- multimedia systems in automotive systems, i.e. development of infotainment unit;
- methodologies for testing and verification of software systems in automotive industry;
- at least one course covering non-software fields important for understanding the automobile as the system: e.g. electronics, mechanical engineering, thermodynamics.

The suggested areas still require a lot of prerequisite knowledge which is obtained in classical courses in electrical and computer engineering, as well as computer science, which is why we propose this curriculum to be on the master level or in the last year of the bachelor studies.

Following is the list of courses in a suggested curriculum for automotive software engineering which is based on the identified topics:

- Introduction to the automotive engineering (bachelor level, year 4)
- Architectures and methods of the design of safety-critical software in automotive systems (bachelor level, year 4)
- Processes in the automotive software design (master level)
- Computer networks, buses and protocols in automotive systems (master level)
- Methods of testing the automotive control software (master level)
- Deep learning in the systems of autonomous and connected vehicles (master level)
- Multimedia systems in automotive (master level)
- Principles of digital image processing in automotive systems (master level).

Some of the courses are already ongoing at FTN, while the rest will be included in the new accreditation cycle. The previous list contains the suggested level and the year in which the course is planned in the new accreditation at FTN.

At FERIT, the new study program "Automotive computing and communications" has already been established and more information about it can be found on an institutional webpage [7].

IV. CONCLUSIONS

The DRIVE project, part of the Interreg IPA CBC Croatia-Serbia program, allowed equipping the four laboratories in two institutions which will lead to the increase of competitiveness of the region and increase of the quality of teaching in the field of automotive software development.

During the year 2019 the DRIVE project will enter its final phase. FTN and FERIT will organize the workshops which will be attended by 100 engineers invited from companies in the region. Course materials for all courses listed in section III will be finalized and their full application will begin in the academic year 2019/20. Courses and workshops will allow students, current and future engineers to be ready for high demands of automotive industry.

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Using Raspberry Pi Computers in Education

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Abstract - **This paper describes the ideas of using Raspberry Pi computers in high schools and higher education. Raspberry Pi is a powerful computer in a size of a credit card. It was created by the Raspberry Pi Foundation charity, whose primary goal was the re-introduction of computer skills learning among students. The Raspbian operating system is based on Linux and offers an excellent working environment for students, as it includes software solutions designed to expand students' knowledge of computer science in an interesting way. Besides computer science knowledge, it is also suitable for acquiring basic knowledge in electronics. It is also very important to have the possibility of interconnecting such acquired knowledge. Our students have adopted the knowledge how to install and use the Raspbian operating system, how to network and connect to the Internet, how to write programs using the Python programming language, and how to develop hardware-based projects. From our own experience in Raspberry Pi we can conclude that this is an ideal platform for students to acquire new knowledge and competences in the field of computer science and electronics.**

Keywords - Raspberry Pi; Education; Raspbian; Python

I. INTRODUCTION

The Raspberry Pi is a brand of tiny single-board computers developed by in the United Kingdom. It was originally designed as an educational tool for promoting teaching of basic computer science in schools. However, it quickly became very popular as a cheap general purpose computer without any peripherals. Nevertheless, there are various official and unofficial accessories available [1]. .

Raspberry Pi organisation is divided into Raspberry Pi Trading that develops the technology, and the Raspberry Pi Foundation - an educational charity that promotes computer science teaching and learning, especially in the developing countries.

Five million units of Raspberry Pi computers were sold by 2015, making it the best selling British computer. In March 2018 the cumulative sales of Raspberry Pi reached 19 million units and it became one of the best selling general purpose computers worldwide [1].

II. RASPBERRY PI HARDWARE IN TEACHING

Why do we choose Raspberry Pi and not the Arduino platform for out teaching puprposes? Raspberry Pi is a complete functional mini computer, while Ardiuno is basically a microcontroller. There are also several other reasons. Using RPI students can familiarize themselves with Linux OS, they have the ability to program in Python, and they still can control the world the same as with microcontrolller in Arduino platform.

For our teaching purposes we have chosen Raspberry Pi 3 B, as it is the latest iteration of the world`s most popular single board computer. The biggest change that has been enacted with the Raspberry Pi 3 B is an upgrade to a next generation main processor and improved connectivity with Bluetooth Low Energy (BLE) and Wi-Fi on board. Additionally, the Raspberry Pi 3 has improved power management, with an upgraded switched power source up to 2.5 A, to support more powerful external USB devices. Also, the performance of the Pi 3 is roughly 50-60% faster than the Pi 2 which means it is ten times faster than the original Pi [2].

Built specifically for the new Raspberry Pi 3 B, the Broadcom BCM2837 system-on-chip (SoC) includes four high-performance ARM Cortex-A53 processing cores running at 1.2GHz with 32kB Level 1 and 512kB Level 2 cache memory, a VideoCore IV graphics processor, and is linked to a 1GB LPDDR2 memory module on the rear of the board.

The Raspberry Pi 3's four built-in USB ports provide enough connectivity for a mouse, keyboard, or anything else we need for our teaching purposes, and if it is not enough we can still use a USB hub. Powering the Raspberry Pi 3 is easy, just plug any USB power supply into the micro-USB port [3].

The Raspberry Pi 3 B features the same 40-pin General-Purpose Input-Output (GPIO) as previous versions. It offers several standards of serial communication: UART (Universal Asynchronous Receiver / Transmitter), SPS (Serial Peripheral Interface) and I2C Interface (Integrated Circuit) and the ability to control each of the eight GPIO

pins that can be programmed as inputs or outputs (for sensors, relays and other non-standard peripherals), the feature is very important for our teaching purposes.

There's no need to connect an external antenna to the Raspberry Pi 3 B. It`s radios are connected to this chip antenna soldered directly to the board, in order to keep the size of the device to a minimum. Despite its diminutive stature, this antenna is more than capable of picking up wireless LAN and Bluetooth signals – even through walls, that was important issue for our school, which has wireless LAN installed on all floors.

III. RASPBERRY PI SOFTWARE IN TEACHING

It is recommended to install Raspbian operating system on Raspberry Pi. Raspbian is a free operating system based on Debian distribution of Linux and optimized for the Raspberry Pi hardware. An operating system is the set of basic programs and utilities that make Raspberry Pi run. However, Raspbian provides more than just an OS: it comes with over 35,000 packages, pre-compiled software bundled in a nice format for easy installation on Raspberry Pi [4].

The initial build of over 35,000 Raspbian packages, optimized for best performance on the Raspberry Pi, was completed in June of 2012. However, Raspbian is still under active development with an emphasis on improving the stability and performance of as many Debian packages as possible. Raspbian is not affiliated with the Raspberry Pi Foundation. Raspbian was created by a small, dedicated team of developers (mainly Mike Thompson and Peter Green) that are fans of the Raspberry Pi hardware, the educational goals of the Raspberry Pi Foundation and, of course, the Debian Project.

There are several versions of Raspbian including Raspbian Stretch and Raspbian Jessie. Since 2015 it has been officially provided by the Raspberry Pi Foundation as the primary operating system for the family of Raspberry Pi single-board computers. Raspbian OS is highly optimized for the Raspberry Pi ARM CPUs [5].

Raspbian Stretch uses PIXEL, Pi Improved X-Window Environment, Lightweight as it`s main desktop environment as of the latest update. It is composed of a modified LXDE desktop environment and the Openbox stacking window manager with a new theme and few other changes [6].

The distribution is shipped with a copy of computer algebra program Mathematica and as well as a lightweight version of Chromium as of the latest version.

Raspberry Pi 3 also supports many other operating systems such as Ubuntu Mate, Windows 10 IoT Core or Android Things. For our teaching purposes we have chosen Raspbian Stretch (Debian 9) version as it suits best to our teaching requirements. Debian 9 distribution is very simple, so it's an excellent choice for our teaching with Raspberry Pi.

IV. APPLICATION OF RASPBERRY PI IN THE FIRST TECHNICAL SCHOOL TESLA

Raspberry Pi 3 computers are used at laboratory exercise course at the First Technical School Tesla, Zagreb, Croatia, in the fourth grade in the electrical and computer technicians program. Laboratory exercises are organized in small groups of students (maximum 10 students) so that every week one part of the class comes to the Laboratory for 3 school hours. There are a total of 9 exercises devoted to the Raspberry Pi 3 B computer. They are divided into two main parts. The first part refers to getting started with Raspberry Pi 3 B computer and to become familiar with its design, its hardware components and also the Raspbian operating system. In the second part of this Laboratory exercises students do some practical electronic projects. They combine various electronic components and write code in the Python programming language to control them [7] [8] [9].

Here is a brief description of these Laboratory exercises:

A. Lab. 1: Introduction to Raspberry Pi 3 single board computer

B.

Students get acquainted with all of the Raspberry Pi 3 hardware components, especially details of the GPIO connector (functions and pinout).

C. Lab. 2: Install Raspbian Stretch OS

Students learn how to download the right version of Raspbian from Internet and install it on SD card. They learn and understand the characteristics of the Raspbian operating system and modify some settings. They master different Raspbian interfaces.



Figure 1. Instaling OS on Raspberry Pi

- From "www.raspberrypi.org/downloads/raspbian/" students download the Raspbian operating system and they install Raspbian on a microSD card that will be used by Raspberry Pi.
- After downloading the file containing Raspbian OS students have to unpack it, and then set the operating system to the memory card. First they format the card appropriately with the use of SD Formatter.
- After unpacking the Raspbian OS students get an .img file that contains the operating system. To install the operating system on the card students use Win32 Disk Imager.
- Now students are ready to run the Raspberry Pi device, insert a micro SD card into the card slot, the keyboard and mouse plug into the USB ports, and the monitor to the HDMI port.

D. Lab. 3: Working in Raspbian OS and the GNU nano

Students learn to apply basic Raspbian commands, adopt the function of GNU nano text editor and apply basic commands in the GNU nano text editor.

-Students learn how to get help with Linux Commands, how to work with directories and files and how to change the user rights.

E. Lab. 4: Connecting Raspberry Pi 3 and remote computer

Students are introduced to different protocols and connecting programs. Students master different protocols and programs for connecting and working on a remote computer.

- Students connect Raspberry Pi to the network and they dont know exactly which IP address the Raspberry Pi will get. Raspberry Pis network name is set to "raspberrypi" by default. So, after students connect Raspberry Pi to the network, they try to ping it over the network name with "*ping raspberrypi"* . In our laboratory students find out the IP address and it reads 192.168.178.26.
- After students have managed to find out the IP address they can start connecting to Raspberry Pi via SSH protocol. On our laboratory computer students use the Windows 10 operating system, and Windows systems do not have a built-in SSH client. That's why we use *Putty*, a free SSH client that students download from http://www.putty.org/.

F. Lab. 5: Controlling Light Emitting Diodes (LED) with Raspberry Pi 3

Students learn how to write the code in Python to control LEDs on output pins of the GPIO connector. They learn how to connect the electronic elements according to the given scheme.

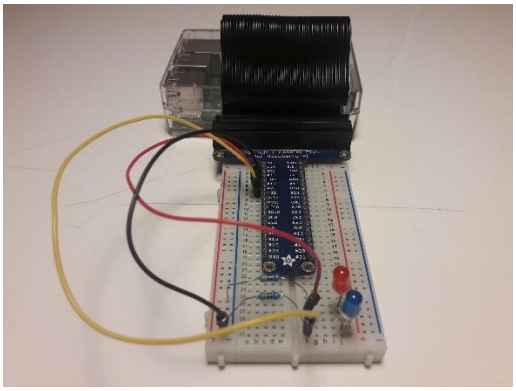

Figure 2. Controlling LEDs

Example of the code:

```
#!/usr/bin/python
from time import sleep # import the time
function from the sleep
# library
import RPi.GPIO as GPIO # import our GPIO
library
GPIO.setmode(GPIO.BCM) # set the board
numbering system to BCM
# setup our output pins
GPIO.setup(17,GPIO.OUT)
GPIO.setup(27,GPIO.OUT)
# Turn LEDs on
print "lights on"
GPIO.output(17,GPIO.HIGH)
GPIO.output(27,GPIO.HIGH)
sleep(1) # sleep for 1 second
# Turn LEDs off
print "lights off"
GPIO.output(17,GPIO.LOW)
GPIO.output(27,GPIO.LOW)
sleep(1)
# Turn LEDs on
print "lights on"
GPIO.output(17,GPIO.HIGH)
GPIO.output(27,GPIO.HIGH)
sleep(1)
# Turn LEDs off
print "lights off"

GPIO.output(17,GPIO.LOW)
GPIO.output(27,GPIO.LOW)
GPIO.cleanup()
```

G. Lab. 6: Controlling the servomotor with Raspberry Pi 3

Students learn how to write the code in Python to control the power-operated servomotor SG90 on output pins of the GPIO connector. They also learn how to connect the

power-operated servo motor SG90 according to the given scheme.

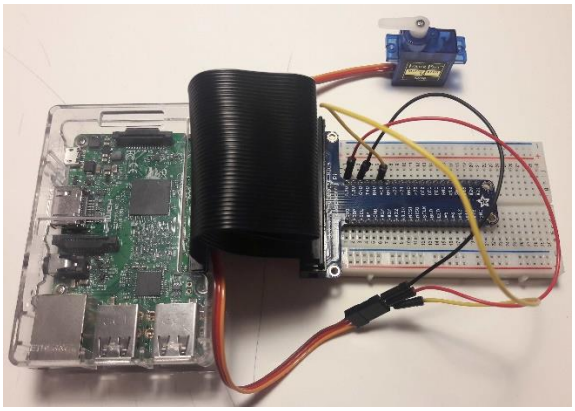

Figure 3. Controlling the servomotor SG90

Students control the servomotor by sending the PWM signal over the control wire. It is one of the PWM pins on Raspberry PI. Depending on the length of the impulse the rotor rotates to the desired position. SG90, as well as most servomotors, has a 90 degree rotation in both directions, total 180 degrees.

Example of the code:

```
import RPi.GPIO as GPIO
import time

GPIO.setmode(GPIO.BOARD)
GPIO.setup(12, GPIO.OUT)
p = GPIO.PWM(12, 50)
p.start(7.5)

try:
  while True:
     p.ChangeDutyCycle(7.5)#turn towards 90
                           degree
     time.sleep(1) # sleep 1 second
     p.ChangeDutyCycle(2.5)# turn towards 0
                           degree
     time.sleep(1) # sleep 1 second
     p.ChangeDutyCycle(12.5)# turn towards
                           180 degree
     time.sleep(1) # sleep 1 second

except KeyboardInterrupt:
        p.stop()
        GPIO.cleanup()
```

H. Lab. 7: Controlling temperature and humidity sensors with Raspberry Pi 3

Students learn how to write the code in Python to control temperature and humidity sensors DHT11 on input pins of the GPIO connector. They learn how to connect these electronic elements according to the given scheme.

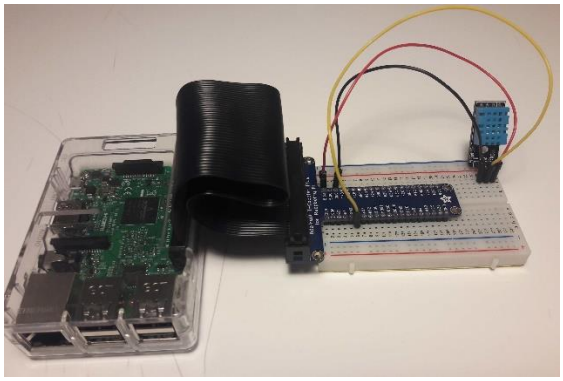

Figure 4. Controlling the sensors for temperature and humidity

DHT11 is the simplest temperature and humidity sensor on the market. It connects to Raspberry Pi with just one pin, and returns two variables - temperature and humidity. There is no need for calibration, students simply connect it and use.

Example of the code:

```
import RPi.GPIO as GPIO
import dht11
import time
import datetime

# initialize GPIO
GPIO.setwarnings(False)
GPIO.setmode(GPIO.BCM)
GPIO.cleanup()

# read data using pin 17
instance = dht11.DHT11(pin=17)

while True:
    result = instance.read()

if result.is_valid():
    print("Last valid input: " +
              str(datetime.datetime.now()))
    print("Temperature: %d C" %
                 result.temperature)
    print("Humidity: %d %%" %
                 result.humidity)

    time.sleep(1)
```

I. Lab. 8: Distance measurement sensor with Raspberry Pi 3

Students learn how to write the code in Python to control distance measurement sensor HC-SR04 on input pins of

the GPIO connector. They learn how to connect these electronic elements according to the given scheme.

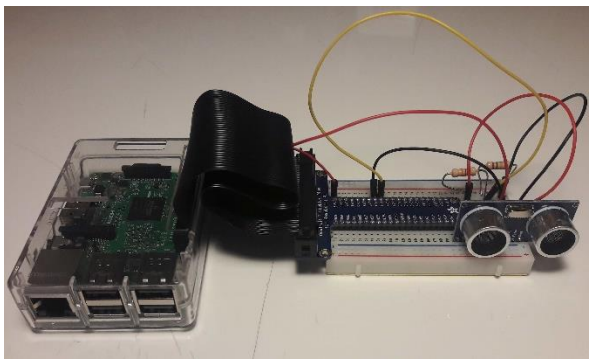

Figure 5. Controlling distance measurement sensor

HC-SR04 uses ultrasonic waves to determine the distance from the subject. The two basic modules on which the work principle is based are *trig* (switch) and *echo* (reflection). With Raspberry Pi, we send 5V to the trigger module lasting at least 10 microseconds. In this way, we activate an ultrasonic transducer that emits eight 40 kHz impulses and waits for their reflection. When the sensor registers the reflected pulse, it sends the data back to Raspberry Pi via the echo pin. These data are actually the duration of the reflected pulse, from 150 micro to 25 milliseconds. If "echo" lasts longer than 35 milliseconds, the sensor registers that the subject is out of reach.

Example of the code:

```
import RPi.GPIO as GPIO        #Import GPIO library
import time                    #Import time library
GPIO.setmode(GPIO.BCM)     #Set GPIO pin numbering
TRIG = 23                      #Associate pin 23 to TRIG
ECHO = 24                      #Associate pin 24 to ECHO
print "Distance measurement in progress"

GPIO.setup(TRIG,GPIO.OUT)    #Set pin as GPIO out
GPIO.setup(ECHO,GPIO.IN)       #Set pin as GPIO in

while True:
  GPIO.output(TRIG, False)     #Set TRIG as LOW
  print "Waitng For Sensor To Settle"
  time.sleep(2)                    #Delay of 2 seconds

  GPIO.output(TRIG, True)      #Set TRIG as HIGH
  time.sleep(0.00001)      #Delay of 0.00001 sec
  GPIO.output(TRIG, False)      #Set TRIG as LOW

  while GPIO.input(ECHO)==0: #Check if ECHO LOW
    pulse_start = time.time()    #Saves the last  LOW time

 while GPIO.input(ECHO)==1    #Check if ECHO HIGH
     pulse_end = time.time()     #Saves the last HIGH time
  pulse_duration = pulse_end - pulse_start
   #Get pulse duration to a variable
 distance = pulse_duration * 17150
          #Multiply pulse duration by 17150 to get distance
 distance = round(distance, 2)
                    #Round to two decimal points

  if distance > 2 and distance < 400:      #Check whether
                                  the distance is within range
   print "Distance:",distance - 0.5,"cm"
  else:
   print "Out Of Range"    #display out of range
```

J. Lab. 9: Connecting and programming LCD display

Students learn how to write the code in Python to control the mini LCD display RG1602A on output pins of the GPIO connector. They also learn how to connect the mini LCD display RG1602A according to the given scheme.

V. APPLICATION OF RASPBERRY PI IN VSITE - COLLEGE FOR INFORMATION TECHNOLOGIES

VSITE - College for Information Technologies regulary organizes one day workshops for technical schools and other secondary schools students. The topics are always cutting edge IT technologies. The last was held on April 19, 2018 and the topic was Raspberry Pi [10].

The main goal of this new workshop was to teach the students how to measure the physical quantities, like temperature and pressure, store them in the Raspberry Pi 3 B, allow any computer from outside to connect to the network and use the web browser to monitor the current status and history of the measurement results. It was also intended to demonstrate technology that can capture measured data on a remote network server and be able to simultaneously monitor the results of all measurements of all workshop participants.

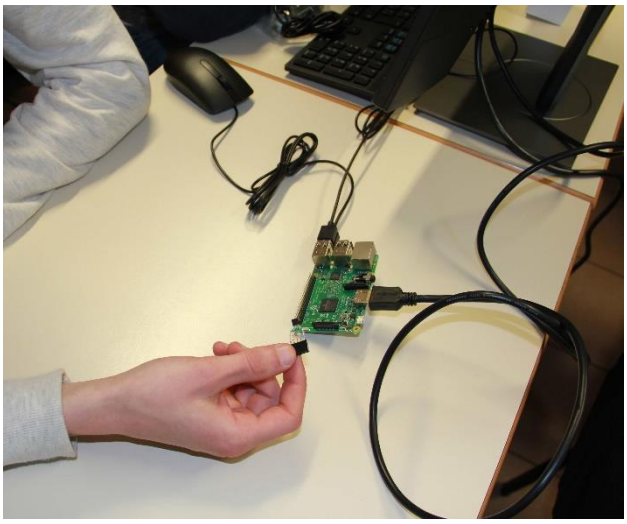

Figure 6. Conecting the sensors to Raspberry Pi 3 B

In the introductory part of the workshop participants were briefly introduced to Raspberry Pi 3 B, its hardware design and compare its capabilities with some of the most powerful computers at the time. Lecturers from College for Information Technologies introduced the participants with the most practical details and challenges of using Raspberry Pi 3 B single-board computer and showed examples of professional solutions from their own practices. There was also a team of experienced IT professionals (Linux experts, Web developers and hardware experts) that were at the service to assist the students and trainees throughout the workshop if something gets stuck.

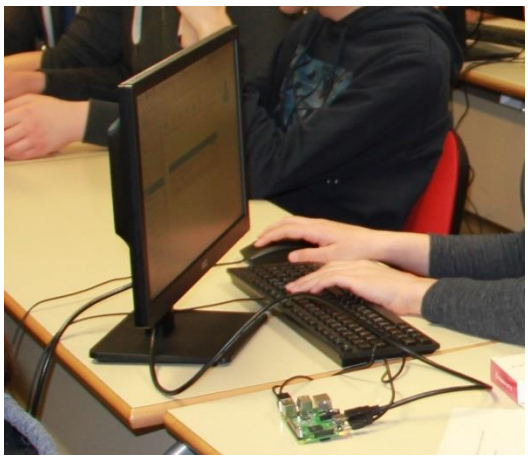

Figure 7. Data acquisition on Raspberry Pi 3 B

At the workshop there were involved altogether 72 students from 16 different schools and organized in 24 teams. In addition to high school students that were sitting in the benches of College for Information Technology, there was also a 9 year old elementary school pupil who participated in the workshop on a total equal footing. The workshop was successful and Raspberry Pi 3 B single-board computer was awarded for every participant so they could develop and improve the acquired knowledge in their schools.

VI. CONCLUSION

This paper presents how the idea of using Raspberry Pi computers in education was implemented in the First Technical School Tesla, and in VSITE - College for Information Technologies, both from Zagreb, Croatia. The students are taught through examples and are encouraged to combine different disciplines to successfully solve problems. Theory is complemented by demonstrations and, finally, by the practical work of students. We conclude that Raspberry Pi single-board computer is an ideal platform for students to acquire new knowledge and competences not only in the field of computer science but also electronics and many other related fields. As students were encouraged to use Raspberry Pi computers during their schooling and studies, many of them now want to do their finishing and graduating works in projects involving Raspberry Pi.

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A Model of an Online Evaluation System for STEM Education

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Abstract **- To achieve better learning results, students should be motivated for continuous learning. This is particularly important in areas such as STEM, where for the purpose of understanding the new content students have to master the topics that precede them. This paper describes a work in progress with the aim to develop an online evaluation system for STEM education based on the principles of Education Recommender Systems. The structure of the proposed system includes a domain model, student model, activity model, and a recommender. Domain model will represent concepts of subject matter. Student model will be built on data gathered during continuous evaluation together with students' learning styles and foreknowledge about digital tools. Activity model represents items that will be recommended: learning materials, tasks for learning using digital tools, and colleagues that can help in mastering particular subject content together with materials needed for knowledge assessment. The recommender will include original pedagogical rules for generating recommendations. The proposed model should encourage and motivate students for continuous learning and consequently lead to better learning results.**

Keywords – formative evaluation; evaluation system; knowledge assessment; STEM; Educational Recommender System

I. INTRODUCTION

In the last three decades much research has focused on exploring different motivational strategies for STEM (science, technology, engineering and mathematics) education [1, 2, 3, 4, 5, 6] but also on evaluation techniques and the way they could be implemented in teaching and learning processes [7, 8, 9, 10]. Evaluation approaches using online systems for their implementation have shown the possibility of using these systems as a motivational platform [4, 7]. Also, since assessment results and grades achieved by students through evaluation processes have a great impact on different aspects of student life (such as career and academic opportunities of a student [8]), evaluation approaches must be carefully planned and implemented [10].

Evaluation approaches can generally be divided into two types: formative and summative. In formative assessment, student work is measured during the semester and its main purpose is to provide feedback to both the students and the teachers regarding the results of the teaching and learning process. On the other hand, summative assessment is conducted at the end of the instructional periods (such as midterm and final exams) with the main purpose of grading and verifying the effectiveness of learning and teaching during the semester [7, 11].

While exploring possibilities for introducing adequate educational motivation strategies for STEM students at the University of Rijeka, it was observed that majority of students that participated in conducted research approach their study in a non-continuous way [12, 13]. Usually, students concentrate their learning efforts in a short period of time before a midterm or final exams. The observed problem was researched in detail through the use of paper-based questionnaire surveys. Obtained results showed that students lack the necessary motivation and that they expect to be additionally motivated for learning by their teachers.

In aforementioned research, Educational Recommender System ELARS was used in order to promote the use of digital tools for collaborative learning. ELARS was designed, built and tested in real educational environments [12, 14, 15]. Introduced digital tools and their use for learning was positively accepted by students and influenced their motivation for subject content. Unfortunately, this motivation strategy did not succeed in motivating students to start to learn continuously.

This paper proposes a model of an evaluation system for STEM education that addresses the observed problem. The system will combine methods and techniques of recommender systems [16] with continuous formative and summative assessment adequate for STEM education purposes in order to motivate STEM students to work continuously. The structure of the model will include a domain model, student model, activity model, and a recommender. Such a structure will enable the generation of timely appropriate feedback information about students' progress together with recommendations that will be based on achieved assessment results and other students' characteristics.

II. KNOWLEDGE ASSESSMENT IN STEM

In STEM, many topics require proficiency in mathematics in order for students to understand presented concepts [17]. Also, when theoretical knowledge is transformed into a practical implementation in STEM some form of mathematical procedures and computations are commonly used. Assessment of acquired knowledge (both formative and summative) includes solving math-based

tasks using predetermined steps in well-established math procedures with a certain number of intermediate solutions.

In university courses, summative assessment in STEM is commonly conducted through several midterm exams and/or projects with a final exam at the end of the semester. Due to various reasons, it was observed that a great number of students concentrate their learning efforts in short time periods just before the midterm exams or set deadlines [15, 18]. By approaching their learning in this non-continuous way, students miss out the opportunity to acquire a deeper understanding of the material that can be achieved over longer time periods. In this way, students approach their learning in so-called surface approach [19] where the main intention is to complete the task and memorize information without distinction between new concepts and already acquired knowledge. Because of that, when new material is presented for learning, students can find themselves in a situation where they do not possess an adequate understanding of the already completed materials needed to grasp and understand the new concepts. This lack of deeper understanding can affect their assessment results and their grades, thus influencing their future academic and career possibilities [8].

Formative assessment in STEM is used during the semester for providing students with quick feedback about their current level of knowledge. Because of the number of students, especially in basic courses of university study programmes, formative assessment can be overwhelming for the teachers if done in a traditional way (offline, in paper form). Also, in that case, students have to wait for feedback about their results, thus minimizing the positive aspects of this type of assessment method [8]. Research results indicate that students prefer online assessment possibilities versus traditional paper-based assessment approaches because online assessment addresses these issues and offer acceptable solutions expected by students: possibility for conducting assessment in environment that resemble recreational activities, easiness of use with quick feedback but also flexibility regarding time management of their study obligations [20, 21].

Todays' evaluation systems regarding math-based tasks usually focus on the final solution of the set task (in the form of multiple choice questions or numerical question type [22]) thus neglecting intermediate results that lead toward it. As students progress through the content of a subject, they are faced with increasingly complex tasks that encompass elements from the related previous subject content. In order to successfully solve the set task students need to master that related subject content. By focusing on intermediate results that students provide during the evaluation process, it should be possible to determine which parts of the subject content student needs to study more thoroughly in order to master it on an expected level.

III. A Model of Proposed Online Evaluation System

The proposed model of an online evaluation system for STEM education is built around the idea that intermediate results in math-based tasks can provide additional information regarding students knowledge.

Using the system, teachers will have to define the order of the course activities that will also include online assessments with math-based tasks. These tasks may have several intermediate results and one final result. If student inputs the wrong answer as one of the intermediate results that information can be used in order to determine which part of the subject content should have been mastered by the student to correctly solve that part of the set task. Also, from the wrong answer can be concluded that student either lack expected foreknowledge about related previously learned the material or hasn't learned new material which is evaluated by the set task. By providing feedback about these two possible causes for the wrong answer given as an intermediate result, the proposed model can help students to focus their learning activities at the subject content that they must master (both from previously finished and recently taught learning materials).

To further enhance student experience while using the system, the model includes *recommender* in order to generate adequate recommendations. In this way, the proposed model will not only give simple feedback to the students regarding parts of the subject materials on which they have to focus their learning activities, but also provide

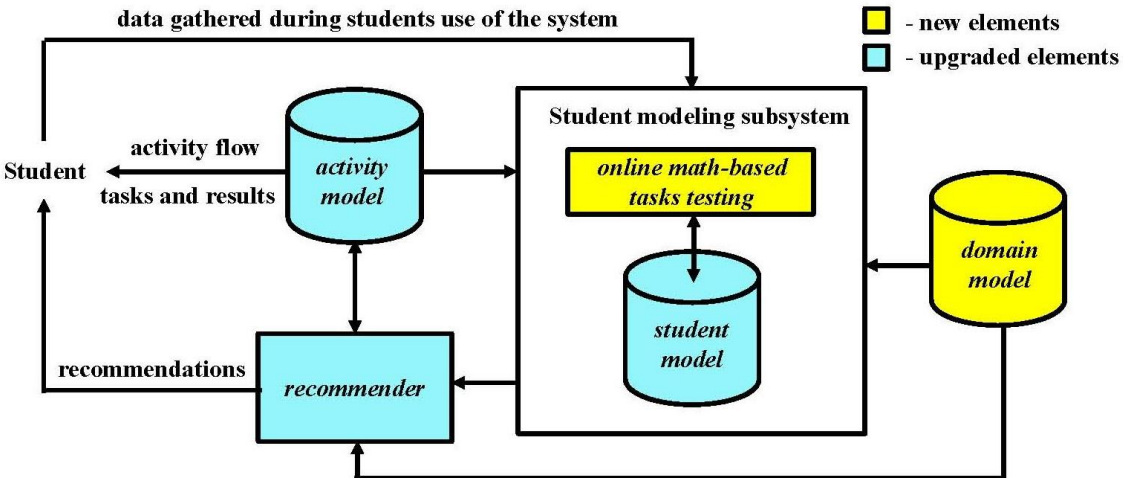

Figure 1. A model of an online evaluation system for STEM education

them with individual recommendations aimed to help them to learn these materials.

A proposed model of an evaluation online system for STEM evaluation is presented in Fig. 1. The model consists of a *domain model*, *student model*, *activity model*, and a *recommender*. In *domain model* concepts of subject matter are represented. *Student model* is built on data gathered during continuous evaluation together with students' foreknowledge about digital tools and their learning styles. *Activity model* represents items that will be recommended: learning materials, tasks for learning using digital tools, and colleagues whose knowledge is at the level that they can offer their help in mastering that content. Also, in the activity model order of the activities and materials needed for knowledge assessment is included. The *recommender* will include original pedagogical rules for generating recommendations.

By combining evaluation procedures with capabilities to generate individual recommendations, the proposed model should be able to influence students' approach to learning an motivate them to start working in a continuous way. Thus, the proposed model will be used as a tool for implementing a motivational strategy aimed at helping students to achieve a deeper understanding of the course material that can only be gained through continuous learning.

IV. IMPLEMENTATION

In order to implement the proposed model of the evaluation system, educational recommender system ELARS will be used as a base.

ELARS model consists of an activity model, student model and recommender [15]. Activity model represents learning design components (planned activities grouped in learning modules) and items that can be recommended to students (optional e-tivities, possible collaborators, tools, and pieces of advice for successful participation in e-tivities). Student model consists of four elements used for modeling students and groups of students (level of initial knowledge, preferences of digital tools, learning styles according to the VARK model, and level of activity during student use of the system). Recommender includes algorithms based on pedagogical rules for generating individual and group recommendations.

To implement the model presented in Fig. 1., some of the structural elements of the ELARS system will be upgraded. Also, since the proposed system will include an online evaluation of students' knowledge, adequate structure elements must be introduced to the system during its implementation.

As can be seen from the model structure shown in Fig. 1, one of the new elements is "*online math-based tasks testing*" for carrying out an online assessment of student knowledge. This part will include tasks with related intermediate and final solutions.

The other new element is the *domain model*. It will contain a representation of concepts of a subject matter and learning outcomes that will be used by Student modeling subsystem and *recommender*.

Activity model is part of the ELARS system that has to be upgraded with representations of new items that could be recommended. Those are learning materials, tasks to be solved using digital tools, and colleagues that have sufficient knowledge and can offer help in mastering particular subject content. In addition, a new type of activity "solving mathematical tasks" will be added to the activity model in order to allow the teacher to include online assessment in the course activity flow. *Activity model* will be connected with Student modeling subsystem and *recommender* in order to provide quick feedback about the accuracy of their intermediate and final assessment results and generate a recommendation.

Existing *student model* will be upgraded with new student's characteristics. Assessment results will be used to represent the student's knowledge of concepts from the *domain model*. In addition, student's foreknowledge about digital tools and data gathered during students use of the system (e.g. accepted recommendations, number and duration of system use, etc.) will be stored in the *student model*. Therefore, the subsystem for student modeling is connected with the *activity model* and the *domain model*.

The existing *recommender* will be upgraded with new algorithms and pedagogical rules for generating recommendations. Data gathered through students use of a system will be used in order to create an as accurate model of each student. Correct and incorrect results of an assessment sessions together with data regarding the duration of system use and type of recommendation that student chooses to use will be utilized for this purpose. This data will be combined with information stored in the *activity model* and the *domain model* in order to generate individual recommendations. Recommendations relating to learning materials and colleagues that can help in mastering particular subject content can help a student in carrying out a more traditional approach to learning. On the other hand, recommendations relating to the use of digital tools for solving appropriate tasks aim to promote the use of digital tools for learning.

V. CONCLUSION AND FUTURE RESEARCH

The model of an evaluation system for STEM education was designed to address the problem of non-continuous approach to learning that was observed during previous research. The system will be used for continuous formative and/or summative assessment and to promote the use of digital tools for learning. Used as a motivational tool, the system should be able to motivate students to work more continuously thus creating the precondition for students to achieve better learning results.

The proposed model is built around the structure of the educational recommender system ELARS. ELARS was used as a starting point and its structure was expanded with the domain model and the "online math-based tasks testing" for carrying out an online assessment of achieved learning outcomes. To generate appropriate individual recommendations, several components of the ELARS system needs to be upgraded. These are activity model, student model, and recommender. Data gathered from assessment sessions will be included in the student model and used to determine parts of the course material that is

not yet mastered by a student at the expected level. This information will be given as feedback to the student but also used to generate appropriate individual recommendations. Through three types of generated recommendations, the system will have the potential to help students to focus their learning efforts at the specific area that they need to master.

Further research steps will primarily focus on building a prototype of the system and testing it in a real educational environment within STEM education.

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Development of Human Capital via Modern Informatics Education

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***Abstract* - In the new digital world, information is available anywhere at any time, computer power is ubiquitous, communication of vast amounts of information is almost instantaneous, and storage capacities seem infinite. But these powerful possibilities are beneficial only for those who have learned to use them effectively. Educational system should be able to react appropriately to the development and trends. We educate our students for the future. They will face many changes in their future careers and lives. Their school knowledge and skills become obsolete within a short time. That is why they must be robust enough to meet the challenges of the rapidly changing world, and also enable the students to cope with the changes. It is important to consider that the knowledge and skills for today must be adaptable to serve future needs. The core of education must be independent of the changes in tools and technologies. Nowadays, not only classical literacy (reading, writing, counting) is needed, but also the high level of digital literacy, creative, logical and critical thinking, and last but not least, the potential for permanent development of human capital. The article summarizes the experience in teaching Informatics at the Faculty of Economics, Technical University, Košice.**

Keywords – informatics education, human capital

I. INTRODUCTION

Since we work at the Faculty of Economics, Technical University in Košice (TUKE), we try to look at the education in the field of Informatics from the perspectives of both economists and managers which, it is not only interesting but many times very useful as well.

The widening discrepancies between market value of companies and reported tangible book value is considered to be an indication of the significance of intangible resources in the modern knowledge economy, which forces managers to visualize the value of intellectual assets in their organization [9].

The greatest power of companies, firms, organizations, and institutions is nowadays recognized in its non-visible and intangible assets derived from knowledge creation, which involves knowledge sharing, knowledge distribution and social interaction within a company. At this point, there is a question of what is considered to be „intellectual capital“ within a company and how it contributes to the higher performance and better competitiveness arises [24].

Nowadays, employees are faced with the task to meet requirements of the company to do more brainwork and implement their personal knowledge into new applications and innovative products.

Knowledge and intellectual capital are now considered to be the main drivers in value creation, due to its unique capability to be utilized again and again without being consumed unlike tangible assets [4].

Understanding of intellectual capital concept enables us to understand how knowledge can be profitably transformed into the valuable activity outputs within enterprises. Intellectual capital has acquired an unprecedented role in contemporary society, since it has become an important factor for economic growth and business development. We can find a characteristic of intellectual capital as intellectual assets that can create value, drive the development of business and provide economic growth [13].

A simplified model of intellectual capital consists of two dominant components: human capital and intellectual assets. According to most of theoretical approaches, for example [11], [12], [25], the following main components of the intellectual capital can be commonly identified:

- human capital,
- structural or organizational capital,
- customer or relational capital [6].

As we can read in [21], intellectual capital consists of collective wisdom and energy, which is difficult to be measured and more difficult to be managed. Intellectual capital includes three crucial components: human capital (being the sum of existing status of learning, innovation and mentality, experiences embodied in employees); structural capital (being the sum of existing stock of knowledge effectively tested and organized within a company); and finally, customer capital (being the relationship with the company related persons and parties, which includes customer loyalty and satisfaction).

Due to the latest managers' practice, human capital is a very important source of value in every company because it is only through humans how the company can gain an ability to create and add value.

Human capital can be defined as:

- Capabilities of employees required to provide value to customers [19].
- A sum of a company´s individual employees, each of whom possesses unique physical and mental qualities, knowledge and skills, as well as capabilities of suppliers, contractors, and other organization related persons to create and deliver value to a customer [22].

The most important parts of the human capital are knowledge, experiences, skills, and know-how of all employees of the company/firm/organization.

II. HOW COULD WE DEVELOP STUDENTS´ HUMAN CAPITAL VIA INFORMATICS EDUCATION ?

The system of university education is one of the basic parts of education, culture, teaching, social welfare and economic development in every country. The institutions of university education are capable of training an educated, intelligent and knowledgeable society and raising national intellectual and creative potential. That is why it is necessary for higher education institutions, to search for the new possibilities of improving the potential of human capital development and skills of future specialists and professionals, developing individual abilities and acquiring high level professional competences [10].

Knowledge, experiences, skills, and know-how are the most important parts of our students´ human capital we are focusing on.

A. Knowledge

Business informatics, management of information systems and business process modelling have been chosen as the main topics of Informatics II, in accordance with practice demands. There are some reasons why we consider education in the mentioned fields important:

- The information aspects of the management at all levels have a very important function in increasing competitiveness and management quality of all economic systems.
- Nowadays managers in a higher position are expected to be information managers as well [7]. They have to be involved in analysis, modeling and building of the effective information systems (IS) of the companies and organizations.
- Current business entities are forced to improve their products and services consistently. They have to utilize their IS, ICT application/implementation and modern management methods, as well. This is the only way they can succeed in such competitive environments.
- Based on studies in more than 150 companies, more than a half of the projects of reengineering business processes either failed or was not able to reach even the minimum of the planned results. The typical obstructions and shortcomings are reluctance towards changes in organization, inertia of employees and management, incorrect choice and insufficient preparation of project team, lack of communication, lack of time for a precise planning, not detailed knowledge of essentials of particular problems, estimating of unclear aims, disability to estimate an extent of projects, incorrect choice and preparation of methodology [17].
- On the other hand, for critical factors of success we can consider direct connection of the management, active support of the leading management, support of employees, ensuring a high rate of connected people, match of improving projects with company's strategy, strict business case study, good methodology, clear understanding of strategic not only technical aspect of changes.

In determining both the content and the method of teaching, we consider an evaluation of the students' knowledge base in the field of Informatics as a very important step. At the beginning of study at the Faculty of Economics we use a questionnaire as a research tool, administrated on the first seminars of Informatics I Course. We search for both the extent and content of compulsory education in the field of informatics/computer science and ICT at secondary schools. We have created the questionnaire entries based on legislation, pedagogical documentation, and standards of Slovak educational system. Our questionnaire is divided into several parts. Within the first part of the questionnaire our students are asked the questions like: What type of secondary school did you attend? How many obligatory informatics lessons per week did you get over at secondary school in particular school years? In the second part of the questionnaire we focus on students´ knowledge in the field of basic terms of informatics, hardware architecture, operation systems, text editors etc. In the third part we want students to describe their experience in information systems. The questionnaire evaluation results were published in detail in [18].

The sample of our research consists of all secondary school graduates who entered their first year at Faculty of Economics TUKE. Numbers of respondents in the presented period, and type of graduates´ secondary schools are shown in Tab. 1 in detail. Letter "G" stands for Grammar School, "B" for Business School, and "O" for Other/Vocational School. Low number of these graduates in our sample is due to the practical focus of these schools, but as we can see in Tab. 1, it has recently increased.

Based on the questionnaire evaluation, we can say that the education of Informatics at secondary schools is in many cases surprisingly very poor. It is focused on handling with different packages of applications´ programs. There is a lack of understanding of basic terms, of data processing, of modeling (e.g. IS), regardless of the fact, that students work with modeling and different types of IS in some form "every day".

TABLE I. NUMBER OF RESPONDENTS FROM DIFFERENT TYPES OF SECONDARY SCHOOLS

Year	Total number	Type of school		
		G	B	O
2012	**144**	125	17	2
2013	**152**	129	22	1
2014	**166**	137	25	4
2015	**136**	118	18	0
2016	**200**	127	56	17
2017	**199**	111	72	16
2018	**204**	119	57	28
	1201 100 %	**866 72 %**	**267 22 %**	**68 6 %**

As we have been comparing the questionnaire evaluation for more than ten years, we have to conclude that the algorithmic approach, the using of knowledge for creating "something new", problem solving abilities, and interdisciplinary relations are often missing in the informatics education, and this situation is not improving.

We also compare evaluation of Informatics II (within the standard scale). As we can see in Fig. 1, the level of students' knowledge is decreasing, despite the fact that ICT and Informatics applications have penetrated into all areas of life.

Due to negative trends in the education system in Slovakia (decreasing level of knowledge [18]) as well as due to increasing differences in the sample of secondary school graduates entering our faculty, we have to work with a very diverse group of students. That is why at first, it is necessary to integrate level of students´ knowledge of the basics of computer science and using basic applications in the scope and content similar to ECDL standard within the first term - subject Informatics I. Students can learn how to work in text editor environment, spread sheets, presentation software, database systems, and various web-services, which we consider vital for further correct understanding business informatics – the main topic of subject Informatics II.

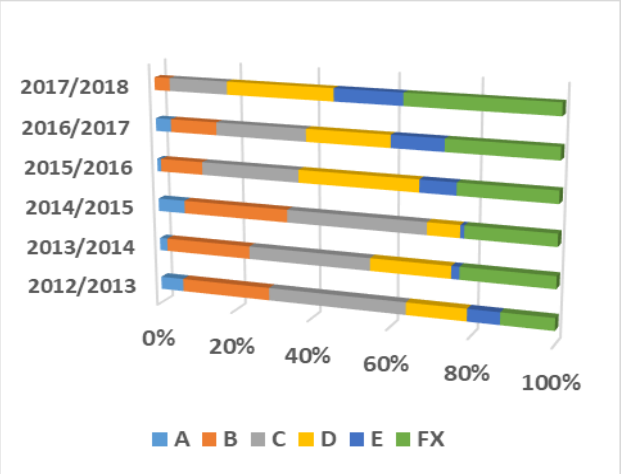

Figure 1. Evaluation of subject Informatics II in percentage

After that, our effort is focused on designing a modern education system within the Informatics II - knowledge base, skills and activities supporting development of human capital of future advanced users/managers at an area of "understanding and using business informatics and ICT".

The main question we are dealing with is: How to optimize and personalize education in the subject Informatics II according to individual needs and knowledge base levels of students to maximize development of their human capital?

We developed an innovative manner of teaching to support students' human capital development - their potential to learn, creativity, logical thinking and problem solving skills. Our education is based on modeling, simulation and on a well-known opinion that "no kind of teaching can replace the personal experience".

We created two basic studying materials that cover two particular areas:

1. Information systems for economists, divided to the following chapters: Development in the information area, Basics terms and their meaning, Information systems, Specification of user requirements, Modeling using the Unified Modeling Language (UML).

2. Basics of business process modeling with content: Information and knowledge society, Business processes, Business process modeling methodology, Business process modeling standards, Business process modeling tools.

In addition to the mentioned study materials, students can use recommended literature, e-resources and a set of solved examples – all accessible in LMS Moodle.

We have decided for a concept of education in two parallel planes as represented Tab. 2. The first plane is the standard way of teaching via lectures and seminars. The parallel plane, where the business informatics and management of IS are the key themes, seems to be in close relation to modeling of business processes.

The dominant method in this area is problem-oriented project teaching, while we are using the functionality of LMS Moodle environment. We are trying to develop education with a potential to support our students by personalizing learning process to meet the individual characteristics and needs. To achieve this, our system recommends learning materials, project template, learning paths, consultations, teachers´ feedback, activities and optional possibilities, etc. in a Moodle course. We found inspiration for personalization of education for example in sources [5], [8], and [14].

In this innovative way of teaching we are trying to transform the problem solving process into an active process of cognition.

TABLE II. THE STRUCTURE OF THE SUBJECT INFORMATICS II

The beginning	Second semester - subject Informatics II			The end
First plane – "classical" way of teaching/learning, face to face lectures and seminars				
MS Excel	MS Access		ARIS Expres	Test
Second (parallel) plane – "new" way of teaching/learning, personalised education, project oriented education				
The main aim is development of user requirenments project of information system				
Face to face teaching and consultation	Project proposals	Project first draft	e-learning, learning-by-doing using Moodle providing feedback	Project final version evaluation presentation

B. *Experience and skills*

As the most valuable skills we consider problem solving abilities. To gain experience our students are taking part in projects of building IS in one of many types of virtual firms, companies or institutions.

All our students find themselves at a position of a manager of a virtual company – in the role of IT executive such as Chief Information Officer (CIO) in ensuring continuous development and innovation of both IT applications and IT infrastructure. It offers us a possibility for gamification of education that can motivate students to learn new concepts via games.

In project of specifying users' requirements, they have to think about how to differ from the others, what kind of innovations they should bring into the model of the main process of a chosen company. They have to have by the method of learning-by-doing get knowledge of IS and its management.

Fig. 2 presents an example of the students´ projects. The recommended structure of the project consists of four parts. In part 1 there are questions and answers on theoretical background about modeling and using IS. In the second part, student describes a core business process in words and also by graphical model. On this basis they create requirements on the IS in the third part of the task. They describe the functionality on the project in the fourth part using UML - use case diagram and the basis for the data model is a proposal of classes and their attributes using UML class diagram. The last part which follows is a proposal of tables of relation database in MS Access environment in connection to first plane of teaching.

It is well known that students learn best when they have an opportunity to collaborate, discuss, use knowledge in practice, and interact in a natural and intuitive manner [1]. This has been already implemented in our education as supportive collaborative learning environment. Students can choose their own way and they can reach different level of knowledge.

Our goal is to train students in advanced topics without having them sacrifice quality of life. This can be achieved by improving efficiency of education through technology by maximizing learning at realistic time investments by teachers as well as students [1].

The major part of the mentioned critical factors of success or failure can be tried in practical creation of tasks of IS user requirements projects for supporting main process in the firm. We consider this fact to be the most significant benefit in performed change of the way of teaching.

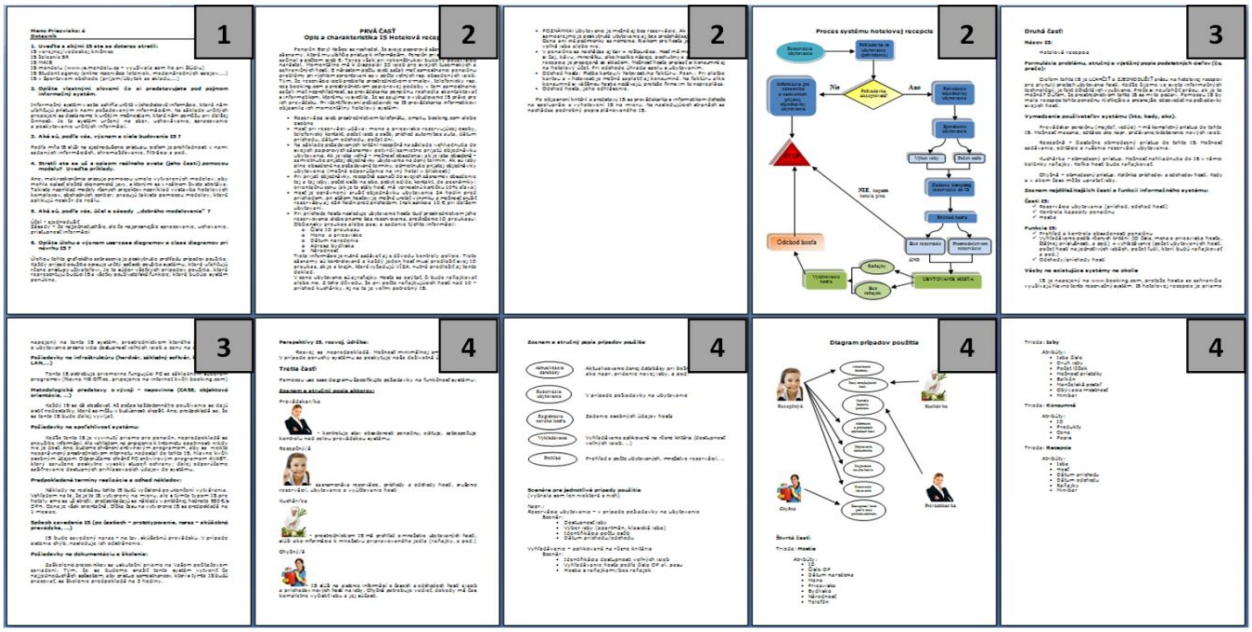

Figure 2. Example of students´project

C. Know-how

Recent advances in computer graphics and virtual reality technology, in modeling and visualization tools help people to overcome barriers in communication, understanding each other, learning, systems analysis, programming, process modeling, defining user requirements and so on.

We present to our students very useful environment ARIS Express, because as according to [3] it is:

- free of charge,
- perfect tool for occasional users and beginners in Business Process Management,
- intuitive user interface − modelers can work productively from the start,
- it contains models for organizational structures, processes, application systems, data, and more,
- free training material available in ARIS Community,
- all results can be re-used and enhanced in professional ARIS Platform products.

ARIS Cloud is a full-scale Business Process Analysis-as-a-Service product which is available completely free of charge for research and educational purposes. It powers collaborative process improvement projects around the globe. It allows to design, analyze, share and improve processes within minutes. ARIS Cloud is available in three editions: Basic, Advanced and Enterprise, each providing you with the right features for your current project needs [2]. The web page provides a feature "Universities" – an area for students and faculty members. It is integrated in the larger ARIS Community, but works independently.

Recent decades witnessed a significant increase in the share of jobs that require high levels of problem-solving skills. Our findings (published in [18]) as well as international researches show that the ability of students in problem solving area in ICT rich environment does not reach satisfactory level.

To improve this situation, we implement during the creation of students projects the system approach, as it is presented at Fig. 3. It is a way of identifying and viewing component parts and functions as integral elements of a whole system. We consider it as very important and valuable tool in all kind of problem solving procedure.

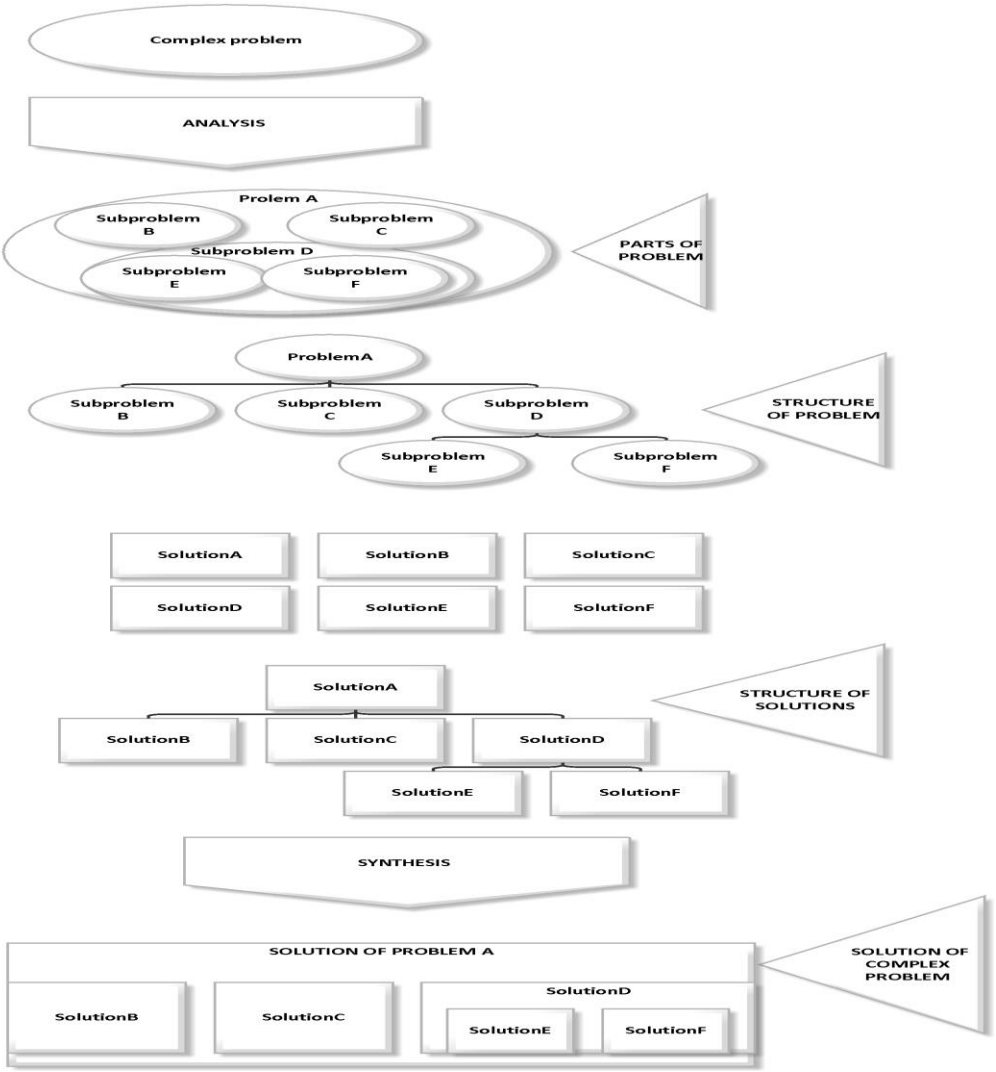

Figure 3. Application of analysis and synthesis in the solution of problems - the systems approach [16], p.21

III. CONCLUSION

The paper deals with experience in teaching and it also discusses the body of knowledge and methods which have been implemented into the subject Informatics II at the Faculty of Economics, Technical university of Košice.

The methodologist's cognitions achieved by experience in education resulted in the fact that the center of education must be transferred from a teacher to a student. The result of such an approach is the development of personal environment for learning [20]. We are trying to implement these modern trends into our education to support students' human capital development.

Human capital should be viewed as a very special source of wealth. The benefits of better ICT skilled users and employees for companies and organizations can be found (for example in [15], [23]) as higher productivity and performance of the company/organization, possibility of implementation new organizational forms (e.g. development of business nets, participation in supply chains), increased added value of the product or services, entry to new markets, utilization of new business channels, new products or services, changing business processes, responding to new business activities of competitors.

University education has been accepted as the foundation for public priority, economic prosperity and life quality [10]. By using our system, level of students' computer literacy, knowledge, skills, creativity and problem solving abilities can be increased.

"A success often comes to those, who are willing to manage their intellectual capital wisely" [21].

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The uniqueness of Computational thinking

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***Abstract* - The concept of computational thinking is timely. It is widely agreed that in order to benefit and thrive in a digital world, more than digital literacy is required. Computational thinking promises understanding of information technology and its utilization without necessarily knowing how to write code. According to many authors, skills in computational thinking include the ability to evaluate and design solutions to problems. However, the vision for computational thinking, laid out by a number of scholars, is even bigger than this. It proposes that thinking habits from computer science are beneficial for any kind of problem solving and that those thinking habits form a central part of modern sciences. It might be that components of computational thinking are indeed useful in problem solving and that they play an important part in other sciences. However, computer science combines three types of thinking traditions: theoretical (mathematical) tradition, engineering tradition and scientific tradition, and it is important to differentiate between what is an aspect in one or more of these traditions and what is unique for computer science. This clarification will support the application and teaching of computational thinking. This paper explores the uniqueness of computational thinking and its roots in theoretical, engineering and scientific traditions of computing.**

Keywords* - *Computational thinking; Computer science education; CSER; Computational ideas; History of computational thinking; Disciplinary ways of thinking and practicing

I. INTRODUCTION

The ongoing digitalization of most functions of society has followed the ubiquity of computing technology. Digitalization is not anymore about technology, but how we do things and what kind of form our organizations are taking. The change brings new opportunities and benefits, but also possible negative effects. It has been estimated that 47% of US jobs [1], and one third of Finnish jobs [2] are in risk of being automated in the next decade or two. Even though these estimations might be exaggerations, it is likely that automation will be a part of most of our occupations in the future [3]. Those who have the necessary skills will be able to benefit from this change [4]. In such digital world Computational thinking (CT) is a foundational competency for being an informed citizen [5].

The school should prepare pupils for the new digital world. Along with the digitalization of our society, also our schools are getting digitized. Especially in STEM subjects, CT skills are central [5]. This doesn't necessarily mean that CT always involves use of computers. CT is a way of thinking that has developed in Computer science (CS). Jeannette Wing [6] located CT in the intersection between mathematical thinking, engineering thinking, and scientific thinking. Engineering, mathematics and science also constitute the basic pillars of CS [7]. CT is a movement, which has only recently started to look for its identity. This means that there is no clear consensus as to what CT is, and no clear guidelines on how to teach CT for different learner groups. Denning [8] noted that teachers still ask, "What is computational thinking?" This paper's aim is to contribute to finding an answer to that question.

The article is structured as follows: in the following section, related research is presented. The third section discuss issues with the definition of CT and recognize that there is need to clarify how it is interpreted. The theoretical, engineering and scientific ways of thinking provide perspectives on CT, but there is also a need to identify what makes it unique. The fourth section provide a framework for describing the perspectives using seminal examples. In the fifth section the examples are analyzed for components of CT to illustrate the differences of the perspectives and find the uniqueness in CT. The final section present's the conclusion of the paper.

II. RELATED WORK

CS is multidisciplinary and continually evolving research field. Discoveries are transforming existing research and new subfields are born. The field of CS can now be classified into 18 knowledge areas. This complexity makes it difficult to agree on a definition of CS [9]. The history of the field let us examine its core traits at a time when the complexity was more manageable. This work relates to uses of the historical perspective to analyze CT for teaching or learning contexts. Matti Tedre and Nella Moisseinen [10] investigated the notion of CS as an empirical science by going through examples and opinions of experimental research from decades of the field's evolution. Since CS field is multidisciplinary, the terminology used can be conflicting. Their aim was to clarify the terminology and contribute to the disciplines self-understanding through the examples. Matti Tedre and Peter Denning [11] looked at how thinking and practicing in CS, CS education and its research, and computational science and society's digitalization has evolved. Their aim was to support the development of CT by warning of past mistakes and informing of great ideas. They also identified different threats to current CT initiatives. Benvenuti et al. [12] took an historical perspective when offering guidelines for the definition of the computing part of hybrid computing curriculum. They recommended following Tedre's and

Apiola's [7] observations that educators should understand the complex nature of computing by being familiar with how theoretical, engineering and scientific styles of computing culture manifests in the different topics. If some style is neglected, the student's lack of theoretical, technical or scientific understanding will put them at disadvantage compared to a more balanced teaching.

III. Issues in the definition of CT

CT promises abilities to solve problems, design systems and understanding human behavior using concepts fundamental to CS. Jeannette Wing made this idea popular in her article in the Communication of the ACM [13]. She claimed that everybody would benefit from learning the thinking habits of computer scientists. Wing showed examples of useful concepts from different parts of the CS field but didn't offer an explicit definition of CT. CS is very broad field [9] and this opens for variety of possible interpretations. Shute et al. [14] literature review shows a diversity of definitions, interventions, assessments and models of CT in education. There is a lack of generally agreed-upon definition of CT and its main components. This makes it difficult for teachers to incorporate CT in their teaching [14].

Seymour Papert [15] coined the term CT meaning a method where programming is used for learning mathematics. This was self-guided learning where domain specific functions and feedback from the computer gave support to the student. Later Jeanette Wing [13] re-introduced CT and defined it as thinking patterns used by computer scientists that entailed more than programming. In the context of the Scratch-programming environment, CT has been about computational concepts, practices and perspectives [16]. Children engage with programming concepts, form practices while using the concepts and through their engagement gain perspective of the world and themselves. Peter Denning [8] quoting Aho [17] defined CT to be about defining algorithms using a computational model. In a recent definition based on cognitive science computation is replaced with modelling and simulation [18].

There seems to be differences in interpretation of CT even within a small sample of definitions (above). Shute et al. [14] set out to demystify [19] CT by giving a definition and creating a model of the core components based on a literature review. They [14] defined CT as "the conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts ". The core components were defined as decomposition, abstraction, algorithm design, debugging, iteration and generalization.

We find the definition made by Shute et al. [14] of CT and its components well founded and welcome clarification. However, with the goal of making the definition general also the gist of CS seems to be lost (except the mention of computer). Since the intended audience (teachers) might be from outside of the field, they might lack the necessary intuition of what CS is. CS combines theoretical, engineering and scientific perspectives [7]. This can make it difficult to separate what might already be a part of a subject [20] and what CS can contribute. In this paper, the aim is to clarify how the perspectives differ and what is unique to computational thinking by using a framework of the three CS perspectives.

IV. A framework describing Computational thinking perspectives

Computational thinking consists of theoretical, engineering and scientific perspectives [6]. Teachers should explicitly consider what emphasis is placed on the different perspectives in teaching CS or utilizing computational thinking in other subjects [12]. If the teacher doesn't have a background in CS, it might be difficult to separate the different perspectives and it might also be difficult to spot what is uniquely Computational thinking. We share the historical approach of Benvenuti et al. [12] and use the task force on the core of CS report [21] as a framework to answer these questions. The report describes theoretical, engineering and scientific perspectives as distinct problem-solving processes consisting of four steps. Here we describe the steps of the processes and motivate the choice of a seminal examples for further illumination.

The theoretical perspective has its roots in mathematics where the central issue is theorem proving. First, the objects of study must be described using rules to define their properties and relationships (axioms). Then a possible new relationship between the objects can be suggested (theorem). The theorem is proved by deduction where axioms and other theorems are combined using the rules of logic. The result is interpreted to motivate why it is significant or useful. Of all the models of computation, the Turing machine [22] is regarded as the one representing a theory of CS. We use the original proof that the decision problem is unsolvable as an example of the theoretical perspective.

The engineering perspective of CS began with Electrical Engineering, which later developed into Computer Engineering when the basic logical computer components had been invented [23]. The aim of engineering is to solve a problem by constructing a system or device. First, the requirements related to the expected solution of the problem is identified. Requirements are turned into exact specification, which governs the development of the system. Following the specification, the system is designed and implemented. The system is tested for conformance to the specification. ENIAC – The Electronic Numerical Integrator and Computer [24] is generally held as the world's first computer. It is chosen as an example of the engineering perspective since it can be seen to exemplify pure engineering before the von Neumann architecture introduced mathematical logic to be a part of designing computers.

Of the three perspectives, the scientific, which refers to empirical inquiry, came last. Its aim is to explore some phenomena by devising experiments. First, a hypothesis is formed about some real-world phenomena. Then a model is constructed which allows to make predictions of its effects. To test the model an experiment is designed, and

data is collected from its execution. The results are analyzed and compared with the predictions. Allen Newell and Herbert Simon [25] stated The Physical Symbol System hypothesis in the context of artificial intelligence. The hypothesis is chosen as an example since it was presented in a Turing award lecture in 1975 where CS was interpreted as an empirical science. This was the last of the perspectives and adjoining examples, which are summarized in TABLE I.

TABLE I. COMPUTER SCIENCE PERSPECTIVES AND ILLUSTRATIVE EXAMPLES

Step	Perspective		
	Theoretical	***Engineering***	***Scientific***
1	Define objects of study	State requirements	Form a hypothesis
2	Hypothesize possible relations between objects	Define specification	Construct a model and make a prediction
3	Determine if the relationship is true	Design and implement the system	Design an experiment and collect data
4	Interpret the results	Test the system	Analyze results
e.g.	Turing machine	ENIAC – the worlds first computer	The Physical Symbol System hypothesis

The previous three examples will be used to describe the problem-solving processes of the theoretical, engineering and scientific perspectives of CS. We will later use the Shute et al. [14] components of Computational thinking to highlight the differences of the perspectives. At the same time, the examples are searched for a commonality that could said to be the gist of Computational thinking.

A. The Theoretical perspective – Case: Turing machine

Alan Turing [22] proved the Entscheidungsproblem unsolvable and was going to publish the result in an article 1936, but Alonzo Church [26] beat him to it by having published an equivalent result earlier. Both articles made an explicit definition of an algorithm and using that definition showed that an algorithm that could decide if a formula is provable is impossible. Even though the results and the method are similar, the definitions of an algorithm were different. Church created a mathematical formalism, lambda calculus, using the concept of a function. Turing mechanized the act of calculating until it could be described as a process performed by an imaginary machine, Turing machine, governed by rules. To calculate with Lambda calculus, you have to understand how to use the terms, but the Turing machine and the rules controlling it didn't require understanding anything more than was shown. As a definition of an algorithm, the Turing machine was deemed more explicit [27].

The creation of the Turing machine can be presented with the four steps of the theoretical perspective. Entscheidungsproblem or the decision problem was stated by David Hilbert as the question of the possibility of a procedure, in today's parlance algorithm, that would allow mechanically, without any thought (according to talk by Behman 1921 in [28]), to decide if a well-formed formula is provable. The objects of study are algorithms. Given a formula, the result of executing the algorithm is true if the formula is provable and false if not. Every step in the decision algorithm has to be explicit to qualify as a proof and therefore we need an exact way to define an algorithm.

Turing simplified human calculating on a paper to create an explicit definition of an algorithm. The paper can be replaced with an infinite tape divided into squares. Only one square is under work at any time and one symbol can be written per square. The symbol written (or erased) and the movement on the tape are governed by rules. To simulate the state of mind of the calculator every rule point to the next rule. There are different versions of rules depending on the symbol that is read from the active square. Turing's definition of an algorithm was an imaginary machine that a human could use to perform a computation mechanically following the rules without any understanding of what was calculated. The rules of one machine could perform a particular computation. To make the proof Turing needed machine that could perform the same calculations as another machine. He made a universal machine so that it could emulate another machine if its description was given on the tape.

Turing suspected that the decision algorithm was not possible. First, he showed that it is impossible to devise a machine that could in general, utilizing a finite process, calculate if another machine would print the digit zero. Then he restated the description of an example machine presented in the paper using the language of first-order logic. He made a proof-machine that took another machine's logical description as an input. The proof-machine executed a logical formula which stated that the machine given as input was only provable if the machine ever printed zero. Turing proved the formulas correctness and since he had earlier shown that, this kind of machine is impossible it showed that the decision problem is not solvable.

B. The Engineering perspective – Case: The ENIAC computer

ENIAC – The Electronic Numerical Integrator and Computer [24] often regarded as the world's first electronic computer was built originally to calculate ballistic trajectories for different kind of artillery during the World War II. In 1943 in preparation to join, the war in Europe USA accelerated the creation of new types of artillery and shells. Each combination needed firing tables to aid the use of the gun in field conditions were there were no time to perform complex calculations. The firing tables were calculated in the army's Ballistic Research Laboratory in Aberdeen Proving ground in Maryland using mechanical desktop calculators and a differential analyzer. Even with mechanical aids, the calculation of one firing table took three months [29]. The development of ENIAC was proposed as a solution in April 1943.

The creation of ENIAC can be described with the four steps of the Engineering perspective. Preparing firing-

tables was a time-consuming process [29]. For a human using a mechanical desktop calculator it required approximately twelve hours and with a mechanical differential analyzer it took ten or twenty minutes to compute a trajectory (the preparing time for the analyzer was considerably longer). A firing table was composed of two to four thousand trajectories. In 1943 there were only three differential analyzers in the USA of which army used the ones in Ballistic Research Laboratory and the nearby Pennsylvania University's Moore School of (Electrical) Engineering. The university provided also human calculators and two hundred women graduate students were calculating trajectories in two shifts. Still there were not enough capacity to match the need for new firing-tables. The need for additional computing capacity and the mathematics of the shell trajectories formed the requirements and specification of ENIAC.

In April 1943 John William Mauchly, J. Presper Eckert and John Brainerd submitted a proposal for the ENIAC to the army [30]. The ENIAC was presented as an all-electronic version of the mechanical differential analyzer, which would perform the same calculations with greater speed (100 to 1000 times faster) and accuracy (mechanical analyzer was not as accurate as a human computer). The machine structures were similar; the original differential analyzer had several integrators that did the calculations and connecting rods transferred the values where ENIAC had accumulators and connecting wires. However, the operation principle was different since in ENIAC the accumulators held the values and the wires represented functions. The control of the operation in ENIAC was modeled after how human computers arranged their calculations. The idea was new and its implementation an open question. The submitted design of ENIAC was a combination of the two models of computation [30].

The work on the ENIAC was an engineering project which aimed to realize the design presented in the proposal, not to pursue further innovations [30]. ENIAC consisted of nine different type of units which all had to be designed, tested and debugged [31]. Central to the ENIAC architecture where twenty accumulators and the master programmer [32]. When an accumulator receives a number, the number is added to its store. Each accumulator was locally programmable through switches to control how many times numbers were received and results transmitted. When an accumulator had finished operation, it transmitted a control signal to activate the next unit or units. How the control was transferred were done through wiring for instance to add a number one accumulator triggered another two to transmit and receive a number. The operations of the units were synchronized through signals from a cycling unit. The master programmer controlled the operation of other units allowing for repetition of a set of operational steps.

C. The Scientific perspective – Case: Physical Symbol System

Allen Newell and Herbert Simon held their ACM Turing Award lecture in 1975 entitled "Computer Science as Empirical Inquiry: Symbols and Search" [25]. They compared their topic with previous award lectures and noted that their presentation brought a new perspective on CS as an empirical inquiry. Experiments are central to CS, but they differ from how experiments are traditionally understood. In CS it is the execution of the created combination of hardware and software that makes the experiment. Even though the method is unique, the goal is the same than in other sciences to discover new phenomena and analyze ones already known. Newell and Simon used symbol systems and heuristic search from their research on artificial intelligence to exemplify empirical research. We will use the investigation of the Physical symbol system hypothesis to illustrate the process of the scientific perspective.

The Physical Symbol System Hypothesis states: "A physical symbol system has the necessary and sufficient means for general intelligent action." [25, page 116]. By being physical the system is tangible and obeys the laws of physics. According to Newell and Simon [25] such a system can also be engineered from a set of components. A symbol system consists of symbols that form expressions which are structures where symbols are related by some organizing principle. The system is not static, it contains processes that operate on expressions to produce new expressions. As such, it can be interpreted as a symbol-producing machine. The machine exists in a world of objects other than the symbols of the system. Designation and interpretation are central: the expressions designate objects, which means that the machine's behavior can influence or be influenced by objects; the machine interprets expressions if it can carry out the processes that the expressions designate. These features are required for acting intelligently in the world.

A general-purpose computer is a machine with capabilities that form a symbol system. The previous assertion can be argued for with the development of CS [25]. The development of mathematical logic made it possible to manipulate symbols formally. The Turing machine and other computational models defined what can be computed and what cannot. Since Turing machine is capable of performing computations based on a description, it satisfies half of the principle of interpretation in a symbol system. The stored program concept of the von Neumann architecture gives the other half, since the program is part of the systems data and not given from outside. The invention of list processing gave data structures, that contained symbols and whose structure could be dynamically altered. This was an implementation of designation in accordance to the Physical Symbol System. The conclusion was that the computer has all the required features for intelligent action.

The properties of general-purpose computer can be used both as an implementation and model of intelligence [25]. The hypothesis stated that a physical symbol system is necessary and sufficient for intelligent action. The statement cannot be theoretically proven, it needs to be confirmed by experimental evidence [25]. Sufficiency can be shown by implementing a computer system that act's intelligently. This is the research topic of Artificial intelligence that was first concerned with particular problems where solutions required intelligence. From that followed research that aimed to generalize the

mechanisms used in intelligent problem solving. Necessity can be shown by trying to explain intelligent action of which humans are the prime example. Research in Cognitive Psychology uses experiments and observations of behavior to understand intelligence. The computer is used as a model of the reason why certain situation or problem leads to a certain behavior. The benefit to traditional modelling is that these models can be executed, which allow for easier prediction of different kinds of scenarios.

V. WHAT IS UNIQUE IN COMPUTATIONAL THINKING

Computational thinking combines the theoretical, engineering and scientific perspectives. The perspectives look at the world differently: what problems can be solved, what tasks can be accomplished, or what features of the world can be understood computationally [33]. We have described above each perspective using seminal examples and the basic method of problem-solving belonging to the perspective. To reveal how they differ we look at each description using Shute et al. [14] components of Computational thinking: decomposition, abstraction, algorithm design, debugging, iteration and generalization. However, the goal of this paper is to find also, what is unique to Computational thinking, so we are looking at the same time for what is common to all the perspectives.

Alan Turing proved that the decision problem isn't solvable by mechanizing the execution of an algorithm. Use of the Turing machine as a device for proof contains the six components of Computational thinking. First, the process of a human calculating on a paper was *decomposed* to consequent parts. *Abstraction* was utilized when the paper was substituted with an infinite squared tape, calculation was simplified to manipulating one symbol at a time and human thinking was replaced with rules. *Algorithms* played central role both as a tool and as the target of investigation. Both the creation of the Turing machine and the preparation of the proof had many *iterations* were every step was important in the deductive chain. *Generalization* was utilized when Turing made a machine that could emulate any other Turing machine. *Debugging* can certainly be imagined in this kind of process and corrections to the original paper was published [34] later.

The ENIAC project took what was known of mechanical and human calculation and turned it into an electronic form [30]. The electronic form made it possible to automate (a more full-ended form of mechanization) the computing process. The six components of Computational thinking can also be found in the engineering of ENIAC. The calculation was *decomposed* to follow how a human arranges his computation. The computer was an *abstraction* combining mechanical and human method of computing. *Algorithms* were central since the computation had to be constructed from simple operations. The engineering process was *iterative* with design, testing and *debugging*. Even though ENIAC was made specifically for calculating trajectories its design was *general* enough that it could be used for other computations which was lucky since the need for trajectory tables was diminished because the World War II ended.

Newell's and Simon's [25] use of artificial intelligence and models of cognition to illustrate CS as an empirical science is particularly appropriate since the criteria of intelligence is given from the outside. For comparison, in Software Engineering the method and the object of the investigation is not that easily separated [10]. In the scientific perspective, the six components of Computational thinking can be found in the Physical Symbol System hypothesis example. *Decomposition* is natural for investigating symbol systems since they are composed of symbols, expressions and processes that operate on them. The use of a machine as a model for intelligence is a mechanical *abstraction* of something neurological [35]. The processes in symbol systems are *algorithmic* since they are computational. *Debugging* is a part of artificial intelligence because problems in the results can also be due to programming errors. *Iteration* is natural for the scientific process were progress is in relation to what has been done before. Artificial intelligence started with creating solutions to particular problems, which later became *generalized* as mechanisms for creating intelligence. The examples give three different instantiations of the six components of CT summarized in TABLE II.

TABLE II. MODEL OF CT COMPONENTS APPLIED TO EXAMPLES OF CS PERSPECTIVES

CT	***Turing machine (Theory)***	***ENIAC (Technical)***	***The physical symbol system (Science)***
Decomposition	computational steps	how human perform calculation	system (symbols, expressions, processes)
Abstraction	tape/paper, symbol/numbers, rules/thought	combining human and mechanical method	mechanical/ neurological
Algorithm design	tool, target	operations	computations in machine and mind
Iterations	proof process	desing, testing, debugging	scientific process
Debugging	correcting algorithmic errors	design errors	AI* and cognitive model operation errors
Generalization	universal machine	other uses than calulating trajectories	intelligence regardles of implementation

* Artificial intelligence

However, making computation mechanical seems to be a common to all the processes described. The goal of the six components of the model is to make the problem solving mechanical. The application of the model to theoretical, engineering and scientific examples in this paper highlight the nature of the different perspectives. We have defined what is unique to problem solving in CT and illustrated how the processes of the perspectives differ related to CT.

This supports the teachers in applying Shute et al. [14] definition and model when planning on how to incorporate CT in teaching different topics.

VI. CONCLUSION

High hopes are placed on learning Computational thinking. The claim is that the thinking habits from CS are beneficial for any kind of problem solving and that they form a central part of skills needed in modern sciences. However, there is a diversity of definitions, interventions, assessments and models of CT for education. There is also a lack of generally agreed-upon definition of CT and its main components. This makes it difficult for teachers to incorporate CT in their teaching. In this paper we augmented an existing definition and model of CT. Based on theoretical, engineering and scientific perspective on CS we defined CT to be about mechanization of computation. This gives the teacher a goal of using CT and a context for applying the model. We applied the model to examples of the different perspectives to highlight how their problem solving differ. The teacher can use this as a supporting framework when applying CT to new topic.

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Methods for Double-Blind Peer Review and Grade Prediction of Student Software Projects

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***Abstract* - In software engineering courses with many students, it is often impossible for a professor to give a detailed review of the software project for each student. One solution is to give students a task to make reviews for a few projects. One review consists of a comment on a project and a score. The score represents an ordinal number of the project when student sorts all projects in order by quality. The comment can be used as feedback to their colleagues and the score can be used in the final grade prediction. Double-blind peer review is used to prevent favoritism and unfairness. In the paper methods for random projects distribution, reviews gathering and analysis are presented. Methods have been used on over 100 projects and data gathered from them show moderate to high correlation with final grades. Project rank and project points have correlation factors from r=-0.6 to r=-0.66 and significance p<0.001. Projects have been independently graded with automatic tests.**

***Keywords* - peer review; software projects analysis; software in education**

I. INTRODUCTION

In the field of software engineering practice of code review is often used to improve code quality where other team members give feedback on the code to their colleagues. In the classroom environment often only a teacher is giving feedback to a project. When the number of students is too large that feedback is reduced to a few remarks. Importance of a code review is described in many papers [1], [2], [3] and [4].

A. Background

During one semester course on web technologies, students had one project divided into four iterations. Each iteration has multiple tasks. Iterations are two weeks long, and after an iteration students need to push their solution to a private repository. Private repositories are used so that students can not see each others solutions.

Each iteration is tested using an automatic test. Automatic tests are designed so that they detect most common errors but they often can not say why an error is present. In the paper [5] authors say that beginner students often find difficult to detect where in the code error appears when they get a failed test. They propose a solution which gives automatic feedback where is an error in the code and how to fix it, but it has limitations. The project description has to be very detailed and errors need to be predictable. We can not meet this requirement, because not all task can be given that way. Some of the tasks in the course have a higher degree of freedom of implementation. The course is a final year course and students need to demonstrate some independence in solving their tasks. If tasks are too strictly formulated then it is hard to write a task definition where a part of the solution or a method is not revealed.

There is also a problem with too strict automatic tests. If tests are too strict or coarse-grained then students who have a partially correct solution will get 0 points. Tests need to be fine-grained so that they can detect multiple errors that are present, otherwise if just one big error is reported students cannot learn very much from it.

Another solution to feedback is via peer evaluation. In this case, students who worked on tasks evaluate other solutions to the same tasks from their colleagues. In this case, the evaluation is more subjective than with automatic tests.

B. Literature overview

There are many papers who describe using automatic grading of programming assignments. In the paper [6] authors describe grading method where students write tests and code and grading system validates their testing performance. Testing performance is assessed in three ways: tests' validity, tests' completeness and code quality.

In the paper [7] authors propose a method where students review other students solutions by writing tests and running them. Reviewers get compiled programs not a code of the solution.

In the paper [8] authors give systematic literature review of assessment tools for programming assignments. They identify three types of approaches: instructor-centered, student-centered and hybrid approaches. In their research authors found that most of the tools support Java or C++ programming languages, they did not mention tools support for web-oriented languages (JavaScript, HTML and CSS).

There are also many papers who describe peer feedback and evaluation in teaching.

In the paper [9] authors propose a solution for peer feedback. This solution is used to rate discussion questions which assist students in their learning process.

In the paper [10] authors describe a few guidelines for the peer assessment task. Assessment groups should not be too large and assessors should not have many dimensions to assess.

Paper [11] concludes that peer evaluation should be used not only for students grading but also to improve the learning process and critical reflection.

By combining all the benefits of the code review, objective automatic tests, and peer feedback we tried to help students to recognize and correct their mistakes in code. For this purpose, we made one software solution and few methods which allow students to review each other work and rank their peers. This ranking showed moderate to high correlation with points gained by automatic tests.

In chapter II we described methods for a project assignment. In subchapter II.A structure of tasks is described. In subchapter II.B the software for the review process is presented. Analysis of the review results is also discussed. In the chapter III conclusion is given.

II. REVIEW METHODS AND SOFTWARE

A. Student's Tasks

During a course on web technologies, students (N ~ 130) had one project divided into four iterations. All students had same project to implement. One iteration represents portion of the project students need to implement and it has its deadline. After each deadline, all students got 5 projects to evaluate and rank. They evaluate only current iteration.

Rules for evaluation, listed by importance, are iteration completeness, number of bugs and code quality. For each project, a student writes comment and rank projects by quality, where the first project is best and the last project is worst.

Students have a few days to analyze, evaluate and rank projects. After the deadline for a review ends reviews are analyzed and all students get comments from their colleges and the average rank of their project.

Students keep their projects as private repositories on BitBucket. Only teacher and student have access to the repository. Project iterations are on individual branches. Teacher runs a node.js script which gets a list of all student's repositories with correct branch using BitBucket web API.

After the list is composed teacher uses bash script which clones all repositories from the list. Each repository is then randomly assigned to five different students so that all get five different projects.

When projects assignment is done students get projects for review as a zip file on the branch of the current iteration (Figure 1). Readme files and any files which contain information about the identity of the student are removed from projects. This is done to reduce potential favoritism or conflicts in a peer evaluation process.

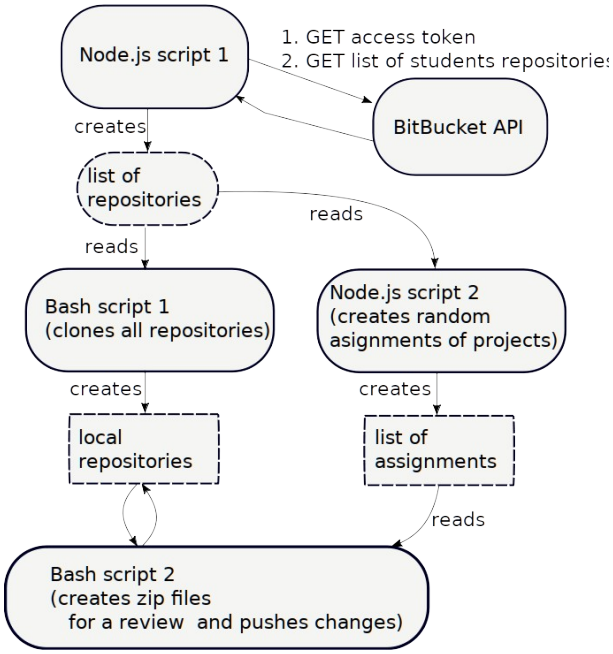

Figure 1. Reviews preparation process

New software solution has been made for project review.

B. The Software for review

This software is made using opensource technologies. Electron.js [12] is used as desktop fronted solution written in javascript and Hapi.js [13] framework with PostgreSQL database for web API development (backend). The frontend is built for Windows, Linux and MacOS. The backend is deployed on a free virtual machine on Heroku cloud platform.

It is designed as a service-oriented solution. Communication between the desktop application and the backend is made using asynchronous HTTP requests.

Students use the desktop application to login to the system. After login, they can view all their reviews and when review deadline ends, all reviews from their colleagues for their project. The user interface is simple with only few relevant information is displayed.

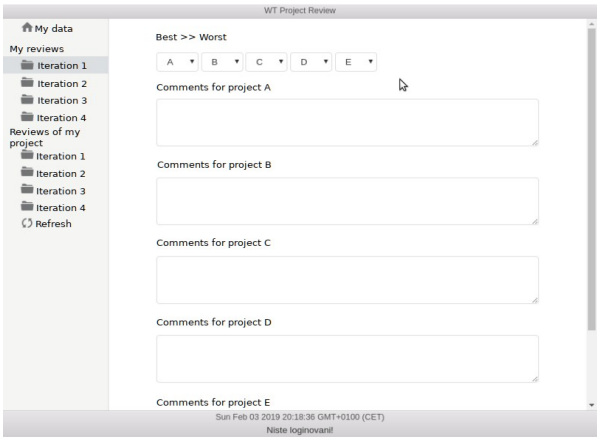

Figure 2. User interface of the software

Students rank five projects by quality from best to worst. Projects are named as letters A to E. For each project there is a text area for comment and there are five drop-down lists with project names representing the rank of a project (Figure 2).

Projects are distributed on BitBucket [15] repositories. In this way traffic to the backend is reduced and this system can be hosted on a free virtual machine instance on Heroku [16]. The number of tables in the database is also reduced to fit limits of free deployment. In the database, data about students, reviews, review results, project distribution and review deadlines are stored.

C. *Review result analysis*

When an iteration ends projects are tested by automatic tests. Tests detect errors in a project and the project is marked in a way that a project with no failed tests (no errors) gets all the points. If there are detected errors, percent of failed tests is deducted from the points. Each iteration is marked by 10 points where 1 point students can get for the review. Half of the point they can get for their review and half of the point is calculated using average rank their project is ranked.

The average rank of a project is calculated as the average of all ranks project got in the current iteration. One project is ranked by five different students. The average rank and final grade are then compared for each iteration. A moderate to strong negative correlation is observed ($r \sim -0.6$). Pearson correlation factors for all iterations are given in Table 1. Significance for all correlations is $p<0.001$.

TABLE I. PEARSON CORRELATION BETWEEN RANK AND FINAL POINTS ($P<0.001$)

	Iteration 1	Iteration 2	Iteration 3	Iteration 4
r =	-0.603	-0.623	-0.597	-0.657

These results show that the rank can be used as a predictor of the final grade. In Figure 3 graphs of ranks and final points are presented.

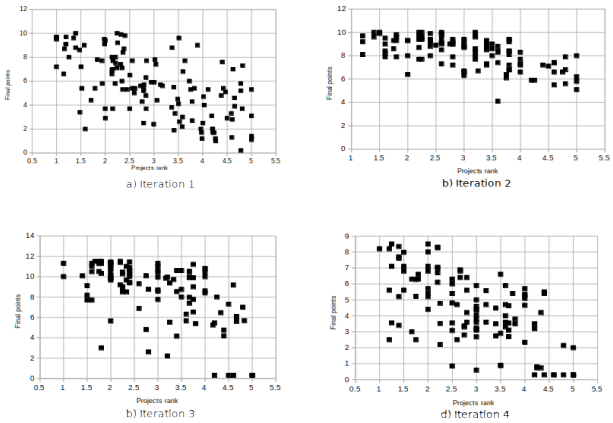

Figure 3. Graphs of the rank and points for each iteration

Students error in ranking projects is also observed and no correlation between students points and error could be found. Error is measured using the largest difference between ranks and average positions, this value is then multiplied by the variance of average positions of all projects student reviewed in the current iteration. The variance of average potions is used so that error for students who get projects of different quality is larger than the error of students who get a very similar projects.

This error is compared to the points students get on the iteration. The observed correlation is low but this result does not have high statistical significance, correlation factor $r=0.07$, and $p=0.108$.

III. CONLUSION

Evaluation of student's projects can take a lot of time, especially if classes have a large number of students. Feedback from evaluation needs to be adequate to support the learning process. Peer evaluation can be used in software engineering courses complementary with an automatic test to give feedback to the students. More research needs to be done to evaluate does peer feedback help students to understand why and how their programs failed on automatic tests.

Further research needs to be done which will analyze the effects of peer evaluation in software engineering courses on code quality. A detailed analysis could be done on how students view peer feedback as a complementary tool to automatic tests.

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Problem Based Learning for Primary School Junior Grade Students Using Digital Tools

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***Abstract* - Problem based learning (PBL) is a learning strategy that uses a certain problem to encourage learners' critical thinking, information seeking, and finding solution for solving that problem. Such solutions are mostly identified in collaboration with other students. The role of the teacher is to develop innovative ideas for the implementation of PBL activities, using digital tools and digital contents. Learning scenarios as materials that offer such ideas can contribute in the involvement of young students in the process of PBL. The ongoing Erasmus+ project "GLAT-Games for Learning Algorithmic Thinking" involved 24 primary school junior grade teachers in education with different teaching strategies for stimulating the algorithmic thinking of their students in everyday situations. During the second workshop the participants were introduced to the use of digital tools for developing logical tasks and for the conduction of PBL. The set task for the participants was to conceive such activities, create a learning scenario of PBL and perform it with their students. After performing the activity in the classroom, a qualitative analysis of the preparation and implementation of the conceived activity was carried out. This paper presents a part of the analysis concerning the teachers' attitudes on the preparation of PBL activity using digital tools.**

***Keywords* – problem based learning, logical tasks, digital tools, algorithmic thinking, primary school students**

I. INTRODUCTION

The aim of contemporary teaching is to actively involve students in the learning process, thus expressing their creativity. This can be achieved by using modern approaches and teaching methods like Problem Based Learning. Solving a problem is very usual and important activity in everyday life as well as in professional work. The problem is most often associated with theoretical and practical difficulties that need to be overcome in an appropriate way. Contemporary teaching is based on the co-constructivist curriculum, where the emphasis is placed on active learning, recognition of students' potential and the development of specific interests of each individual [16], [13]. The Croatian National Curriculum Framework for preschool education and general compulsory education in primary and secondary schools was established in line with "The European framework of key competences for lifelong learning" where three out of eight lifelong competences point out "the ability of solving problem". In the context of global social and educational reforms it is necessary to apply such teaching methods that can structure the learning task, guide learners through the process of learning and help them to understand and apply the acquired knowledge. Problem-solving skills and managing new information, as well as logical thinking and linking all aspects of knowledge, are the competences required by every individual and should be developed through the education system. Schelfhout et al. [15], emphasize that the most fundamental problem encountered during the learning-teaching process is that students memorize the new information and fail to convey what they have learned into new situations.

Since Gagné pointed out that "the central point of education is to teach people to think, to use their rational powers, to become better problem solvers" [4], most psychologists and educators regard problem solving as the most important lifelong learning outcome. Ball and Forzani emphasize that the vision of better education includes an innovative use of technology, emphasizes group work, and integrated and problem teaching which should take place on the basis of a changed curricula and higher expectations of students [1]. There is no unique instructional design for the problem solving process, since there are differences among problems in terms of their structure, domain specificity (abstraction), and complexity [8]. Contemporary education is based on research, exchange of information, teamwork, connection between different cognitions and application of knowledge and skills. Such a curriculum encourages critical thinking, self-conceptualizing conclusions, problem solving, and a creativity in approach and communication among students. The use of technology in all sectors, particularly in education, requires teachers with certain digital competencies in order to use the teaching technology and make the learning process more interesting to students. Within this context, primary school teachers should possess skills to implement contemporary approaches and adapt them in order to enable young students to carry out active learning.

II. TEACHING WITH PROBLEM SOLVING

Teaching approaches like project based learning, problem based learning, inquiry based learning, scenario based learning and reflective learning in teacher education have gained considerable attention in the past decade in the area of teacher education [15]. The problem solving

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access to educational content is always in the function of enabling students to experience, understand and evaluate the content that is being studied. The student is the researcher and the creator, while the teacher is the organizer, the motivator and the facilitator [8], [9]. Most of the studies have been conducted with the aim of comparing the efficiency of contemporary teaching approaches with traditional methods [5], [10], [21]. Organization and teaching procedures should be chosen to maximize and sustain the student's thought activity and contribute to their conclusions and decision abilities. The organization of teaching with problem solving differs from the classical teaching, it is more in line with scientific research [18]:

- Creating a problem situation
- Formulating of the problem: finding an algorithm of the solution
- Hypothesis setting: selection of methods and forms of research
- Solving problems: verifying the hypothesis
- Analysis of research results that are followed by a conclusion and an application to new problem situations.

Vujičić, Pejic Papak and Valenčić Zuljan [22] emphasize that the key task of teachers in problem teaching is to provide conditions for the creative and research activity of students at all the above mentioned phases. M. Rijavec views teaching with problem solving from a psychological standpoint: "The main shift to the teacher's approach is from deductive thinking to inductive thinking. Instead of expounding the ideas and concepts, he has to take on a more passive role, and by applying Socrates's technique of conducting conversations, let students draw conclusions themselves and try to understand what they learn." [10]. Teaching, besides explicit theoretical knowledge, should be focused on the process of gaining knowledge, i.e. on understanding of the process of research and discovery. Therefore, it is necessary to apply teaching strategies which, according to Cindrić et al. [2] include "a thoughtful combination of methods and procedures that encourage the student's activity and enable him to manage his/her own learning process in order to achieve the goals of education." Students are becoming more independent with the use of learning materials, while with the reflection on their work they are able to take on more and more responsibility for the obtained knowledge [5]. In order to implement creative problem-solving lessons, teachers use diverse methods of modern didactics and different forms of work, with a predominance of collaborative work and work in pairs, but sometimes, individual work, based on individualization and differentiation, is present as well.

Studies conducted in recent years have shown the advantages of collaborative problem-solving prior to the usual teaching methods to enhance students' conceptual understanding in mathematics and problem solving competency [17], but there are rarely found studies that adopt this approach in science learning in primary education. In collaborative problem solving for young learners, structured and guided approaches are recommended. Problem solving competency means engaging students in solving a problem using different strategies, from multiple perspectives and with diverse modalities. Its processes include: exploring and understanding; representing and formulating; planning and executing; and monitoring and reflecting [12]. The research literature shows that project-based learning can help students enhance learning performance in knowledge advancement and skill development, and motivate them to learn [17].

Song also highlights the "productive-failure" as ''a learning design that affords students opportunities to generate solutions to a novel problem that targets a concept they have not learned yet, followed by consolidation and knowledge assembly where they learn the targeted concept'' [17]. This instructional design involves students first in unguided problem solving activities in order to evoke their prior knowledge, particularly the failure to solve the problem. Later students use this information to determine and assemble new knowledge after the teacher helps them solve misconceptions. This approach can be useful for young students to stimulate their active learning process. Active learning is defined as "learning that provides a high level of autonomy and self-control to students, as well as an application of various mental strategies and specific cognitive abilities for distinguishing important and unimportant information, analysis and comparison, knowledge acquisition based on previous experiences and critical thinking" [11]. The aforementioned context of the contemporary teaching process determines according to Suprayogi & Valcke [19] the application of strategies, the diversity in learning activities, monitoring individual student needs and achieving learning outcomes. Although many studies mention that active learning with problem solving should consider ill-structured problems, which will encourage critical thinking and evaluation of solutions [8], [14], it is better to start with well-structured problems with young learners. Novice learners need guidance to develop their problem solving skills, as well as self-directed learning skills. Furthermore, collaboration is yet another important factor in problem solving teaching in younger pupils because individual differences in prior knowledge and critical thinking encourage better achievements.

Nowadays, more attention is paid to the application of modern technology in the teaching process. As technology has emerged in all school subjects, not only Computer science teachers are allowed to use it. Digital tools ensured an application of new opportunities in the educational process. Active learning by using technology enables a faster realization of certain activities. However, teachers will be able to conduct effective teaching when they are fully equipped in their professions. [9] Therefore, it is clear why teacher education is crucial in this sense.

III. THE GLAT PROJECT

With the desire to enhance the teaching skills of primary junior grade teachers, the Erasmus+ project "Games for Learning Algorithmic Thinking" (GLAT) was developed. The main goal of the project is to encourage the inclusion of coding and algorithmic thinking in teaching different subjects in lower grades of elementary

school in a fun and attractive way. This project started on October 2, 2017, and will run until September 1, 2019. The most important activities of the project include the professional development of primary school teachers with various innovative teaching methods using information and communication technology. Special focus is on using educational strategies of Game Based Learning (GBL) and gamification in order to foster creativity, logical thinking, and problem-solving skills. Primary school teachers were participating in education through three workshops and the online part with the e-learning system Moodle. The topic of the second workshop, held on August 2018, was Problem Based Learning (PBL), online quizzes and logical tasks. The emphasis was on the examples of learning scenarios and the accompanying materials for the implementation of problem based activities and logical tasks. This paper presents the results of the GLAT project after the second workshop. The focus group of teachers developed learning scenarios, and applied design activities in schools with their students.

A. Algorithmic thinking

Encouraging algorithmic thinking in younger students is one of the main goals of the project. Algorithmic thinking as part of computer thinking can be stimulated through a series of activities:

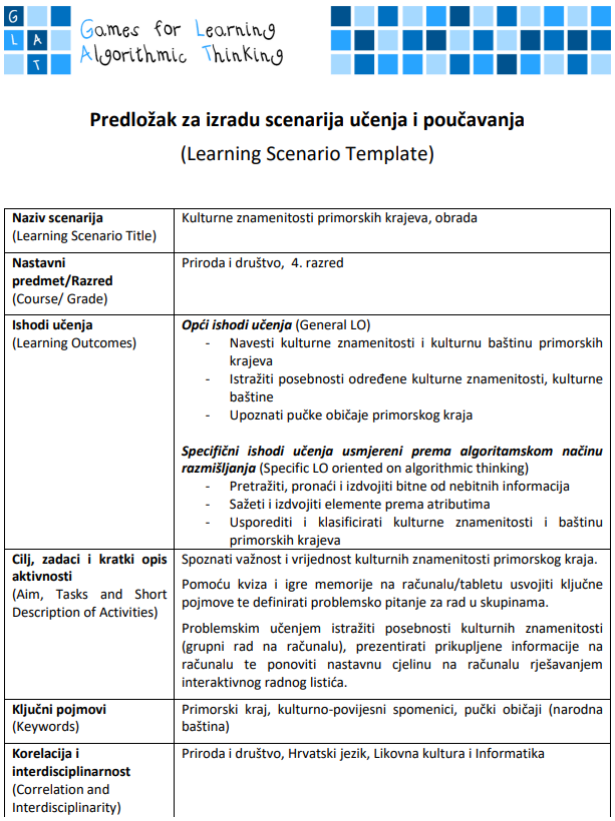
- Searching and sifting essential from non-essential data
- Summarizing and excluding items by attribute
- Comparison and classification of items
- Defining and describing a sequence of actions (algorithm)
- Detecting errors in the algorithm

Since our second workshop related to PBL, online quizzes and logical tasks, algorithmic thinking has played a major role in designing activities. When explaining a problem as algorithm, it is breaking down in smaller, more familiar sections, which can be solved using a set of rules (algorithms) to find solutions and using abstractions to generalize those solutions to similar problems [20]. For example, in early grades, teachers could highlight the steps involved in solving any problem thus explaining the algorithm. Algorithmic thinking can be developed through all school subjects for which appropriate teaching methods are needed either with or without technology. Any learning situation can be improved by incorporating such methods in an appropriate learning scenario from the first grade of primary school, and it can only be conducted by the teachers who have been trained for it.

B. Learning scenarios of PBL

The aim of each of our workshops was that teachers design and develop learning scenarios on the chosen topic of the existing curriculum using the principles of tools highlighted at the workshop. The planned activities should be carried out with their students.

Designing a learning scenario is a process by which teachers plan or structure a learning situation. A scenario consists of a subject and class, a complexity level, key concepts, learning outcomes and a description of activities complemented with materials and resources for the teacher and students [7], [9]. For the purpose of the second workshop a Learning Scenario Example was produced as shown in Figure 1.



Games for Learning Algorithmic Thinking

Predložak za izradu scenarija učenja i poučavanja

(Learning Scenario Template)

Naziv scenarija (Learning Scenario Title)	Kulturne znamenitosti primorskih krajeva, obrada
Nastavni predmet/Razred (Course/ Grade)	Priroda i društvo, 4. razred
Ishodi učenja (Learning Outcomes)	***Opći ishodi učenja*** (General LO) - Navesti kulturne znamenitosti i kulturnu baštinu primorskih krajeva - Istražiti posebnosti određene kulturne znamenitosti, kulturne baštine - Upoznati pučke običaje primorskog kraja ***Specifični ishodi učenja usmjereni prema algoritamskom načinu razmišljanja*** (Specific LO oriented on algorithmic thinking) - Pretražiti, pronaći i izdvojiti bitne od nebitnih informacija - Sažeti i izdvojiti elemente prema atributima - Usporediti i klasificirati kulturne znamenitosti i baštinu primorskih krajeva
Cilj, zadaci i kratki opis aktivnosti (Aim, Tasks and Short Description of Activities)	Spoznati važnost i vrijednost kulturnih znamenitosti primorskog kraja. Pomoću kviza i igre memorije na računalu/tabletu usvojiti ključne pojmove te definirati problemsko pitanje za rad u skupinama. Problemskim učenjem istražiti posebnosti kulturnih znamenitosti (grupni rad na računalu), prezentirati prikupljene informacije na računalu te ponoviti nastavnu cjelinu na računalu rješavanjem interaktivnog radnog listića.
Ključni pojmovi (Keywords)	Primorski kraj, kulturno-povijesni spomenici, pučki običaji (narodna baština)
Korelacija i interdisciplinarnost (Correlation and Interdisciplinarity)	Priroda i društvo, Hrvatski jezik, Likovna kultura i Informatika

Figure 1. Example of PBL learning scenario

The learning scenario should have accentuated correlations with other teaching subjects, as well as designed activities in order to emphasize and encourage this connection. As described in the example, the aim of this activity is to understand the importance and value of the cultural sights of the coastal region. The teacher will use a self-prepared quiz and a memory game on the computer/tablet for students to adopt key concepts and define a problem issue for group work. Via problem-based learning, students will explore the specifics of cultural sights (group work on a computer), present the collected information, and repeat the learning unit by solving an interactive worksheet on the computer. The applications used for conducting online quizzes and logical tasks were Kahoot! quiz, Match the Memory game, Wizer.me and LearningApps interactive worksheets.

During the November and December 2018, teachers implemented their conceived activities in the class and gave a reflection on the conducted activity. Reflection included performance considerations, whether performance required additional assistance to teachers, the number of students involved with the activity, how the students accepted the designed activities, whether all the learning outcomes stated in the learning scenario were realized and the possible changes in the scenario before the next implementation.

IV. TEACHERS' ATTITUDES TO THE PREPARATION OF PBL ACTIVITY USING DIGITAL TOOLS

At the beginning of January 2019, qualitative research was conducted through three focus groups with a total of 24 teachers. Each group consisted of eight teachers deployed per class, where they conducted problem teaching activities using digital tools (1st grade, 2nd grade, 3rd and 4th grade). The focus group method was selected as a preliminary survey of attitudes to education and improving personal competencies as a basis for the preparation of quantitative final evaluation of the entire project.

The aim of the research was to examine the teachers' opinions, attitudes and their personal experience in preparing for problem teaching with the help of the digital tools they had implemented with their students. The focus groups' implementation took place predominantly as a targeted conversation with pre-structured topics and subtopics on the competences of using digital tools in the process of teaching, preparation and implementation of problem based learning scenarios and using digital technology in the teaching process. Teachers expressed their attitudes and opinions through a conversation, describing their experience of problem based learning/teaching. The implementation of each focus group was audio recorded. Based on the obtained transcripts, the results were analyzed by systematizing the participants' answers to a particular question.

For the purpose of this paper the topic *Preparation and implementation of problem based learning scenarios* was analyzed through structured questions:

- How demanding is the preparation for this type of teaching and learning?
- How much time has been invested in developing the learning scenario?
- Do you estimate that your participation in GLAT education enhanced your teaching competences?
- Is the school well-equipped with technology?
- Was additional support of the IT teachers needed before the implementation of the designed scenario?

The systematization of the answers leads to the conclusion that design and writing of preparations for this kind of problem teaching is demanding, with which the group agrees. There has been a small polarization of attitudes in the opinion that the requirement for preparation is reflected only at the beginning of the application of this type of teaching. Here are some answers:

- "Preparation needed a recollection of everything we have learned through training"
- "I had to additionally test and try digital tools we used on the workshop"
- "I solved the doubts with the method of attempts and mistakes and successfully prepared the teaching scenarios"
- "On a scale from 1 to 10 I think the requirement of preparation is somewhere between 8 and 9"…

The group agrees that they have been using this kind of preparation for the first time, with an emphasis on the outcomes and activities that will be achieved with the help of digital tools. They consider: "Any subsequent activity and learning scenario design will be much easier". "This form of preparation is extremely good regarding the direction of the curricular reform we are undergoing". The group concludes that the efforts they have invested in designing activities have resulted in showing interest in the more frequent implementation of the digital tools in teaching activities by students but also themselves in the context of innovation of the teaching process.

Due to the expressed demands of design activities, respondents were asked the question "How much time has been invested in making preparations/learning scenario for one lesson?" The group opinion is several days and stages in the process, because they encountered a new way of preparing lesson. The problem was not to elaborate the course of one lesson, but rather to envisage the time required for preparation of quizzes and logical tasks with digital tools and designing extra activities of the kind. Many teachers especially liked the Leplanner – graphical tool for creating a learning scenario.

The group also emphasizes the improvement of personal competency of teaching after the implementation of the learning scenario. Here are the highlighted answers:

- "The novelty of using digital tools in other subjects and not only informatics and I can do it"
- "The pupils are using computers and digital tools and they are not in the computer class and not with an IT teacher"
- "Students are showing their digital literacy through their work on the computers while the teacher directs it"
- "I am the creator and inventor of games, assignments and quizzes that I have never conducted before"
- "I can devise activities by organizing lessons on computers"
- "Such planned teaching can contribute to the thematic-integrated teaching"
- "The learning scenarios we have created can also be used in our subsequent work, as forms to be revised".

By systematizing the answers to the question: "Is school well equipped with technology?" a good equipment of computer classrooms was confirmed in all schools. The problems that the teachers point out about equipment are as follows:

- "There is only one computer classroom in school."
- "Access to an IT classroom is not always possible in scheduled time."
- "There is only one computer classroom that is permanently locked."
- "Classical classrooms should be equipped with a computer, projector and internet connection."
- "At least one tablet set to be used in parallel classes is required."

However, it is concluded that for all planned scenarios, all teachers managed to organize the classroom availability.

The polarization of attitudes was most apparent in the answers to the question: "Did you need additional help or collaboration with an IT teacher before the implementation of the activity?" The group did not have a common attitude. The most commonly expressed attitudes were:

- "I asked for the collaboration of the IT teacher to assist students during the implementation of activities in terms of typing keywords into a search engine or typing applications links, etc."
- "I did not need any help from colleagues."
- "I did ask for help from my colleague, but it was not adequately achieved."
- "I think that I will be able to bring digital tools into the teaching process more independently with each subsequent activity implementation. "

V. CONLUSION

There is not enough research related to the implementation of Problem Based Learning into teaching very young students. An integration of PBL scenarios in the teaching process can increase teachers' knowledge and skills and enhance their teaching practices. Furthermore, such method can contribute to developing creativity and logical thinking in young students so they will be able to convey what they have learned in new situations. The GLAT project will try, with contemporary methods and teaching strategies and through different school subjects, to implement the algorithmic way of thinking, problem-solving skills, logic and creativity into the daily learning.

All teachers involved in focus groups emphasize the improvement of personal competency of teaching after the implementation of a learning scenario, as well as the novelty of the use of digital tools in other subjects, not only informatics. Finally, teachers point out that overall GLAT education will be useful to them in regard to the changes in the education system and the transition to a curricular approach, as the learning platforms are similar. They have regularly exchanged reflections on the forum and thus also learned. Teachers showed great satisfaction with the prepared scenarios and readiness for investing further efforts.

The learning scenarios are based on general and specific learning outcomes and activities that deliver the outcomes, and the greatest novelty is the use of digital teaching tools, as well as the high motivation of students for game and problem based learning. The results obtained through the focus group will be used to improve the training syllabus, which is one of the goals of the GLAT project. Teachers consider that additional educational cycles for primary school junior grade teachers about the learning scenarios and the use of educational technology and web tools should be carried out and that they should become part of a continuous lifelong training of primary school junior grade teachers.

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Assistive technologies for children with cognitive and/or motor disabilities: a diagnosis of the training needs of informal caregivers

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Abstract - Assistive technologies promote communication, personal independence as well as the inclusion of children with cognitive or motor disabilities. Despite the human and material resources available, the implementation of assistive technologies in many family settings is still a struggling task. With the present study we seek to survey information and training needs of informal caregivers related to the use of assistive technologies at home, so as to, in the near future, try to meet them. Therefore, we are conducting a focus group on that topic with therapists, special education teachers and an educational psychologist and analyzing the content of the discussion. The data gives a perspective on (i) how thorough informal caregivers' knowledge of what assistive technologies and their advantages are, (ii) difficulties reported by informal caregivers when using them with their children, (iii) reasons that may lead them to the abandonment of assistive technology devices, (iv) how they can develop their skills and use the technology more effectively and (v) how information on assistive technologies can be made available to them. Therefore, the full aim of this research is to contribute to reducing technology abandonment and to enhancing its use in the family setting by children with cognitive and/or motor limitations. Some preliminary results are put forward.

Keywords - Assistive technologies; cognitive and motor disabilities; informal caregivers; family setting; focus group.

I. INTRODUCTION

This study places a strong focus on the importance of using assistive technologies (AT) to promote the global development of students with disabilities at cognitive and/or motor level. Moreover, it is intended to reflect on the factors leading to the technology dropout by the users, a phenomenon named in the literature as *assistive technology abandonment* [1]–[3]. This abandonment of AT devices is a worldwide, worrying reality. This is widely documented in the literature, where it is strongly sustained the need for improved research on the theme of AT use in the family setting.

Within an action research methodology, our aim is to study that specific context and intervene with the purpose of instilling change and improvement in the practices and therefore contributing to reducing the problem of technology abandonment. In this manner the first step is to diagnose information and training needs of the informal caregivers. The present study is intended to answer one of the sub questions of the main research: What are the training needs of informal caregivers to enhance the use of AT? Therefore, our objective is to identify the training needs of informal caregivers of children with cognitive and/or motor limitations who use AT. Informal caregivers are said to be the parents, siblings, grandparents, nannies, maids, that is to say everyone likely to interact with the student at home.

To achieve our objective, as an initial step we have conducted a focus group with education and rehabilitation professionals. The qualitative analysis of the data gathered will contribute to a proposal of improvement of practices namely a parental training project on the use of AT, to be implemented throughout 2019.

The literature review in this paper focuses on AT and the tendency to abandon it. The methodology section clarifies the nature of this study, its planning, data gathering techniques and instruments. Finally, there is a description of the results achieved with the focus group and some conclusions are withdrawn.

II. CONTEXTUALIZATION AND METHODOLOGY

A. State of the art

The social movements in the second half of the XX century made society more aware of the needs of people with disabilities. The awareness that the latter can actively participate in society with devices to help them fulfil their daily tasks led to the emergence of assistive technologies [4]. These researchers stress that AT refers not only to the devices chosen on the grounds of the previous evaluation of the user's needs, but also on the importance to provide training on the device, technical support, planning an intervention and assessing it [4].

There is an emphasis on the functional skills of disabled students and on the importance of using appropriate strategies and abilities likely to lead to successful fulfilling of activities in different contexts [5]. Therefore, AT refers to a set of devices, services, strategies and practices designed and applied to reduce the

limitations faced by disabled people, to improve their functionality and quality of life, enhancing their autonomy in everyday tasks and active participation in society [4], [6]. The World Report on Disability [7] describes several practical examples that if AT are adjusted to the user and his/her environment, they are likely to be powerful tools to increase independence and improve participation. In fact, AT can help in oral and written communication, reading, seeing, hearing and mobility, since there is a wide variety of devices to compensate for all types of limitations.

It is important to stress the idea that each user is unique in his/her needs so, when selecting an AT device, it is essential to assess his/her functional, physical, cognitive and sensorial abilities, identify the activities and the context where they will be performed [6].

The students addressed in this study will be children with cognitive/intellectual limitations, described in the literature as individuals whose intellectual performance and adaptive behavior causes them to face global problems in academic and social learning [8], [9]. We have also included children with motor limitations, whose physical skills have been altered, causing them exhibit manual or mobility incapacities [8], [9]. Both populations tend to have communication constraints, which is particularly important in view of their functional limitations, and the advantages of applying communication strategies supported by AT. Nonetheless, the success of an alternative and augmentative communication system largely depends on the involvement of parents or other informal caregivers. Therefore, it is important not to restrict the use of a communication system to the school or the therapeutic setting, but to create opportunities that allow its use at home [10]. Indeed, it is vital to include the child's family in the process, since it is the main vehicle to have the AT device transposed to other more regular and lasting contexts of life [11]. The literature places strong emphasis on the relevance of the family setting to enhance the use of AT by children with limitations.

Users´ tendency to quit using AT is a reality widely felt by teachers, rehabilitation technicians and health professionals. It is important to understand the motivations behind the user's decision to reach for AT, since that may help teachers and rehabilitation professionals to design and implement effective interventions against AT abandonment [12]. Some factors are said to be related to acceptance or rejection of AT devices: not taking into consideration the user´s opinion when selecting the AT; low performance of the device; changes in the user's needs and priorities [13]. Results in these researchers' study pointed to the need to reinforce the user's involvement and identify his/her needs in the long term, so as to increase satisfaction and reduce abandonment [13].

Therefore, Brotherson, Cook and Parette suggested creating a parental training program to promote the use of AT [14]. One must bear in mind that the family setting is the children's first and main learning environment and it contributes decisively to developing skills. Besides, considering the family culture, resources and family interactions is essential for a successful introduction of AT at home [14]. The state of the art in this field of research reveals that despite the fact that the need to invest in the family setting is mentioned in the literature, in Portugal there are no validated parental training programs for AT use at home. At an international level it is possible to find "Assistive Technology – a parent's guide" which specifically focuses on AT for individuals with learning limitations [15]. The "Assistive Technology – Pointers for parents" addressed to parents and informal caregivers, published by the Wyoming Institute for Disabilities, provides practical advice for parents to enable them to actively participate in the process [16].

B. Nature of the investigation

This is an exploratory, descriptive study, with a qualitative approach. Such approach explores the characteristics of individuals and situations, placing emphasis on processes and meanings that are neither measurable nor experimentally examinable [17], [18]. It is our goal to get a comprehensive and holistic understanding of the problem in its historical, socioeconomic and cultural background and interpret it through an inferential and inductive process [17]. Indeed, in a qualitative approach, the focus is on the process, since the purpose is to understand, interpret and find meanings [19].

The main investigation qualifies as action-research, for the investigator has a participative role and aims at gaining knowledge to understand the context and intervene with the final purpose of contributing to solve a problem. The nature of this research follows an inductive model but aims to go beyond the descriptive level [20]. In this case, there is the need to study the family setting and intervene so as to instill change and improve practices. So, the purpose is to identify the training needs of informal caregivers and to develop, make available and evaluate a training program validated and adjusted to their needs.

Given the research questions, the objectives to be accomplished and the qualitative and descriptive methodology, this study fits in the interpretative paradigm, also known as naturalist or qualitative [20].

Since the critical dimension of action research methodology is to solve problems diagnosed in specific situations, in this case the lack of skills of informal caregivers to use AT in the family setting, it involves changes in people and institutions aiming at better living conditions and full participation of all [21]. In this case the aim is to introduce change in the context and in the participants, addressing the needs identified and improving the interactions between the informal caregivers and the children using AT.

C. Planning of the investigation

In the first step, based on the literature review on this subject, we have conducted a survey of the training needs, limitations and resources of the informal caregivers of children who use assistive technology. The final aim is to conceive and implement a parental training program and reflect on its results. The methodological steps of this investigation project are described next.

The decision to hold a focus group relies on two identifying characteristics of this technique of data gathering: the interactions arising inside the group are the main source of information or data collection, and this method focuses on a specific topic about which participants have experience or knowledge [20].

The focus group technique is commonly used in qualitative studies [22], [23]. The possibility to watch a large quantity of interactions and to gather a large amount of data about a theme in a short period of time are said to be the main advantages of holding a focus group [24]–[26]. Moreover, the data is directly targeted to the researchers´ interests. On the other hand, the fact that a focus group is driven by the researcher´s interests may pose as a weakness of this data collecting method because there is the concern that the moderator will influence the group´s interactions so as to maintain the interview´s focus [24]. Besides speech itself, non-verbal behaviors of the participants (tone, gestures, emotion) can also provide relevant data in a focus group [27]. In this particular study, data transcription comprised mostly linguistic features, even though some participants´ gestures were registered, mostly to reinforce their answers.

The purpose of this focus group was to explore the perceptions, experience and meanings that different professionals have on AT knowledge of users' parents. The first phase consisted in determining the purpose of the focus group interview, selecting an appropriate sample and draw up a script/guideline. The concepts or questions to be investigated were previously defined and clarified since these would determine the participants' selection, the kind of questions to ask during the session and the type of analysis to carry out afterwards [22].

Sampling is said to be a major key to the success of focus groups [24]. These participants were brought together because the topics are closely related to their professional experience. Another important point is the homogeneity of the group elements (being in touch with children with cognitive and/or motor disabilities) which fosters the integration of the participants within the group, but there should be some variation allowing contrasting opinions. The decision as to the number of participants in the focus group depends on the objectives predefined for the study. So, based on the review of the literature [20], [22], [27], [28] we decided to include six participants. Therefore, we have selected different professionals: two teachers, three therapists and a psychologist [28].

Carrying out this focus group required the previous elaboration and validation of a script/guideline containing open questions, using plain language and encouraging lines of thought besides those initially planned [22]. During the discussion, participants were stimulated to spontaneously share their personal experience, ideas and feelings in an open atmosphere. The role of the moderator was essential to conduct the focus group: posing the questions, keeping the discussion flowing and enabling group members to participate fully [22], [23]. The researcher acted as the moderator in this focus group, being well aware of the dynamics so as not to bias the interventions, either consciously or unconsciously. Indeed, the fact that focus groups are driven by the researcher´s interests raises the concern that the interviewer will influence the group´s interactions [28]. The moderator of this focus group directed the discussion and encouraged interaction in a non-threatening, emphatic atmosphere. Therefore, the discussion took place in a comfortable and ensuring classroom environment at the University, without noise or other inhibitors of communication.

Besides the importance of the quality of the personal relationship between the researcher and the focus group members, there are important aspects concerning validity, reliability and ethics. There was careful attention to ethical issues during the process: participants were informed of the purpose of the study, gave their informed consent including permission for video recording and were made aware of the need to maintain confidentiality about the content of the session [23], [27], [29].

This focus group session took place on 11th January 2019, lasted for about 90 minutes and was video recorded. Afterwards, the transcription of the discussions was sent to the participants so that they could check, correct or confirm their contribution to the discussion. This procedure of sending the text to the participants for validation is a way to ensure the desired quality of the study [20].

The following step was the analysis and interpretation of the data content. We adopted the content analysis technique within the methodologies in social research [30]. Content analysis allows progress in capturing the meaning of the discourse through its classification in categories and subcategories and coding. The coding process respected the fundamental rules: exclusivity, homogeneity, pertinence, objectivity, completeness and productivity [17]. This procedure was validated by two external researchers so as to ensure the reliability of the analysis [26]. The procedure was supported by webQDA, a web-based software aimed at researchers who need to analyze qualitative data (either text, image, video or audio sources) individually or collaboratively.

Given the main research question (How to promote the use of assistive technology in the family setting) and the literature review, the following dimensions of analysis were defined: (i) skills of the informal caregivers and contexts of AT usage, (ii) obstacles to the use of AT in the family setting, and (iii) training needs of the informal caregivers.

The theoretical framework or the state of the art also allowed us to define six a priori categories of analysis: (i) knowledge of informal caregivers about AT and its advantages, (ii) reasons for giving continuity to the training at home, (iii) difficulties faced by informal caregivers in using AT, (iv) reasons for AT abandonment, (v) requirements for a better use of AT by informal caregivers, and (vi) training informal caregivers on AT.

The following step consisted in repeated and active reading of the data corpus (the written transcription of the focus group) and deciding on the unit of analysis [23], [30]. In this case, the unit of analysis ranged from parts of sentences to whole sentences. Thereafter, a careful and active reading allowed us to define the empirical/inferential sub-categories of analysis shown in

table I [17]. Thereafter we proceeded with the coding of the text references into these categories and subcategories.

TABLE I. INTERNAL CONSISTENCY OF THE ANALYSIS

Categories	Sub-categories
Knowledge of informal caregivers about AT and its advantages	Lack of knowledge
	Partial knowledge
	Technologies known by informal caregivers
Reasons for giving continuity to the training at home	Involvement and responsibility of all interveners
	Widespread use of AT in all contexts
	Motivation and awareness of the advantages
Difficulties faced by informal caregivers in using AT	Delay in obtaining results
	Personal limitations and/or self-indulgence
	Material and technical limitations
	Time constraints
Reasons for abandoning AT in the home setting	Lack of material conditions
	Shortage of time
	Lack of articulation between professionals
	Unawareness of the need to use AT
Requirements for a better use of AT by informal caregivers	Articulation
	Information search to meet specific needs
	Ease and desire to search for information
	Better research and access to information
	Encouragement and advice by professionals
	Ways to make information available
	Training
Training informal caregivers on AT	Setting
	Schedule
	Method

III. DESCRIPTION OF RESULTS

Within the first dimension of analysis, in order to assess the skills of the informal caregivers in using AT and the context of usage, the focus group participants were asked if informal caregivers know what AT are, why they should be used, which AT devices they would be able to identify and indicate their purpose. Their answers allowed us to create two categories of analysis: lack of knowledge and partial knowledge. The majority of the references coded in this category (68%) point towards lack of knowledge. It is said that "*most of them don't know what AT is, their lack of knowledge", "they find it hard to understand", "they probably don't know", "they aren't aware of the functions", "they are completely unfamiliar with it"*. Only 22% of the references refer to partial knowledge in terms of "*at least they have got some idea of what it is", "perhaps they are starting to realize", "they are already familiar with some things".*

Concerning the next category - AT devices known by informal caregivers - participants mentioned that parents are usually acquainted with technologies for mobility and daily life activities, that is to say, that compensate for immediate difficulties/needs. They also mention a growing familiarity with augmentative and alternative communication aids on tablets or computers, even though other informal caregivers are only familiar with communication tables without the multimedia resource.

As far as the next category is concerned, based on the common group opinion that teachers and therapists shouldn't be the only ones training the use of AT devices, some justifications are presented in favor of giving continuity to the training at home. An analysis of the references allowed us to divide the reasons into three subcategories as shown in table 1.

The most frequently referred subcategory - Involvement and responsibility of all interveners - applies to the need to involve and assign responsibility to everyone who interacts with the child (teachers, therapists, relatives, tutors). This idea is evident in references such as *"parents must give continuity to the training at home", "it should be shared responsibility", "the family should be part of the training", "for the family spends long regular periods of time with the child".*

The second most addressed reason for using AT in the family setting - Widespread use of AT in all contexts – is justified by the advantages of using AT not only at school or in therapy but also at home, because, as the focus group argues, *"it is designed for functionality at school, at home and in other life contexts", "at home there are also communication needs, not just at school", "besides, there are routines that only happen at home", "it is important to embed the use in their daily routines at home too".*

The third reason - Motivation and awareness of the advantages – is justified with the fact that giving continuity to the training of AT at home makes the child more motivated to use it and aware of its advantages, as the focus group outlined: *"make the child feel that using the AT device will facilitate her life", "it aims for the autonomy of both the child and the parents".*

As to the difficulties faced by informal caregivers in using AT, the references codified in this category point mostly to the delay in obtaining results since training a skill using an AT device sometimes takes a long time to produce results, because, as the focus group stresses, *"these children take their time to give some kind of response", "it takes a long time", "often the results are not immediate", "the search for the most immediate".*

To address situations deriving from caregivers´ lack of digital literacy to solve technical problems or their lack of proactivity to seek specialized support, we created the subcategory Personal limitations and/or self-indulgence. As far as personal limitations are concerned, it is mentioned in references that *"there's a lot of people who still don't have skills to use a computer", "aren't used to using a computer", "they don't know how to access and how to help", "sometimes it is hard for them to use devices and figure out how to do it".* On the other hand, the above mentioned self-indulgence or lack of proactivity is evident in references such as *"There is free software and they don't use it", "they have access to technology and don't use it", "Even if they have technicians available, they don't address them", "there are training sessions and few parents attend", "Parents can come and ask us for training but very few do".*

Another limitation mentioned by informal caregivers, though with less references, has to do with time constraints. Their work schedule, their children's therapies

and the household tasks leave them little or no time available, as shown in these references: *"families have such time restraints", "lack of time available", "it is complicated because it takes time"*. Informal caregivers´ difficulties in using AT are also noticeable in situations where they lack material resources, technical issues, e.g. internet connection, lack of technical support. This subcategory – material and technical limitations – is the less referenced. Nevertheless, it is referenced that *"there are children who haven't got a computer at home", "who don't have internet"*. Portability is also said to be an issue, even though not as much as in the past: *"they say laptops are not that easy because you have to take them out of the bag, put them on the table, open and close them, and there are often updates running"*. Nevertheless, it is stressed as very positive that *"from the moment the app for tablet and smartphone was made available, it came up as a huge help"*. It should be noted that the subcategories "Time constraints" and "Material & technical limitations" are the ones with the least references, which is in line with the results in the data regarding reasons for abandoning AT in the home setting.

Indeed, the second most mentioned reason for AT abandonment - Lack of articulation between professionals – is a subcategory concerning situations deriving from the absence of communication between teachers and therapists. This often results in a gap between the AT used by the children and his/her real needs, which is illustrated in references such as: *"the lack of communication between professionals", "there are no moments together to reflect", "in my practice I see communication tables that don't exactly meet that child's needs", "there is a gap here because implementation should have been done differently"*. And the most mentioned category - Unawareness of the need to use AT – refers to lack of motivation to use AT as a result of not realizing the need to use the AT device. In this regard there are references such as *"the matter of realizing the need of that technology", "it is as if they don't understand the need to use it", "the children themselves abandon it if they don't feel the need"*.

In the next category - Requirements for a better use of AT by informal caregivers -, the focus group stressed once more the need of articulation between all participants to enhance the use of AT devices. This is clear in references such as *"to be a job well-done it has to be articulated", "to have everyone present and reflect, to reassess the implementation", "in these meetings one could talk and pose doubts", "in an articulated way, to have specific answers for each student"*.

The focus group also reinforced the need for more information on AT. In that sense, Caregivers´ motivation to search for information that meets their needs, in order to solve practical problems of their child, is a subcategory visible in these references: "*It is according to their child's needs that they learn", "as the needs come up, they go on searching", "these parents´ knowledge is closely related to the needs that occur", "most of them need very practical, useful information"*. In this regard, the subcategory "Ease and desire to search for information" seems important to us, for there are parents who take the initiative to seek for information and do it easily, as revealed in some references: *"I have also met some parents who research on their own initiative", "there are parents who are eager for knowledge and like to search for information online", "people who find it easy to access the internet and search"*. On the other hand, there is a significant number of references showing the difficulties faced by many informal caregivers in information search or in handling the information they find online or provided by the therapists. Therefore, in this subcategory - better research and access to information -, we coded references such as *"they have difficulty to access information, to search", "parents find it hard to access information and to search on their own", "I think it is too much information for them to manage", "they get lost in the information"*.

It is worth highlighting that many informal caregivers need to be encouraged and guided by the technicians in their search for information, so the subcategory "need of encouragement and advice by technicians" is also mentioned: *"many parents need to be encouraged, guided and encouraged", "they go on to investigate, read and try to understand through us and sometimes they even question", "they rely a lot on therapists and teachers"*. Questioned about how information on AT could be made available to informal caregivers, the focus group referred that these usually search online for information about similar cases in a local online forum and talk in blogs to other parents who have children with similar problems.

Training was also considered an essential condition to develop informal caregivers´ skills in using AT. So, the last category approached in the focus group regarded the method of training addressed to informal caregivers, namely where, when and how to conduct such training. In relation to the best location for parental training, all participants in this focus group indicated the home setting: *"preferably at home, in their environment, it would be the ideal for them", "in order to be a specific answer for that student", "only showing and working in the context and the parent seeing that the child actually gives feedback, will we be able to take advantage of AT"*. As to the preferential schedule for training addressed to informal caregivers, the general opinion of the group is that it should be at the end of the day, when parents are at home. However, some obstacles are pointed out as well, such as "*that will demand that a set of people are available at a certain place and time, which is not easy", "everything would be extra in terms of time", "there's a shortage of time available to make it possible"*.

As to the ideal method, the group was a clear advocate of face to face training rather than online: *"there are usually better results when we are face-to-face and not online"*. One of the possibilities mentioned was implementing mutual help groups with mediators, in which caregivers share information, experiences and difficulties. One participant suggested *"maybe even a parent could help train other parents by sharing his/her experience", "it is essential that they see how it works, that it is practical and beneficial for the whole family", "parents would see how it works, and realize that there is a way. That it is functional and there are children who use it", "Of course there would be a technician mediating the group"*. It is worth emphasizing the suggestion given in one of the references: *"I think it should be carried out in*

stages: first there would be training on how to implement it for the first time, then there would be an experimental period, then we would meet again, and parents would report the obstacles they faced".

IV. CONCLUSION

There were clear advantages in conducting this focus group, for it gave important contributions to the diagnosis of the needs of informal caregivers who use AT. In terms of knowledge of what AT is and its purposes, informal caregivers are said to have a striking lack of knowledge on the subject. They are said to have only partial knowledge of AT, mostly devices aimed at mobility and daily life activities that address immediate needs. The general opinion that parents should use AT devices at home is mostly based on the need to involve and hold them responsible, but also to generalize their use in all life contexts and increase the motivation and awareness of their advantages. Nevertheless, the focus group reported some serious obstacles to AT usage by parents. The most striking is the delay in obtaining results, followed by parents´ personal limitations and some self-indulgence. Time/availability is also said to pose a problem and it is said to be one of the reasons for AT abandonment. But the most mentioned reasons are unawareness of the need to use AT and lack of articulation between professionals.

Articulation is said to be an essential requirement to improve the use of AT by informal caregivers, as well as information. The data stress the need to improve parental research skills and access to information. Training is also highlighted, and the home setting is said to be the best location for parental training, at the end of the day and in group, so that parents can share experiences and help each other.

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The opinions and attitudes of students – future IT teachers – on the use of VR and AR in teaching

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Abstract **- Recent technological advances in the field of Virtual Reality (VR) have resulted in market release of multiple head mounted displays such as Oculus Rift, Sony Gear VR and HTC Vive. This new technology brings great possibilities in education in terms of new methods of learning, and its applications in teaching have already been studied in several studies worldwide. Augmented Reality (AR), as an emerging technology, is predicted to have even more potential usages than VR, both in education and other areas. The advantages of AR are increased freedom, lack of simulator sickness, and broader application range. The aim of this paper was to investigate the opinions and attitudes of students who will, presumably after their graduation, teach ICT in primary education schools. The research showed that even though a majority of students have positive opinions and expectations of these technologies, such as immersive learning and pupils' motivation, only a few of them feel competent enough to use them in classroom. They also have some concerns regarding health issues of using AR/VR technologies, as well as students losing their concentration in class.**

Keywords - education, teaching, ICT, virtual reality, augmented reality

I. INTRODUCTION

While the virtual and augmented reality (VR/AR) are research topics which have been studied for decades now, recent introduction of novel devices affordable to a large section of customer market has again inspired significant research efforts in these areas. There are multiple definitions of what VR and AR are and what their relationship is. One of the commonly used states in which virtual reality places a user is a completely computer-generated environment, while AR aims to present computer-generated information that is directly registered to the physical environment. While in VR the user's whole field of view (FOV) is occupied by computer-generated content, this is not the case with AR – and according to [1], it needs to have the following characteristics: combination of real and virtual, interactivity in real time, and be registered in 3D. Currently, there are many Head Mounted Display (HMD) devices enabling VR on the market (e.g., Oculus Rift, HTC Vive, PlayStation VR, etc.) while there are only few AR HMD devices (e.g., Microsoft Hololens, Magic Leap). In general, the technology enabling high grade consumer applications in the AR segment is still on a lower level of development in comparison with VR. On the other hand, looking at future use, AR has a significant application advantage: the lack of Simulator Sickness (SS) which originates from elements of visual display and visuo-vestibular interaction and has symptoms similar to those of motion-induced sickness, but tends to be less severe [2]. Nevertheless, both VR and AR have significant possible applications in many areas, especially education.

There are many studies that showed advantages in using VR/AR in education. For instance, [3] in their review showed advantages of using AR in education such as: learning gains, motivation, and students' engagement in class. When it comes to VR, many studies showed improvements in students' academic performance [4][5], motivation [6][7], collaboration [8], and psychomotor and cognitive skills [9][10][11]. VR has been particularly praised as a great tool for students suffering from autistic specter disorder (ASD) [12] [13] [14] and AR has been used for rehabilitation of cognitively disabled children [15]. In [16] it is stated that virtual technologies encourage students to be active learners, because VR/AR promote decision-making when interacting with virtual environments, permitting autonomous exploration, understanding complex concepts, creating new experiences, and learning by doing.

During the past decades, teacher motivation has been studied in relation to student motivation and learning incomes [17] [18] [19]. Some researchers claim that teacher motivation is fundamental to the teaching and learning process [20]; thus, it is very important to investigate the opinions, attitudes and motivation of future ICT teachers when it comes to using new technologies in the classroom – that is the aim of this paper.

II. VR/AR IMPLICATIONS IN EDUCATION

The main motivation for using VR in education is that it gives students the opportunity to experience and experiment in situations that "cannot be physically accessed". In [21], some of the possible situations are as follows:

- Problems with time: travelling in time allows students to experiment with different historical periods; students can travel in time and VR technology allows them to experience different periods in history;
- Physical inaccessibility: e.g. students can explore the solar system by freely moving around planets and galaxies;

• Limitations due to dangerous situations: for example, students who are training to become firefighters can experience the situations in which the physical and psychological stresses are analogous to live firefighting situations.

Other benefits of using VR in education are described in [22] and [23]. VR provides new methods of visualization, and alternate methods for the presentation of learning materials. For example, VR can more precisely illustrate some features and processes by allowing extreme close-up examinations of objects, or observations from a great distance, or observations of areas and events that are not available by other means. For instance, students can study a molecule in great detail, go inside of it, walk around, and become familiar with its parts. As another example, students can explore VR models of their area which will give them a different perspective on the interconnections between buildings, streets, and open areas. Basically, VR allows students to learn by doing, a so-called constructivist approach. VR also grabs the attention of students and it genuinely motivates them. It encourages active participation of students and students find it exciting and challenging. They enjoy walking and interacting within 3D surroundings, as well as creating their own 3D environments. Some types of VR are collaborative and that encourages students to collaborate with each other, which creates a positive social atmosphere in the classroom. VR also allows students to experience new things in their own place and time, not a fixed time in class, and it is very beneficial for special needs students who cannot attend regular classes.

When it comes to AR and its implications in education, it is much more researched than VR. Systematic literature review was done in [24] and it described many benefits such as:

Constructivist learning – AR can be used in a way that encourages students to engage with subjects on a deeper level; that way students can make deeper and more lasting connections within their knowledge base.

Situated learning – AR can enable authentic and contextualized learning by implanting educational experiences through bringing the real-world situations into the classroom.

Games-based learning – AR can be used to enable immersive games-based learning by creating a digital narrative, placing students in certain roles, providing authentic resources and embedding contextually relevant information.

Enquiry-based learning – VR offers means to electronically gather data for future analysis and provides virtual, easily manipulated models located within a real-world context .

In conclusion, [16] elaborates on four main aspects regarding the advantages of using VR/AR technologies in education:

1. Using VR/AR in education can increase student motivation and engagement. Students have immersive experiences while studying 3D models that enhance their learning experience.
2. VR/AR allows for a constructivist approach to learning. Students can freely interact with virtual objects and other students as well. Consequently, students can examine, research, and obtain feedback, resulting in an experience that expands their learning.
3. VR/AR are becoming more affordable and accessible to masses. Recent technological advances have facilitated access to VR/AR with smartphones, tablets, and videogame devices. There is no more need for complex devices, and students can get an easy access to shared VR contents through common online platforms such as YouTube. Additionally, special needs students have easier access to virtual environments and are able to interact with virtual objects and other students.
4. VR/AR allow for more interaction than conventional learning materials. By using VR/AR, students feel more immersed when interacting with different learning concepts by using headsets, tactile gloves, and motion sensors. This special engagement permits students to experience situations with realistic objects that could not be accessed otherwise.

Several disadvantages of using VR/AR in education have been documented in [23] and they are primarily related to the cost and time necessary for learning how to use those new technologies. In [25] it was described that VR could be seen only as a game, something that is fun to play with, but there is a possibility it would not be taken as a serious tool in education and learning. Also, it has been reported that older teachers are sometimes reluctant to use new forms of education in classroom [25], while another research shows that older teachers actually have a positive attitude to new technologies [26] and there is no significant difference in teacher age when it comes to their attitudes towards using new technology [27] [28].

The question of possible health and safety effects are arising, especially with the usage of VR. The occurrence of SS is still not explained in full. In some segments of the population it may never occur while using VR, whereas others get the symptoms really fast. Movement patterns in virtual environment play a significant role in triggering SS symptoms in VR, and previous research showed that users prefer discrete movement methods (i.e., “teleporting” in virtual environment [29]. Also, many developers have opted, in creating applications, with very limited or no movement to limit the effects of SS. There are other safety concerns such as tripping, hitting objects and other people, which limits a broad range of usage cases for VR. Therefore, VR needs to be performed in a specialized and secured space. On the other hand, AR does not have such restrictions because users are at all times completely aware of their real environment. Therefore, AR has higher potential for use

in education in everyday activities as opposed to VR. Pupils can use an AR HMD, which would, for example, display details of DNA structure, while at the same time paying attention to their teachers, all without the presence of any health risks for themselves or their surroundings.

Like with all new technologies, all the issues mentioned could fade away as time goes by and VR/AR could become more commonly used in many areas inside and outside of education. It is very important to ensure that VR/AR technologies do not become a technological problem and it is imperative to encourage teachers to incorporate new technology in classroom.

III. METHODOLOGY

The aim of this paper was to investigate the opinions and attitudes of students about the use of VR/AR in teaching. The students who participated in the research are studying to become primary education teachers as well as ICT teachers in primary education schools.

An online questionnaire was distributed between 83 ICT module students (1st-5th year of study program) at the Faculty of Teacher Education, University of Zagreb. It consisted of 16 statements regarding the participant's opinions, attitudes and motivation on the use of VR/AR in education. Participants specified their level of agreement with each statement on a five-level Likert scale: 1 – Strongly disagree; 2 – Disagree; 3 – Neither agree nor disagree, 4 – Agree, and 5 – Strongly agree. The questionnaire also had 2 open questions where participants could freely express their thoughts on the use of VR/AR in education.

IV. RESULTS

The research showed that 65.1% of the students agree and strongly agree to being computer-literate but only 27.7% of them agree or strongly agree that they follow new technological developments in the field of ICT. Even though the majority of the students agree and strongly agree that it is important to use new technologies in classroom (Chart 1) and consequently the majority of them plan to use new technologies in classroom (Chart 2), only 21.7% of students agree and strongly agree that they are familiar with VR/AR applications for education (Chart 3). It is interesting to note that even students who consider themselves well IT-educated do not feel capable

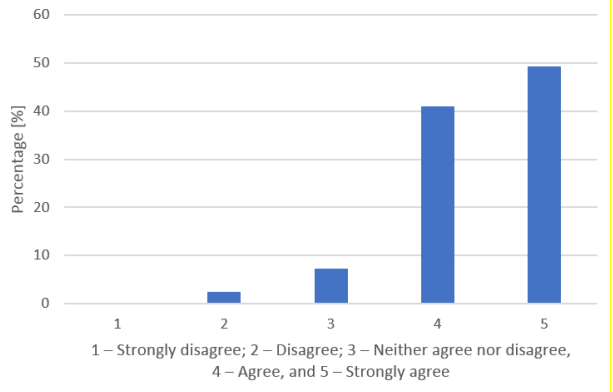

Chart 1 – The importance of using new technologies

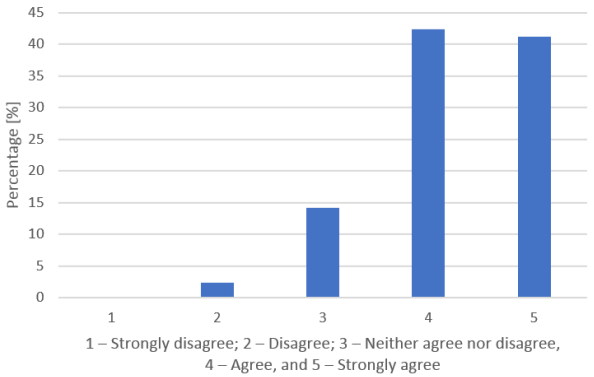

Chart 2 – Planning to use new technologies

of using VR/AR, indicating that these technologies can still be considered emerging. This is shown in Chart 4,where the scale of the bubbles indicates the number of occurrences of particular response). Regarding their motivation towards using AR/VR in classroom, 49.4% of students neither agree nor disagree that they will use this technology in their future teaching.

The students also feel that the use of AR/VR in teaching would allow pupils to visualize teaching materials more easily (69.9% agree and strongly agree) and that the use of AR and VR in teaching would make pupils learn better (66.3 % agree and strongly agree). They also agree and strongly agree (65.1%) that the use of AR and VR would facilitate a more active participation in class. However, they are also unsure about the possible negative aspects of using AR and VR in teaching. 38.9% of the students neither agree or disagree that the use of VR/AR would disrupt pupils' concentration, and 28.9% students agree or strongly agree that it would disrupt pupils' concentration. They also neither agree nor disagree (33.7%) that the use of VR/AR in class would prevent pupils' from paying attention to the teacher. The answers to negative perceptions for VR/AR are displayed in Chart 5, indicating that all have very similar distribution.

In the open question section of the questionnaire, the students had to list the school subjects they think would particularly benefit from the use of VR/AR in teaching and explain why. A lot of students mentioned that studying history would have many benefits; "traveling in time and seeing some things first-hand", "the pupils could easily experience historical battles first-hand",

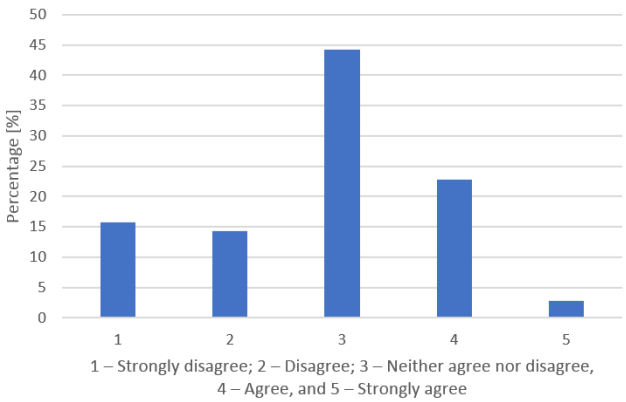

Chart 3 – Familiarity with VR/AR education applications

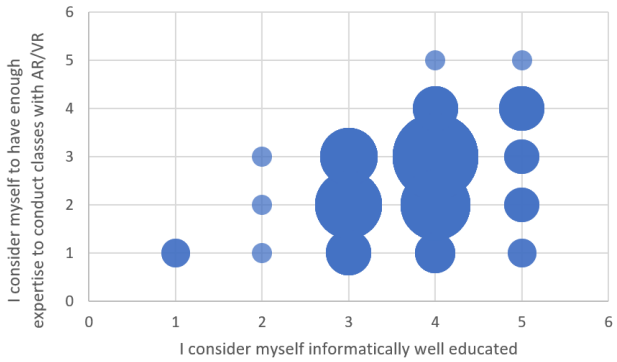

Chart 4 – Confidence of using VR/AR with regard to perception of IT-education

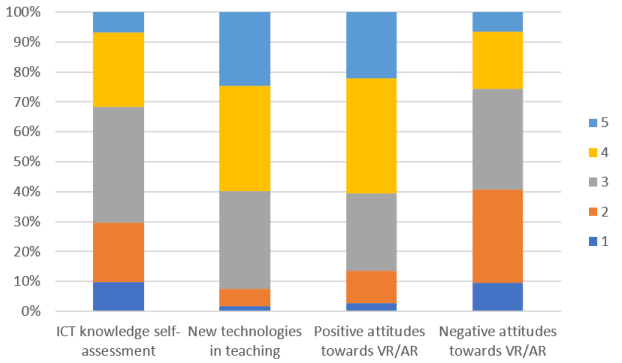

Chart 6 – Summary of responses per question group

"a lot of historical facts could be easily visualized instead of just learning them by heart", "pupils could see what the lost cities looked like, which would be interesting", "walking through the streets of ancient Egypt or Rome". The students also mentioned great potential in using VR/AR in teaching when it comes to natural sciences like biology and geography: "easier visualization of natural phenomena", "close representation of the human body", "experiencing different places and animals", "traveling around the world", "orientation in different places".

Other mentions include chemistry, physics and mathematics, since the students feel these subjects are abstract. VR/AR could bring pupils closer to the understanding of these subjects due to better visualization of learning materials. They also see the benefits of AR/VR in art studies, as well as language learning. Overall, they feel that VR/AR could bring school subjects closer to students and make the learning process more interesting and visually stimulating.

Another open question was regarding potential advantages and disadvantages of using VR/AR in education. Only a few students answered that they do not feel AR/VR should be used in teaching and that pupils should experience learning material "in the flesh" and not through the use of technology. Other students list benefits such as: "something new and exciting for both teachers and pupils", "it would make learning more interesting and interactive", "if used well, it could bring multi-directional communication in classroom", "immersive learning", "modern style of teaching for new generations", "easier memorization", and "more motivation". Overall, they feel that AR/VR technologies could bring many exciting things to classroom.

When it comes to disadvantages, students listed such things as: "it is not good for health, it is too artificial", "there is too much radiation while using VR/AR", "pupils could lose concentration", "children spend too much time looking at screens", "it is expensive and our schools are reluctant to use such new technologies", "teachers could matter less and less", "too different from old style teaching methods", "pupils could lose interest in paper books", "it could be bad for pupils' eyesight", "it would alienate pupils", "pupils could use it more for fun than learning". Many students stated their fears of children being too exposed to screens and new technologies, as well as fears of new technologies alienating pupils. Only a few of the students saw the benefits when it comes to collaboration in classroom. Some of the students wrote that they do not know how to answer the open questions because they were not familiar with VR/AR technologies and their applications in learning.

Finally, we have grouped all questions into four categories related to: *New technologies in teaching*, *ICT knowledge self-assessment*, *Negative attitudes towards VR/AR*, and *Positive attitudes towards VR/AR*. The final results per score in each category are displayed in Chart 6. The chart displays that, in general, the students agree more with positive attitudes towards VR/AR and lean towards using new technologies in teaching. In much lesser extent, the students agree with negative attitudes towards VR/AR, which is very promising for the evolution of teaching in Croatia in regards to the use of new immersive technologies.

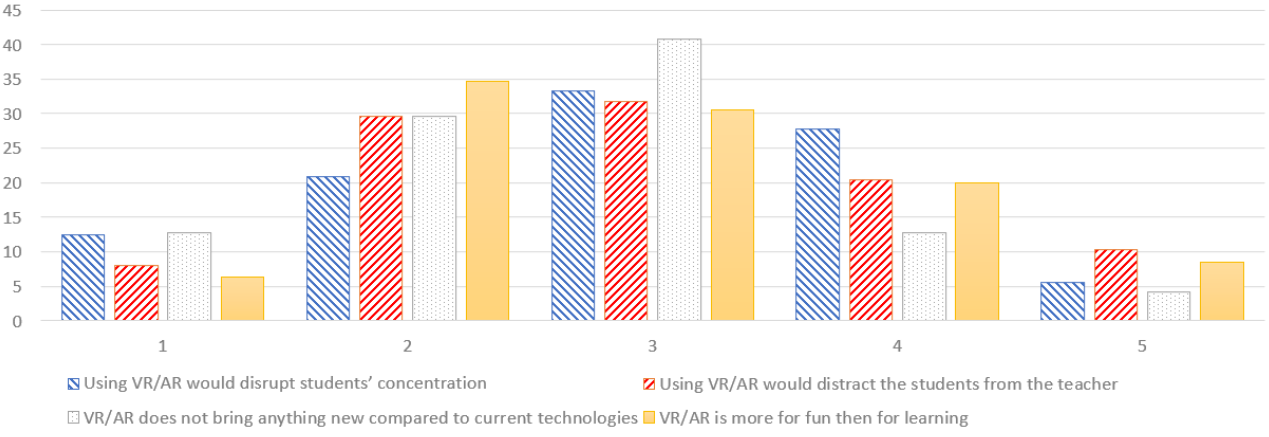

Chart 5 – Distribution of negative responses towards VR/AR

V. DISCUSSION

The research showed that students overall have positive attitudes towards VR/AR in teaching. They believe that using VR/AR in education will help pupils to better visualize teaching materials and that it will help them to learn better. This result is in line with the findings reported in [16][22][23]. In the open question section of the questionnaire, they listed benefits like immersion, better memorization, motivation and feeling like they are in the "real world" as it was described in [24] and time traveling as it was shown in [21]. To sum up: the students recognized many benefits of using VR/AR; these benefits are described in literature, which means that they are familiar with the general benefits of VR/AR for teaching, although the technologies are quite new, and majority of students do not follow new technological developments in ICT-sector?

It is important to state that even though students mentioned many benefits of using VR/AR in teaching, when it comes to disadvantages, they listed a significant number of them. Most of their concerns were about VR/AR being generally used for playing games, not for learning. This problem was also described in [25]. Such concerns could be alleviated by including new technologies in the education process of young teachers and showcasing educational non-gaming usage scenarios. They also fear that VR/AR would disrupt pupils' concentration, and that they would not pay attention to the teacher. It also seems that the students feel the traditional form of teaching methods is still prevalent in primary education schools in Croatia; therefore, they believe that using new technologies could be too different. While this attitude of young teachers is not surprising because of the limited use of technologies in teaching process in Croatian schools, we believe that this issue will be resolved in time, especially with a large project named "e-Schools: Establishment of the system for the development of digitally mature schools" [1] working to bring new technologies into Croatian education system.

Even though research showed that VR/AR have great benefits in work with special needs children [12][13][14][15], none of the students mentioned that fact. They also did not seem to understand that VR/AR could be collaborative technologies [23] and they felt that this would alienate pupils. All of this could be due to the fact that only 27.7% of the students follow new technological developments in ICT, so it is understandable that only 21.7% of them have knowledge about VR/AR technologies and only 14.4% of them feel adequate to teach with VR/AR. Even though the majority of students think it is important to use new technologies in teaching, as was shown in Charts 1 and 2, and although they plan to use them, it seems that they are reluctant to do so when it comes to using VR/AR technologies. They also mentioned many health issues arising from the use of VR/AR, but many of the issues they mentioned could not be found in current literature and belong in the category of widely spread misconceptions regarding technology in general. Therefore, we emphasize again the importance of introducing these new technologies in the process of education of teachers themselves. This process would solve the issue of many misconceptions the students currently have towards VR/AR technologies. In conclusion, as shown in Chart 6, the students agree more with positive attitudes towards VR/AR and lean towards using new technologies in classroom, which is very promising for the evolution of teaching in Croatia in regard to using new immersive technologies.

[1] https://www.e-skole.hr/

VI. CONCLUSION

In this paper, a survey was presented comprising attitudes and opinions of future ICT teachers, students of the Faculty of Teacher Education, University of Zagreb, towards AR/VR technologies as tools in the education process. The results show that while the majority of the students have positive expectations of these new technologies, there is still a significant number of misconceptions present amongst them, especially towards health effects of AR/VR. This is probably due to the fact that only a fraction of students are familiar with VR/AR technologies and how to use them in classroom. We believe it is important to educate future teachers about new technologies and how to use them without fear and restraint, because they can be powerful tools in the teaching process. In our future work we aim to identify the factors which impact the positive attitudes towards AR/VR, so they could be used to increase motivation for using new technologies among future ICT teachers.

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Teaching the physics behind a 3D cinema through experiments supported by ICT

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***Abstract* - In teaching physics, it is always a challenge to present three-dimensional (3D) objects graphically. The use of ICT can help in this respect. We report on how ICT enables a demonstration of how a 3D projection works by using 3D polarizing glasses and polarized light. The effect is well known because it is used in 3D cinemas and as such it is attractive for high school students. We prepared a workshop for high school students interested and talented in Physics to explain how linear and circular polarizing glasses for a 3D cinema work. We developed a set of experiments, supported by our computer animations and simulations to visualize complex physical effects involved. The workshop was held in January 2019. First, we orally assessed the knowledge that the attendees gained through the primary school and the first years of high school. Our assumption that their knowledge about polarization of light is inadequate was confirmed. After the workshop, we assessed the newly acquired knowledge by a written test. The assignments were set on different levels of the Revised Bloom's Taxonomy. Preliminary results, reported in this paper, show that ICT support significantly increases the level of knowledge achieved.**

Keywords - 3D cinema; polarization glasses; polarization of light; ICT; computer animation; Revised Bloom's Taxonomy

I. INTRODUCTION

After years of teaching natural sciences, teaching can become tough for a teacher that is limited by the national curriculum and does not have an innovative approach in teaching. That is why teachers are bound to enhance the theoretical lessons with experiments to motivate the students and to make them understand physics better. In general, demonstrations of the macroscopic effects are easy to realize. Another way to demonstrate an effect is by drawing schematics by hand on the blackboard, by using analogies with other effects that are familiar to students or by using ICT. The use of ICT can change the approach in teaching natural sciences in many ways. By using simulations we are not limited to one perspective only or two dimensions as it is in figures. In addition, students can easily be involved in interactive simulations or/and applications. They can alter the input parameters or the construction of the model to see how the outcome changes [1,2]. We can also teach a certain topic with the use of an appropriate popular software such as computer games [3]. On the other hand, students do not benefit from the educational software only, the use of hardware is also crucial [4-7].

There have been many studies on how much students benefit from learning a new topics with the support of the ICT. It has been confirmed that the ICT support should be used not only at lectures but also in the lab work and tutorials [8,9].

In this paper, we report on a construction of a workshop, the goal of which was to teach students the physics behind a 3D cinema. A major part of the workshop consisted of experiments, demonstrating, how polarizing glasses for a 3D cinema work. Demonstrations were supported by computer animations and simulations. An explanation on how 3D cinema works can be found in several papers, animations and video materials [10-15]. Although these sources use circular polarization, they do not discuss the physics on how circularly polarized light is obtained. We decided to explain how circularly polarized light is obtained by propagation through anisotropic material. To support this explanation, we used and modified the animation Emanim [16], for which the author offers free use on the web and also allows the user to modify the computer code.

The paper is structured as follows. In Sect. II we review the basic physics required to understand how 3D cinema works: stereo vision, wave properties of light, types of polarization of light, linear polarizers and propagation of light through anisotropic materials. Then we describe the construction of the workshop with an emphasis on the experiments, creation of animations and research methods for analyzing the results (Sect. III). The results of the workshop are analyzed and discussed in Sect. IV and the ideas for further research are given in Sect. V.

II. HOW DOES A 3D CINEMA WORK?

To understand, why animations and simulations were required to explain how polarizing glasses for a 3D cinema work, let us briefly consider the concepts required for the explanation.

A. Stereo vision

Firstly, we need to explain that we are able to see in three dimensions, because we have two eyes. The process of combining two slightly shifted pictures of the same surrounding into a 3D picture is called stereo vision and is

widely used in the world of technology. For humans, a 3D vision was an important tool of survival since prehistoric times. It enabled us to estimate the distance to both our predators and prey and to aim well to either gather food or keep us alive.

Thus, to describe how 3D glasses work, the first important concept is the viewing angle. It is given by the angle between two rays of light being scattered into our eyes from the same point of the object (Figure 1(a)).

In 3D cinema, the challenge is to create a 3D picture by projecting pictures on a cinema screen, where each picture element is equally distant from us. The solution is to project on the screen two slightly shifted pictures of the same object. If light from one of the pictures enters into one eye and from the other picture into the other eye, we will see the picture of the object somewhere in front of the screen (see Figure 1(b)). The essential question is, how to make light from only one of the pictures enter only one eye. To explain this one has to consider the wave properties of light.

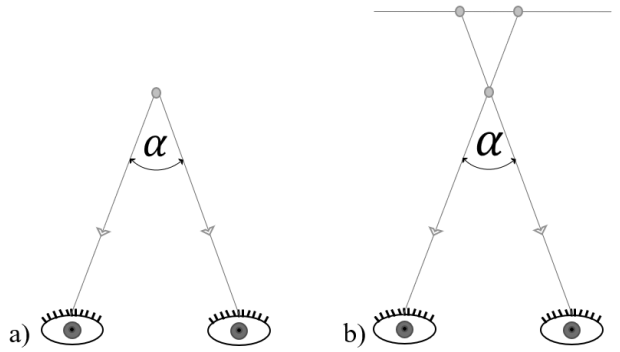

Figure 1. a) The viewing angle α. b) Two slightly shifted figures on the screen will give a feeling of the object to be in front of the screen if light from only one picture enters one eye.

B. Wave properties of light

Within a uniform and isotropic medium, light propagates in straight lines. The propagation direction is presented by a ray. When light is incident on an interface between two media, it reflects and refracts. The ray model of light suffices to describe the basic properties of reflection and refraction, but to derive the laws of reflection and refraction we already need to consider the wave properties of light. Light is a transverse elecromagnetic wave in which the electric and magnetic field oscillate in space and time in the plane perpendicular to the propagation direction.

C. Polarization of light and polarizers

For us, an essential property of light is the plane in which the electric field oscillates. This plane is called the polarization plane. If the plane is constant, light is linearly polarized. If the plane rotates, i.e. the tip of the electric field vector follows the circumference of an ellipse, light is elliptically polarized. A special example of the elliptically polarized light is circularly polarized light.

Let us observe an electromagnetic wave that propagates in a certain direction, which we define as the *z* axis. The electric field oscillates in the *xy* plane, i.e. in the plane perpendicular to the propagation direction. The electric field direction can be given by two mutually perpendicular components along, for example, horizontal (*x*) and vertical (*y*) axes, the components having amplitudes E_{0x} and E_{0y}, respectively. In general, there is a phase shift between these components. If the phase shift is constant, light is polarized, if it changes randomly with time, it is unpolarized.

In general, electromagnetic waves emitted by different light sources, such as for example the sun, are unpolarized, which means that the polarization direction changes randomly in time and space. Polarizers are optical elements, which transform unpolarized light to polarized light. A polarizer that transmits only a certain component of the electric field is called a linear polarizer. The component of the transmitted electric field is defined by the transmission direction of the polarizer. The component of the electric field in the direction perpendicular to the transmission direction is absorbed in the polarizer (Figure 2).

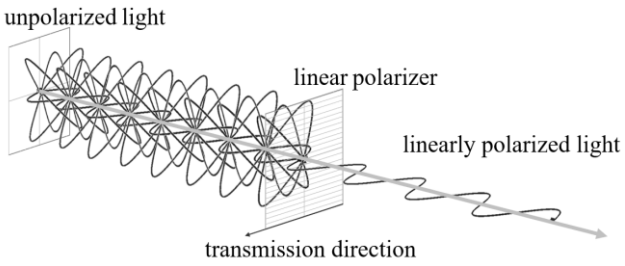

Figure 2. Propagation of unpolarized electromagnetic waves through a linear polarizer. Electromagnetic waves that oscillate parallel to the transmission direction of the linear polarizer are transmitted.

If the phase difference between the *x* and *y* components of the electric field are constant, the magnitude of the phase difference defines the type of the polarization of light. For example, if the phase difference equals a multiple of π, light is linearly polarized. For further use, we will distinguish between the horizontally, vertically and diagonally linearly polarized light. If the magnitudes of the components are equal and the phase shift is ±π/2, light is left or right circularly polarized. Different types of polarizations are shown in Figure 3.

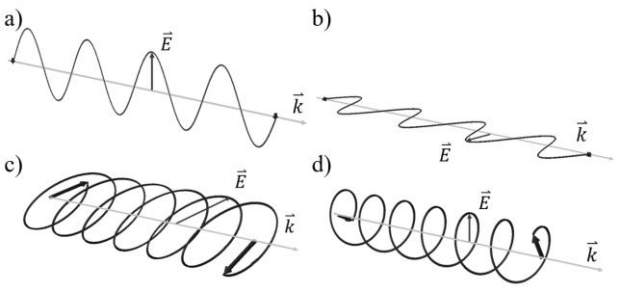

Figure 3. a) Vertically and b) horizontally linearly polarized light. c) elliptically and d) circularly polarized light. Light propagates in the direction denoted by the wave vector $\vec{k}$; $\vec{E}$ is the electric field vector.

D. 3D Cinema with linearly polarized light

At this stage we can already explain the simplest realization of a 3D cinema. To obtain two slightly shifted pictures on the screen we use two projectors. There is a linear polarizer in front of each projector and the transmission directions of the two polarizers are perpendicular to each other (Figure 4). The movie screen has to be silver coated, so that the polarization of the horizontally or vertically polarized light is not changed upon reflection [14,17].

The polarizing 3D glasses filter out only one picture for each eye and our brain joins them together into a 3D picture as shown in Figure 1(b).

The issue with the 3D glasses that use linear polarizers lies in the fact, that the polarization directions of the incident light (light reflected from the screen) must completely align with the transmission directions of the polarizers in 3D glasses. If not, each polarizer will transmit light from both pictures. Any leaning of our head thus reduces the viewing quality and that is why linearly polarized 3D glasses are not used in 3D cinemas any more. To solve this problem, we have to use circularly polarized light. As already mentioned, in circularly polarized light the tip of the electric field vector orbits around the propagation direction. The magnitudes of the x and y components of the electric field are equal and there is a phase shift of $\pm\pi/2$ between the two components, so when one component is maximal the other one is zero. Circularly polarized light can be obtained if initially linearly polarized light propagates through an optically anisotropic material of a proper thickness [17]. Thus, next we have to explain how light propagates through anisotropic materials.

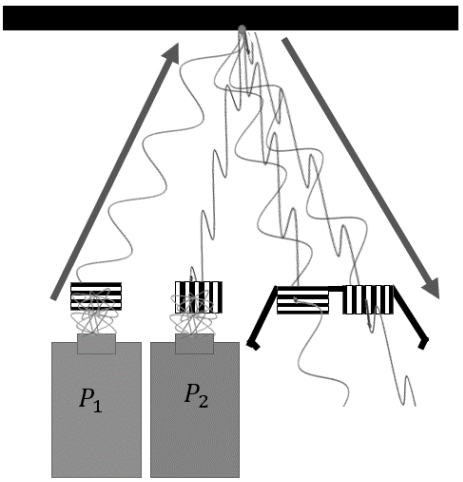

Figure 4. Construction of a 3D movie projection with two projectors P_1 and P_2 with linear polarizers, a silver coated projecting screen and linear polarizing glasses.

E. Optically anisotropic materials

Anisotropic material are materials which have different physical properties in different direction. In optically anisotropic materials, the index of refraction depends on the direction of light propagation and on polarization of light. There are only two waves that can propagate through an optically anisotropic material in a given direction [17]. If their polarizations are linear and mutually perpendicular, such a material is called linearly birefringent.

In optically uniaxial materials there is one direction of propagation of light for which the material behaves as being isotropic. This direction is called the optic axis.

To explain how circular polarized glasses work, we have to consider light propagation through an anisotropic material in the direction perpendicular to the optic axis. If the incident light is diagonally polarized, there are two waves propagating through the anisotropic material: one is polarized in the direction of the optic axis and the other one perpendicular to this direction (Figure 5). These two waves experience different indices of refraction and as a result, upon exiting the anisotropic material they are phase shifted. The thickness of the anisotropic material is chosen such that the phase difference is $\pm\pi/2$. The sign of the phase difference depends on the orientation of the optic axis (for example, it can be in the vertical or horizontal direction) and on which wave, the one polarized along the optic axis or the one polarized perpendicular to it, is slower. The two waves combine when exiting the anisotropic material and as a result the transmitted wave is circularly polarized. A piece of an anisotropic material which, under the above stated conditions transforms linearly polarized light to circularly polarized, is called a quarter-wave retarder plate.

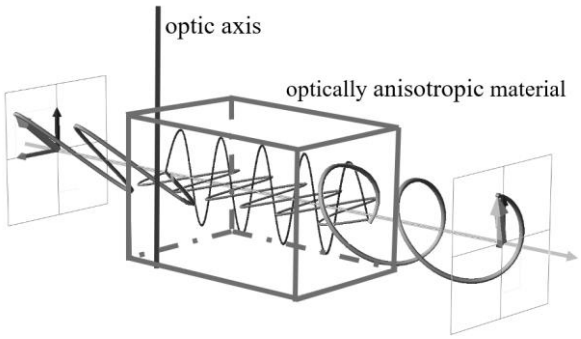

Figure 5. A linearly polarized incident light splits into two linearly polarized waves that can propagate through an optically anisotropic material. The exiting light is elliptically polarized.

F. 3D Cinema with circularly polarized light

Circular polarizing glasses for a 3D cinema consist of a linear polarizer on the side next to the eyes and an anisotropic material on the outer side of the glasses. The transmission directions of polarizers are parallel to each other, while the optic axes of the anisotropic material are perpendicular to each other, but in front of both eyes the optic axis is at an angle 45° with respect to the transmission direction of the linear polarizers (Figure 6). When circularly polarized light reflected from one picture on the screen propagates through the retarders in the glasses, the additional phase shift of $\pi/2$ is introduced, so the total phase shift between the electric field components is either π or $-\pi$. In both cases the exiting light is again diagonally linearly polarized, but in front of one eye in the

transmission direction of the linear polarizer and in front of the other in the direction perpendicular to the polarizer transmission axis (Figure 6). So only one side of glasses will transmit light, depending on the handedness of the circularly polarized light reflected from the screen.

In case of circular polarizing glasses we are free to move the head because the electric field direction rotates and on average the magnitude of the component along the optic axis and perpendicular to it does not depend on the rotation of our head.

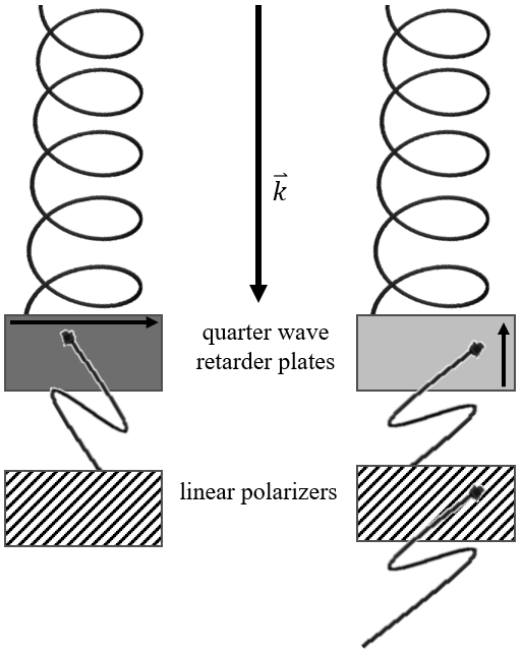

Figure 6. Circularly polarized light incident on the quarter wave retarder plates is transformed to diagonally linearly polarized light. Depending on the orientation of the optic axis (denoted by an arrow on the retarder plates) in the quarter-wave retarder, the direction of the diagonally polarized light coincides with the transmission direction of the linear polarizer or is perpendicular to it. Light propagates in the direction denoted by the wave vector $\vec{k}$.

III. THE RESEARCH PROCESS

The research consisted of three major parts: the preparation of experiments needed for the workshop, planning of the workshop and the selection of the research methods for testing the efficiency of the workshop.

A. Preparation of the workshop

Before we could perform the workshop, we needed a collection of experiments and computer animations. We have looked through various literature, to find suitable experiments or at least an inspiration for them. There is an extensive research on testing the knowledge of students at different stages of education on light polarization and the understanding of optically anisotropic materials [18-27]. This research helped us in choosing the experiments, but we also wanted to support them by computer animations and simulations, since the complex physics behind the phenomena is not visible with our bare eyes.

B. Experiments

The following experiments were chosen to make the workshop more dynamic.

Stereo vision

- Students choose an object, which they cover with a thumb having one eye closed. Then they switch the closed eye. If the thumb and the object remain in the same place, they notice that the object is visible again.
- Students try to catch ping-pong balls with one eye closed.
- Students try to connect two fingers, one from each hand, having one eye closed.

Polarization of light

- Students look through two linear polarizers by changing the angle between the transmission axes.
- Students observe linearly polarized light (e.g. a computer screen) and unpolarized light (e.g. sunlight) through a linear polarizer by rotating its transmission axis.
- Students look at polarization glasses through a linear polarizer by rotating its transmission axis. They observe the difference between the linear and circular 3D glasses and notice the importance of the orientation of the circular 3D glasses (retarder plate or linear polarizer next to the linear polarizer used for analysis).

Optical anisotropy

- Anisotropic materials (transparent rulers, CD covers, florist foil, scotch tape on a glass plate…) are observed between crossed polarizers.
- Unpolarized laser beam splits into two linearly polarized beams upon propagation through a wedge cell filled with a nematic liquid crystal.
- When a text is viewed through a calcite, double text is observed. By a linear polarizer it is checked that the light from each figure is linearly polarized, the two polarizations being mutually perpendicular.
- Three phases (crystal, liquid crystalline and isotropic liquid) of a nematic liquid crystal are shown, by changing the temperature of a sample.

Polarizing glasses for 3D cinema

- Students observe themselves in a mirror, wearing linear or circular 3D glasses. They have one eye closed and observe, which eye they see in the mirror – the opened or the closed one.

C. Animations and simulations

Our animations are available online [28]. The following animations were prepared:

- Dependence of the viewing angle on the distance from the object.

- Different types of polarization of light.
- Propagation of light through anisotropic materials.
- Explanation of why we see the opened eye when looking in the mirror wearing 3D glasses with linear polarizers.
- Explanation of why we see the closed eye when looking in the mirror wearing 3D glasses with circular polarizers.

The viewing angle animation was coded in C# and visualized through a Windows Presentation Foundation client application in Microsoft Visual studio.

To prepare the rest of animations we used an application, which simulates different polarized electromagnetic waves and propagation of waves through optically anisotropic material [16]. The application is opensource. We have modified the source code, written in Python. The simulation was captured by a software for screen capture [29], which enables to create gif files that can be looped. The advantage of this procedure is to keep the file size within reasonable limits. To combine several animations into a new animation, we have used a video editor [30], which is also free to use. The whole project was then exported as a gif file and used in the presentation to visually support the explanation and the experiments.

D. The workshop

The structure of the workshop was as follows (in general, already given by the titles of section II):

- stereo vision,
- how to achieve 3D vision by two shifted pictures on the screen,
- light as an electromagnetic wave and polarization of light,
- linear polarizers,
- how does a 3D cinema with 3D glasses with linear polarizers work,
- optically anisotropic materials,
- how to obtain circularly polarized light,
- how do circularly polarized glasses for 3D cinema work.

We started by a motivation experiment [20]. Each student had a mirror and a pair of polarizing glasses for 3D cinema. They looked at themselves in the mirror with one eye shut. With linearly polarized glasses they saw the opened eye and with circularly polarizing glasses the closed one (Figure 7). This caught their attention and we could continue with the theoretical explanation.

Firstly, we explained the stereo vision. We asked them to cover objects with thumbs with one eye opened and then switch the closed one, to catch ping-pong balls with only one eye opened and to try to put two fingers together with only one eye opened. Then we showed the animation on the dependence of the viewing angle on the distance from the object. Finally, we explained that a 3D effect can be obtained if we project two slightly shifted pictures to the screen and then achieve that light from only one picture enters one eye (Figure 1(b)).

Next, we presented light as an electromagnetic wave and introduced the concept of polarization of light. Computer animations were used again to visually support the explanation. We explained how linear polarization is obtained by propagation of light through a linear polarizer. Each student had a pair of polarizers. They studied qualitatively the light transmitted through a pair of polarizers as a function of the angle between the transmission axes. Then we asked them to take one polarizer and rotate it in front of the 3D glasses and in front of the notebook screen. Now we were able to explain how a 3D projection with linearly polarized glasses work (figure 4) and why we see the opened eye when looking in the mirror wearing glasses with linear polarizers (see animation available at [28]).



Figure 7. Reflection of light on a mirror and linear (left) or circular (right) polarizing glasses for 3D cinema.

Next, we explained the problem with a 3D projection with linearly polarized light and moved on to circular polarization. First, we discussed anisotropic materials, like wood. Then we asked them to view different anisotropic materials between crossed polarizers, so they could see that these materials have different optical properties than the isotropic air. The colored patterns that they observed really caught their attention. Then we presented the major property of an optically anisotropic material, birefringence. We used a wedge cell filled with a liquid crystal and students studied the polarization properties of the two transmitted beams to see that they are linearly polarized. They observed a text through a double refractive crystal (calcite) and saw two slightly shifted images. By using a linear polarizer they could choose only one, which again confirmed that the exiting light is linearly polarized. We also showed them different phases of a liquid crystalline material, synthesized in our lab (for the instructions see [27]). Finally, we explained, how circularly polarized light is obtained if light propagates through an anisotropic material in such a way, that the two linearly polarized beams, that can propagate through anisotropic material, do not split and are only phase shifted upon the transmission (Figure 5). Then we moved on to the explanation of how a 3D projection with circularly polarized light works (Figure 6) and why they see the closed eye if they look in a mirror wearing glasses with circular polarizers.

E. The research method

As a research method we chose a case study [31]. The goal was to test the conceptual understanding gained by the students.

After the workshop, we asked students to complete a written test, including 12 tasks, which were prepared following the revised Bloom taxonomy [32]. The tasks tested the knowledge obtained with or without the support of ICT. Each task was assigned the category/level of the revised Bloom taxonomy. We have joined the categories into three groups: A (1st and 2nd level), B (3rd and 4th level) and C (5th and 6th level). Since there were only few questions from group C, we report the results only for the first two groups. Out of 12 questions, only 3 were testing the knowledge obtained without the support of ICT. 9 tasks were from group A and 3 from group B, with subtasks testing the categories in group C.

IV. Results and Discussion

12 high school students, highly interested and talented in Physics, took part in the workshop. We have marked their success rate in every task and then calculated the average percentage achieved at tasks from groups A and B.

On average, 79 % of students have successfully solved those tasks from group A where the explanations during the workshop were supported by ICT and only 65 % have successfully solved those tasks from group A that were not supported by ICT. 76 % of students have solved those tasks from group B that were supported by ICT and 56 % have solved those tasks from group B that were not supported by ICT. The results are shown in Figure 8.

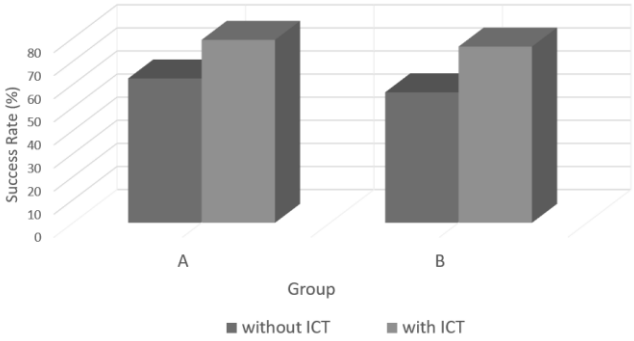

Figure 8. The success rate in solving the tasks in the written test after the workshop, for group A (the first two levels in the revised Bloom taxonomy) and B (the third and the fourth level).

A. Difference between the tasks with or without the support of ICT

The success rate of the students solving the tasks properly was 15 - 20 % higher for the topics that were explained also by the support of the ICT. This shows that an additional visual representation with computer animations and simulations can help students to understand the topic better. But we have to keep in mind that we were working with a very interested and talented group of students. Also, the number of students was low, so even though we have quantitatively assessed the tasks, we have used a qualitative approach [31] in the assessment: we tried to figure out, what students had in mind even though the answer were not fully correct. We thus estimate the error in the achieved success to be ±5 %, but even assuming this error, the success rate in solving the tasks where the explanation at the workshop was supported by ICT is significantly higher compared to the tasks not supported by ICT.

B. Difference between the groups A and B

There is no significant difference in the success rate between the two groups of questions. We can conclude that students were able to reach the first four levels of the revised Bloom taxonomy with a minimum average of 56 % for the tasks not supported by ICT and 76 % for the tasks supported by ICT.

C. Analysis of answers

We have to point out that we cannot assume that ICT is the only way to get a higher success rate in understanding a topic. The explanation accompanying animations and experiments is crucial. During the analysis we have noticed that there was a task, where the success rate was 0 %. Students had to draw the propagation of an electromagnetic wave through an optical anisotropic material, where they had to divide the linearly polarized electromagnetic wave into two linearly polarized waves that can propagate through an anisotropic material. None of the students knew what to do. Probably, we did not give enough emphasis on the animation when we went through that part of the topic in the workshop or that the instructions were not clear enough. Another task was about drawing the electromagnetic waves transmitted through a linear polarizer. During the workshop, we explained how long polymer molecules are arranged in the polarizer and that the component of electric field along the long molecular axes is absorbed. That might have confused them as some of them drew the transmitted electromagnetic waves with the electric field perpendicular on the transmission axis of the linear polarizer. There are also other important circumstances that play a role in the success rate. The workshop was held in late afternoon, right after lunch, which might have had an impact on their concentration. In addition, students were not informed in advance about solving the test after the workshop.

V. Conclusions

Teaching of physics and natural sciences in general should include a variety of methods, the support of ICT being one of them. We used the ICT support to explain the physics behind a 3D cinema. The preliminary results show that an additional visual representation with computer animations and simulations helps students to understand the topic better. However, we were working with a small and very interested and talented group of students. More tests should be performed and a larger audience included to have a better insight in the effectiveness of the ICT support in teaching this topic. In case of performing additional surveys, we intend to include larger number of respondents to ensure greater reliability of the results. It would be interesting to perform a workshop in a standard high school class, with a variety of students of different interests. The test should also consist of more tasks of the

higher categories of the revised Bloom taxonomy to fully test students' understanding on all levels. In addition, in further research we will dedicate particular attention to the customizing of the test question`s level to the knowledge that is adopted during the experiment implementation.

ACKNOWLEDGMENT

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Competence-based Curriculum Development for Business Informatics

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***Abstract* - This paper presents the theoretical and methodological approach used in the development of a business informatics study programme, in the field of social science. The paper advances the theoretical perspectives of a competency-based curriculum, as steps taken toward innovative curriculum development efforts, with further focus on the developed theoretical framework used in the analysis and design of a competency-based curriculum for a business informatics study programme. This theoretical framework was based on several guides and case studies on competency-based programme planning and curriculum development. Identified digital competencies served as a basis for determining the content of the courses in business informatics study programme that would meet the primary objective and be relevant in the light of digital transformation of business.**

Keywords - digital competences; curriculum development; business informatics;

I. INTRODUCTION

Rapid technological development over the last decades, with information and communication technology (ICT) and digital technologies as leading causes of change, has left universities facing numerous challenges. Innovation and modernisation of education and training has been recognized as one of the key priorities of the Europe 2020 strategy, specifically in the Agenda for New Skills and Jobs, the Digital Agenda, etc. Higher education institutions are, more than ever, compelled to continuously transform their study programmes at all academic levels (undergraduate, master's and PhD).

Major developments in the labour market are caused, above all, by the development in ICT [1]. Employers are in demand of an increasing number of qualified and highly specialized ICT professionals, proficient in cloud computing, mobile technologies, handling massive amount of data, social media, intelligent technologies (machine learning, internet of things, blockchain, big data, data intelligence) and software of all sorts. Advances in ICT and practical application of novel technologies has changed the way business operate, at the same time creating demand for ICT-skilled workforce [2], [3].

OECD [2] divides new skills with rising demand into three groups: (1) Specialist ICT skills, such as programming, application development and network management; (2) Generic ICT skills for applying new technology in business; (3) Complementary skills in performing new tasks related to application of ICT in business. The demand for generic ICT skills has been on the rise in a clear majority of countries over the last decade [2].

It is also evident that more occupations, not characterized as ICT specialist occupations, are becoming more ICT-intensive. According to a research by OECD [2], 18 out of 20 ICT-intensive occupations are not among those performed by ICT specialists.

There is an overwhelming sense among the general public that investments in digital technology, with their potential for increasing productivity, may lead to a loss of jobs. However, it is known that digitalization provides possibilities for new jobs as well [4], [5]. In many organizations implementing ICTs, a majority of their employees using these technologies on a daily basis do not possess adequate ICT skill to utilize them to their full potential. This witnesses to a vast unbalance between the supply and demand for generic ICT skills [2]. Individuals are not only under an increasing pressure to process complex information, think systematically, and make decisions burdened by a multitude of information, but also to constantly update their skills as to respond to rapid changes in technology [2].

This is why it is important to emphasize promotion of strong level of skills, digital literacy, capability for abstract thinking, as well as social and emotional skills, which should be referenced in skill-building systems, including formal and informal education [2]. A skill-building system must be agile in order to promptly adapt to the need for new skills [2]. University-industry partnership can serve as a catalyst for generation of required skills, through purposeful joint development of study programme that are optimal in terms of industry's needs [6].

This paper consists of four sections. The introductory considerations, with a brief overview of the importance of the multiplying digital competences that graduates in the domain of social science must possess in order to perform their jobs. This necessitates development of innovative study programmes incorporating a greater number of relevant digital competencies. Such settings triggered the development of the new business informatics study programme. The second section is a brief overview of the concept of competencies, and specifically, digital competencies, i.e. various digital competencies frameworks. Frameworks referenced in this paper were used in the process of identification and selection of digital competencies to be included in the business informatics study programme. The third section is devoted to an overview of process and activities for developing a

competency-based curriculum. The fourth section presents the theoretical and methodological bases chosen for the development of the business informatics study programme, as well as the general structure of the undergraduate study programme. The final section contains conclusions, which highlight the significance of digital competencies in the innovated business informatics study programme, as well as the prospects for graduates' employment.

II. DIGITAL COMPETENCIES AND DIGITAL COMPETENCE FRAMEWORKS

Competencies were introduced as a concept in education during the last two decades, primarily owing to the growing pressure for conforming to the rapidly evolving requirements of the labour market. A competency-based approach to education, embraced mostly by higher education institutions, developed as a response to such circumstances. This approach placed the primary focus of planning, realisation and evaluation of education systems on the desired learning outcomes.

There are numerous definitions of competences available. No definitive consensus on the definition of this notion has been established among researchers, with debates on the difference between the term 'competence' and 'competency' are persisting to this day. Within the scope of this paper, the term "competence" was used in line with the definition by the Bulgarian Industrial Association, namely as "a set of knowledge, skills, attitudes and behaviours used to achieve results (performance levels) in a certain professional role or in a particular organization" [7].

There are various types of competences, corresponding to different requirements. The most commonly quoted groups of competencies include:

- Behavioural (life skills) competencies–a set of human skills used in handling problems and questions commonly encountered in daily human life. They are acquired through education or direct experience.
- Functional (technical) competencies–related to particular functions, processes, and roles within an organisation and include the knowledge of and skill in the exercise of practices required for successful accomplishment of a specific job or task.
- Professional competencies–competencies that facilitate success in an organisational context. They are the accelerators of performance, or the lack of thereof is the reason people fail to excel in their jobs.

In addition to the former division, some organizations divide competencies in accordance to the criteria of their perceived significance: core competencies, key competencies and critical competencies.

A core competency can be defined as a set of appropriate competencies needed to accomplish a key occupational task at a satisfactory or superior level. In other words, core competencies are directly linked to key occupational tasks and represent an integral part of domain-specific and generic competencies.

Domain-specific competencies are related to clusters of knowledge, skills and attitudes associated with a specific content domain within a profession. Generic competencies are called 'generic' because they are needed in all content domains and can be utilised in new professional situations (transfer). The term 'life skills' is sometimes used for the latter group, which indicates that these competencies represent a set of capabilities essential for today's life, both within and outside the profession [8].

Although being a relatively novel concept, digital competencies are indispensable in the 21st century. There is an apparent upsurge in demand for employees possessing digital competences [9], which is reflected in their income [10]. Digital competencies refer to skills required for utilization of digital technology in a specific content [11]. They have not only become essential for work and learning, but also for active participation in the society. Over the last few years, the term 'competency' has gained in popularity, compared to the term 'skill', reflecting the need for a wider and more profound content of the concepts. The relation between competence and skills is defined in an OECD project as follows: "A competency is more than just knowledge and skills. It involves the ability to meet complex demands, by drawing on and mobilizing psychosocial resources (including skills and attitudes) in a particular context" [12].

In the widest sense, based on policy-related papers and reports, digital competence consists not only of digital skills but also social and emotional aspects for using and understanding digital devices [13]. According to Punie & Cabrera [14], The European Commission recognizes digital competence as a "key competence" that individuals need to acquire for personal development, active citizenship, social inclusion and employment [14]. Digital competence is grounded on basic skills in ICT, i.e. the use of computers to retrieve, assess, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet [13]. Digital competencies involve not only the competencies necessary to use ICT, but also to master and understand them, for example, understanding of how ICT applications and services function [15].

Ilomäki, Paavola, Lakkala, & Kantosalo [16] highlight that it is unlikely that a definite unique definition of digital competence to emerge, due to rapid developments within the society and existence of different points of view. One of the most used definitions defines digital competencies as a „set of knowledge, skills, attitudes (thus including abilities, strategies, values and awareness) that are required when using ICT and digital media to perform tasks; solve problems; communicate; manage information; collaborate; create and share content; and build knowledge effectively, efficiently, appropriately, critically, creatively, autonomously, flexibly, ethically, reflectively for work, leisure, participation, learning, socialising, consuming, and empowerment [15, p. 43]". The same author [15] stresses that the concept of digital competency represents

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a constantly moving target, covering many areas and developing with the emergence of new technologies. Alam, Erdiaw-Kwasie, Shahiduzzaman, & Ryan [17] highlight that digital competencies cannot be attained without special attention being devoted to digital orientation and adoption processes. They define digital orientation as a general and permanent mindset, proclivity towards a digitally-enabled life, as well as continuous acceptance of digital technology.

Digital competencies include [16]:

- Technical skills and practice in digital technology.
- Abilities associated with meaningful application of digital technology.
- Ability to understand the phenomena of digital technology.
- Motivation for participation in the digital culture.

Based on the results of a research into 50 different frameworks for developing digital competencies, Ferrari [15] partitioned digital competencies into seven distinct areas: information management; collaboration; communication and sharing; creation of content and knowledge; ethics and responsibility; evaluation and problem-solving; and technical operations. In today's information and knowledge society, digital competences are a vector or social inclusion or social exclusion; they are prerequisite for a person to achieve a certain qualify of life [11]. Therefore, it is necessary to equip everyone with digital technologies [18]. Even though the new generations are digital natives, it is unlikely that they will develop digital competencies alone, without a coherent learning programme [19]. Therefore, Pérez-Escoda & Rodríguez-Conde [19] highlight the need for immediate initiatives towards innovation of present study programmes.

A digital competence framework represents "an instrument for development or assessment of Digital Competence according to a set of criteria, which establishes descriptors of intertwined competences aimed at enhancing the digital literacy of a specific target group" [20].

One of the key prerequisites for a successful competence-based innovation of study programmes is the selection of frameworks to serve as a theoretical basis that would steer the entire process. The readily available frameworks are useful not only as guides detailing specific steps, but as resources that provide a "bigger picture" of what is available today. The three frameworks to be used as basis for the creation of a custom framework of digital competencies were selected as a result of research and collection of case studies.

European Digital Competence Framework for Citizens, also known as Digital competencies framework 2.0 [20], is the first of the three. This Conceptual Reference Model is composed of 5 competence areas and 21 competencies.

The European e-Competence Framework 3.0, a common European framework for ICT Professionals in all industry sectors [21], was the second framework selected. The Framework is a component of the EU's strategy on e-Skills for the 21st Century, while at the same time supporting policy objectives of the 2013 Grand Coalition for Digital Skills. It is promoted as a tool for improving recognition of competences and qualifications across countries, boosting digital skills and the and fostering ICT professionalism in Europe. It serves as a reference of 40 competences required for professional ICT positions, specified at five proficiency levels, described using a common language.

The European eCompetence Framework for lifelong learning [22] was the third selected framework, promoted by EU as a common reference intended to facilitate effortless comparison of qualifications acquired within the different education and training systems, with a primary goal to improve mobility of workforce and learners. The framework itself is based on the learning outcomes is divided into three categories: knowledge, skills and competence. Recognition of these learning outcomes is crucial for the development of individuals, competitiveness, employment and social cohesion in the community.

III. COMPETENCY-BASED CURRICULUM DEVELOPMENT

As stated before, competency-based curriculum development is a rather new concept, which came to existence at the beginning of the 21st century, under considerable prerequire exerted by the business environment and intensifying competition between higher education institutions. Nikolov R. et al. [7] state that the goal of competency-based curriculum design is "to ensure that learners will be able to demonstrate their learned competences after they have acquired a necessary combination of knowledge, skills, and abilities." In other words, it is a way "to conceptualise the relation between education and the world of work" [8]. If sufficient attention in curriculum development is not devoted to specific competencies, the product of the higher education is often not "work-ready", and as such is not acceptable by the industry.

Therefore, in order to improve graduates' prospects for employment, special emphasis in curriculum development should be put on functional competencies, i.e. "occupation-specific competencies". According to Edwards M. et. al. [23], "Competency based curriculum summarizes academic and professional profiles, defines new objectives in the learning process, enhances learning environments and shifts the concept of learning as accumulation of knowledge to learning as a permanent attitude towards knowledge acquisition."

Emergence of such an approach to curriculum development had produced several frameworks that promoted not only overviews and classification of competencies, but also proposed different processes and activities for curriculum development. Most of the frameworks suggest the actual environment as the source of information for identifying competencies, required for ensuring alignment of competences that future graduates will acquire with the actual needs of the environment. The sources proposed for identifying competencies include job postings, documents issued by relevant professional organizations detailing specific competencies within

different areas, analysis of present study programmes, as well as strategic documents that point to future development.

The curriculum development process proposed by Kim J. [24], presented in Figure 1, involves following activities: Job analysis, Competency standards analysis and Curriculum Benchmarking as sources for Program Competency Identification. Competencies identified and selected in such way become clear goals to be achieved through curriculum development, as well as tangible measures of the success of curriculum realization. Competencies identified in the curriculum development process should be organized into groups of competencies, or sub-competencies, as to be used in curriculum design. The performance statements should be aligned with each course's learning outcomes. The last activity within the defined process is "to perform a program evaluation to assess the effectiveness of the curriculum in helping students achieve the established competencies" [24].

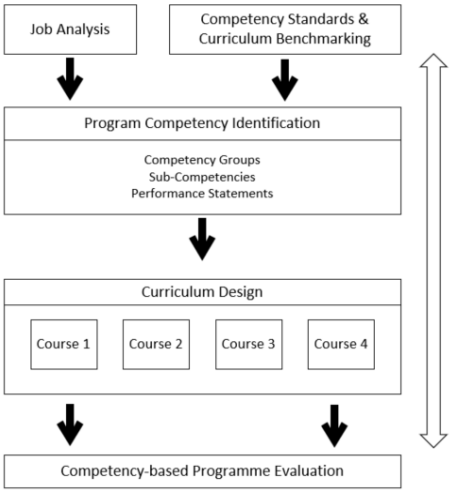

Figure 1. Theoretical framework for competency-based curriculum (Source: adapted according to [24])

IV. COMPETENCY-BASED BUSINESS INFORMATICS STUDY PROGRAMME

Department for business informatics and quantitative methods of the University of Novi Sad developed the undergraduate Business Informatics study programme following the competency-based approach presented in the previous section (Figure 1).

Job analysis, Competency Standards analysis and Curriculum Benchmarking were performed, as prescribed in the model. Job analysis was carried out in cooperation with the industry, namely, the 27 software development companies that served as the Faculty's partners in the development of the programme. Each of the companies presented their expectations of future graduates' competencies.

This was followed by an analysis of current standards for study programmes in information systems, computer science, and software engineering developed by professional associations—ACM (Association for Computing Machinery), IEEE Computer Society, and AIS (Association for Information Systems) [25]. The analysis was also expanded to include the recommendations and criteria for accreditation in the area of informatics, developed within the Euro-Inf Project—European Accreditation of Informatics Programmes (Socrates Programme 2006-2008).

Special attention was devoted to identification and analysis of structure and content of business informatics study programmes offered by European universities [25]. The team involved in the development process analysed a total of 87 business informatics study programmes implemented by universities from Austria, Croatia, Czech Republic, Denmark, France, Germany, Holland, Hungary, Poland, Romania, Slovakia, Slovenia, and Switzerland.

Finally, selection of competencies was preceded by an analysis of the following frameworks: Digital competencies framework 2.0, Common European e-Competence framework 3.0 for ICT professionals in all industry sectors, and The European Qualifications Framework for lifelong learning.

The identified competencies were partitioned in accordance with the narrower scientific and professional areal recognised within the study programme. This was followed by selection and detailing of competence descriptors per each narrower scientific and professional area. The distribution of competences was done in parallel with verification of their fitness against the chosen descriptors, synchronisation (in terms of repetition and level of detail), which in turn produced the final list of competencies. The number of courses and the corresponding ECTS credits were determined in line with an objective assessment of students' workload required for attaining competencies within each narrower scientific and professional areas, expressed in hours.

Prior to compiling a final list of courses to be included in the study programme, the curriculum development team decided on the number of courses and overall ECTS credits per each narrower scientific and professional area, which was one of the constraints to be respected in the prioritisation and final selection of courses. In order to ensure compliance with the requirements laid by the Commission for Accreditation and Quality Assurance, the team developed a template for course specification. Each course in the final list was given a title, and specified in terms of aims, and learning outcomes. The specified courses were divided into compulsory and electives and distributed along the four academic years of the study programme. An overview of courses included in the study programme is presented in Table 1.

V. CONCLUSION

Traditional curriculum development falls short of meeting the rapidly evolving demands of today's business environment, which necessitated new and innovative approaches. With evident results in easing graduates' transition to their future jobs, competency-based curriculum development has imposed itself as an approach to ensure alignment of education outcomes with the needs of the environment.

In an endeavour to respond to the challenges of the changing labour market caused by rapid technological development, the Faculty of Economics in Subotica developed and introduced the Business Informatics undergraduate programme in close collaboration with industry partners, and entirely based on the analysis of the actual needs of the stakeholders.

Table 1. The Business Informatics undergraduate study programme

Course title	Semester	Type	ECTS
FIRST YEAR			
Information Technology and Systems	1	AG	6
Business Mathematics	1	AG	6
Principles of Microeconomics	1	AG	4
Principles of Macroeconomics	1	AG	4
Software Development Processes	1	TM	6
Accounting	2	SP	8
Structural Programming	2	PA	8
Database Models and Systems	2	TM	8
Foreign Language Elective	2	AG	8
Physical Education Elective	2	SP	2
SECOND YEAR			
Organization Theory and Design	3	TM	6
Database Design	3	TM	8
Information System Project Management	3	SP	6
Business Statistics	3	SP	8
Human Resource Management	3	SP	6
Integrated Business Processes	4	TM	6
Object-oriented Programming	4	PA	8
Object-oriented Analysis and Design	4	PA	6
Innovation Management	4	SP	6
THIRD YEAR			
Digital Marketing	5	SP	6
Managing the Digital Firm	5	TM	6
Decision Models and Methods	5	TM	6
Development of Internet Business Solutions	5	PA	8
Management of Data Resources	5	PA	6
Web Programming	6	PA	8
Software Testing and Distribution	6	PA	6
Management Elective (Entrepreneurship / E-business models)	6	SP	6
Informatics Elective (Analysis of Social Media Content – Analysis of Web Structure and Content)	6	PA	8
FOURTH YEAR			
Corporate Finance	7	SP	6
Controlling	7	SP	6
Mathematics Elective (Financial Mathematics and Econometric Models / Financial and Actuarial Mathematics)	7	SP	6
Economics Elective (Financial Statement Analysis – Public Sector Budgeting and Financial Reporting)	7	PA	8
Business Intelligence Systems	8	PA	8
Knowledge Extraction from Data	8	PA	6
Informatics Elective (Business Analysis Techniques–Spreadsheets / Digital transformation)	8	SP	8
Final thesis	8	SP	12

Legend: AG: academic–general knowledge course, TM: theoretical-methodological course, SP: scientific-professional course, PA: professional–applicatory course.

The programme, developed within the Government Initiative for improving study programmes in the domain of information technology, is intended to prepare future graduates for a fast and effortless adaptation to their future jobs. Besides the analysis of the industry's requirements for future ICT professionals and the positive experiences of other European universities, the development of the study programme heavily relied on the guidelines laid in the Digital competencies framework 2.0, Common European e-Competence framework 3.0 for ICT professionals in all industry sectors, and The European Qualifications Framework for lifelong learning.

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Teaching of computer programming in Bulgarian primary school – challenges and solutions

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***Abstract* - In this paper the new school subject in Bulgarian primary school - "Computer modelling" is presented. The subject is introduced to all Bulgarian schools in 2018/2019 year as a core course in third grade (9-year-old students). The curricula for 3rd and 4th grade are outlined and some challenges and problems in implementation of the new school subject are discussed. Also several examples for solutions of main challenges are presented..**

***Keywords* – computer programming, computational thinking, primary school, teaching methods**

I. INTRODUCTION

The world around us becomes more and more digitalized. Nowadays the society needs people that not only use digital devices, but also people with computational thinking who will develop high-tech environment. In [1] authors point out that "To be prepared for the jobs of the 21st century, students must not only be digitally literate but also understand key concepts of informatics." To answer the new requirements of digital society and future jobs a lot of countries started to develop and implement new curricula in their schools with focus on informatics concepts, computational thinking, and algorithmic thinking. A lot of countries started rethinking strategies for informatics education. The school subject Informatics or Computer Science (or similar) has been introduced in different school level in different countries.

Informatics education in Bulgaria started in end of 60s years of 20th century as elective courses in Mathematical gymnasiums. As a compulsory subject it has been involved into school curricula from 1986/1987 year. During the years there were tides according place of informatics education in the school curricula. At 2016 year started new school curricula and new school subject "Computer modeling" was involved for primary school students at 3rd and 4th grade (9-10 years old). The education in the new subject started from 2018/2019 school year.

The new subject in Bulgarian primary school, problems with its implementation and possible solutions are in the focus of this paper.

II. RELATED STUDIES

In several countries informatics concepts and programming are introduced in primary schools as compulsory courses in the curricula. In England the computing curricula for primary school is involved at 2014. [2]

Slovakia has a huge experience in informatics education at school – primary and secondary level. [3] As a mandatory course informatics is involved in Slovakian schools at 2008 year "from year 2 (7 to 8 year olds) to mid-upper secondary stage (16 to 17 year olds)". In 2011 Slovak National Curriculum (2011) outlines two core school subjects – Elementary Informatics for grades 2 to 4 (pupils aged 7 to 10) and Informatics, for school years 5 to 11 (pupils aged 10 to 17). Since 2015 both subject are called Informatics. The subject covers domain from ICT and programming.

In other countries computer science is presented into primary school curricula as an optional course: Slovenia [4] – "Slovenian schools offer an optional elective course Computer Science to the students in the second three-year cycle of primary schools since school year 2014/2015. "

Very popular among children and parents are computing clubs provided by different organizations and companies. Also international online initiatives stimulate children, parents and teachers to self-explore concepts and ideas of informatics and programming.

Independent if computing, or computer science or informatics, are part of informal or formal education, several common problems arise:

- lack of well-prepared teachers to teach the subject in primary school or to integrate elements of programming and computing in other subjects;
- needs of adequate pedagogical approaches related to psychological and cognitive characteristics of children in primary school;
- introducing of abstract informatics concepts in understandable and accessible manner for children;
- choose of appropriate programming environment.

Regarding the pedagogical approaches, it should be mentioned that constructionism based methods create good conditions for implementation of computer programming in primary school. Some example of good practices could be found in [4], [5], [6]. In the frame of ScratchMath project [5] outline "5E" framework of activities: Explore, Explain, Envisage, Exchange, bridgE.

Authors of [7] proposed unplugged game based method for introducing computer memory, basic arithmetic operations and the idea of variables.

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III. CURRICULA "COMPUTER MODELING" IN BULGARIAN PRIMARY SCHOOLS

A. Structure of the school educational system in Bulgaria

In Bulgarian educational system three school subjects related to computer science are part of the school curricula: Information technology, Informatics, and Computer modeling. Courses in Information technology are focused on computer system, application software – graphical editors, word-processing, spreadsheets, presentations, internet services, safety in internet, computer viruses etc. Courses in informatics are directed to algorithms, numbers systems, Boolean algebra, programming. Subject Computer modeling is directed to primary school and joins topics from domain of ICT and Informatics.

In primary school (1st-4th grade) students can study computing in three basic forms:

- 3rd (9 years old students) – 4th (10 years old students) grade - Compulsory subject "Computer modeling" – 1 hour per week;
- 1st – 4th grade - elective or optional – Information technology, 1 or 2 hours per week;
- Extracurricular courses in IT and Informatics – 1 or 2 hours per week, funded by National programs of Ministry of Education.

The compulsory subject "Computer modeling" has been involved since 2018/2019.

Educational process in compulsory subjects is regulated by several state documents:

- State standards – outlines competences in form of learning outcomes (LO) for every educational level.
- Syllabus for every grade - developed by the Ministry of Education; unified form for description; outlines the learning outcomes; compulsory topics; requirements for distribution of hours for different type of lessons and assessment; suggestions for activities that help to achieve LO and development of 9 competences;
- Topic schedules for the academic year, developed by teachers.

For elective or optional courses teachers develop own syllabus, that have to be approved by regional educational inspectorate.

The textbooks are free of charge for students from 1st till 7th grade. Also e-textbooks with extended interactive exercises are provided by the publishers of printed textbooks. The teachers are supported by teacher's book with didactical suggestions for learning scenarios development and lesson implementation.

B. Main topics and learning outcomes in curricula "Computer modeling"

Main topics for 3rd grade are outlined in state syllabus [8] and include core knowledge domains: Digital Devices, Digital Identity, Information, and Algorithms.

The accent is on the obtaining knowledge and skills for: working with files; creating animated projects with use of algorithms with loops in visual environment for block programming; safe and healthy working with computers.

Implementation of the computer models in visual environment could be prepared by: unplugged activities with visual materials – mosaic, jigsaw etc.; working in simulation environment; performing algorithms in programming environment; use of easy for handling robotic devices; etc.

Key concepts are digital device, user, user name, user password, algorithm, code, command, loop, menu, button, animation, animated image, slide, information and data, branching, random number, variable, arithmetic and logical operators, conditions.

C. Chalanges and problems with implementation of the curricula

As every new entity the new school subject and curricula set challenges and problems in front of all stakeholders – teachers, parents, students, etc.

- Providing enough prepared teachers with relevant competency to teach the new subject in primary school. According to the state documents the subject has to be taught by primary school teachers, regardless of their qualification in ICT.
- Choice of appropriate programming environment. The environment has to provide conditions for implementation of the curricula. It should be based on block programming and to be free for the schools and students.
- The syllabuses include a lot of abstract concepts like algorithm, loops, branching, variables, digital identity etc. These concepts have to be precisely defined and in the same time to be explored in accessible manner for the 9-10-year-old students.
- Implementation of basic concepts in block programming environment and main topics of the syllabus requires usage of concepts that are part of mathematics curricula in next grades - negative numbers, coordinates and coordinate system, measurement of angles in degrees, random number.

IV. SOME DIDACTICAL APPROACHES FOR IMPLEMENTATION OF THE CURRICULA

One of the challenges for implementation of the curricula is abstraction of the concepts. For Introduction of the concepts could be applied adequate pedagogical methods and tools as:

- Show of objects with illustration of the concepts.

- Indication of properties of concepts.
- Use of analogies and examples from everyday life.
- Use of fun elements - challenges, riddles, anecdotes, puzzles.
- Use of computer educational games, simulations or demonstrations.
- Interactive tests and an electronic textbook.
- Use of unplugged activities.
- Problem solving.
- Experiments with "backed" (prepared in advance by teachers) and "half backed" codes.

Another challenge is choosing programming environment for implementation of curricula in primary schools. Most of schools have chosen the popular environment Scratch (scratch. mit.edu) due to its intuitive interface, well established community of teachers and other users, localization in many languages, guides for teachers and students.

Aside from well-known real-life algorithms for preparing of sandwiches, doing gymnastic or dancing, for the illustration of loop algorithm algorithms from known tales could also be used.

Example 1: Algorithm from tales

Cinderella – Find Cinderella

1. Find a girl;

2. Try the shoe

3. If the shoe fits, then Cinderella is found, in other case go to step 1.

This example illustrates one of the constructions in programming languages - loop with post condition.

Example 2: Unplugged game activity for digital devices.

In the table are hidden the names of 3 digital devices. Find them. Which are their common elements?

a	l	t	o	p	a	r	i	s	a
s	m	a	r	t	p	h	o	n	e
s	i	b	g	o	a	l	r	o	w
e	a	l	a	p	t	o	p	r	i
t	m	e	m	i	r	a	n	d	y
o	p	t	e	c	o	d	a	n	c

Example 3: Unplugged activity. Find of words in the grid integrates Math, Computer science (Informatics).

1. Find the two-digit numbers with equal digit.

2. Order them in ascending order.

3. Replace the numbers with relevant alphabet sign.

4. Which word do you obtain?

5. Explain how to use it?

34-m	11-P	43-n	25-F	12-b	31-G
43-n	22-a	33-s	33-s	13-c	12-b
21-l	12-b	21-l	44-w	13-c	13-c
23-E	13-c	23-E	55-o	66-r	77-d
13-c	25-F	43-n	23-E	13-c	25-F

To avoid the problem with coordinate system and negative numbers when sprites have to be positioned, it is suitable to use direct manipulation of the sprite, colors for different quadrants [6], experiments and discussion.

Example 4: Use colors to explain coordinate system. This idea was given by prof. Ivan Kalas from Comenius University, Bratislava during a training workshop.

The students work with "half baked" file with colored quadrants in coordinate system as a stage and one sprite (cat). The first task is to move the cat in differently colored areas and to observe the numbers changing in block 

.

After experiment with direct manipulation teacher or students can do conclusions abot use of sign minus, without explanation about negative numbers. The concept about negative numbers is part of 5th grade math curricula. In this way the teacher can do propedeutics of negative numbers and coordinate system and coordinates that are part from 6th grade mathematics curriculum.

A simmilar situation occurs when students have to use blocks for turn



Measurement of the angles is part of 4th grade Math curricula. To reduce level of abstraction, it is suitable to use experiment with clock. The teacher can explain that when the hour arrow is turned from 12 to 1 o'clock it makes an angle from 30 degrees.

Example 5: The task is:

Use file clock.sb2. (Figure 1.) Click on the green flag and after that on the red arrow. What happens? Look at the code. Which new commands are used? Start file again and click 3 times on the red arrow. Which number will show the arrow? In the code 

change number 30 to 60, 90, 15. After every change start code and observe which number shows the arrow.

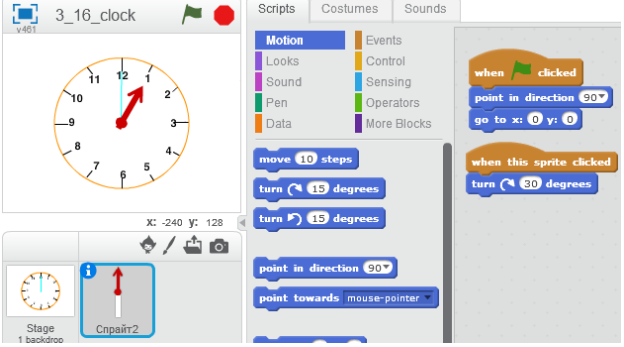

Figure 1. Clock experiment

In this way students will have visual performance of abstraction for angle's metrics.

Example 4 and Example 5 give also a good propaedeutic of math concepts.

Example 6: Use of experiment to involve concept animation. The task is presented in [9].

Open file pinokio.sb2 (Figure 2). Click on the green flag. What kind of activities is Pinocchio performing? See costumes and click on the costumes. What happens? Check the code. Do you find motion blocks?

After this experiment, teachers could involve easy concept animation as a quick change of images.

Experiments at different levels of object controlling help students to better understand concepts and principles of programming.

Example 7:

Along with the experimental work teachers can use tasks that could be enlarged step by step. The example of set of extended tasks is performed in [9]. In the ground of the task is the tale "The Gigantic Turnip".

This is a folklore tale with six characters – grandfather, grandmother, granddaughter, dog, cat and mouse. The grandfather plants a turnip. The turnip grows so big and the grandfather cannot pull it. He thinks: "I have to call grandmother to help me." He calls grandmother and together they try to pull the turnip. They still don't succeed. Grandmother thinks: "I have to call granddaughter." She calls the granddaughter and once again they all together try to pull the turnip, but still unsuccessfully. The granddaughter thinks: "I have to call my dog". She calls the dog. The dog comes. All together they try to pull the turnip. Again they cannot pull it. Dog thinks: "I have to call the cat." The dog calls the cat and cat comes. All together they try to pull the turnip. Again the try is without success. The cat thinks: "I have to call the mouse." The cat calls the mouse. The mouse comes. At the end they all together pull the turnip.

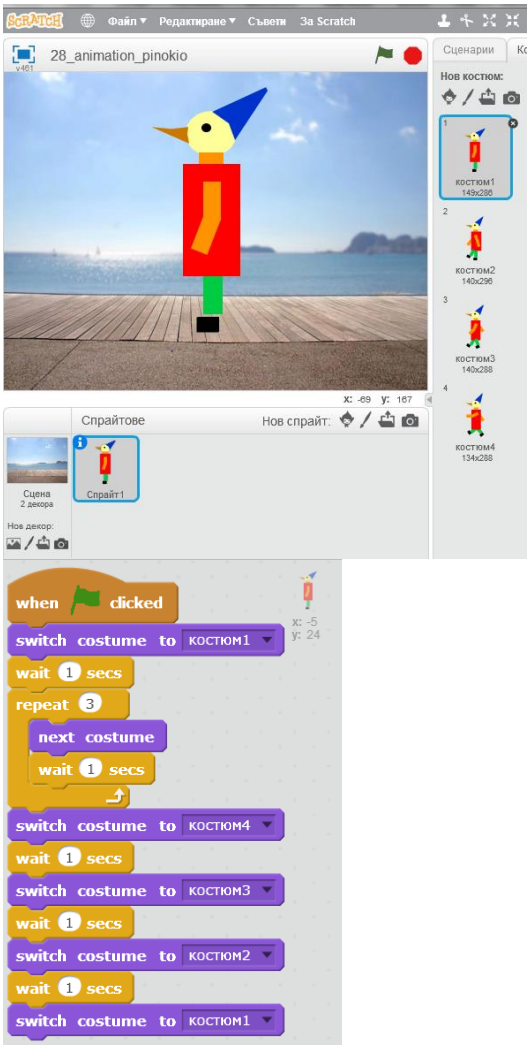

Figure 2. Animation experiment [9]

This tale is well-known by the students. When students learn about algorithms they use interactive micro game to order heroes in the tale (Figure 3).

When students explore Scratch programming environment they can step by step:

- develop stage backdrops;
- use "half backed" file for experiments and observation of code and behavior of part of sprites;
- continue scenario description and implementation;
- implement story telling with costumes changing, events driving with broadcasts (Figure 4.).

The teacher can use slide with codes of grandfather, grandmother and granddaughter. With the help of this slide, similarities and differences could be discussed.

V. CONLUSION

Teaching computer programming in primary schools has many challenges, some of which are outlined and discussed in the paper.

The new school subject was brought to Bulgarian school curricula in the current 2018/2019 school year. There are a lot of challenges in the process of implementation of the curricula. These challenges could be solved with the use of an adequate teaching methods, grounded on the constructionism, with selection of



Figure 3. Micro game for ordering characters from the tale "Gigantic Turnipt " [9]

appropriate tasks – close to the students' everyday practice and their interests. The tasks have to be fun and in the same time help students develop algorithmic thinking and achieve the desired learning outcomes.

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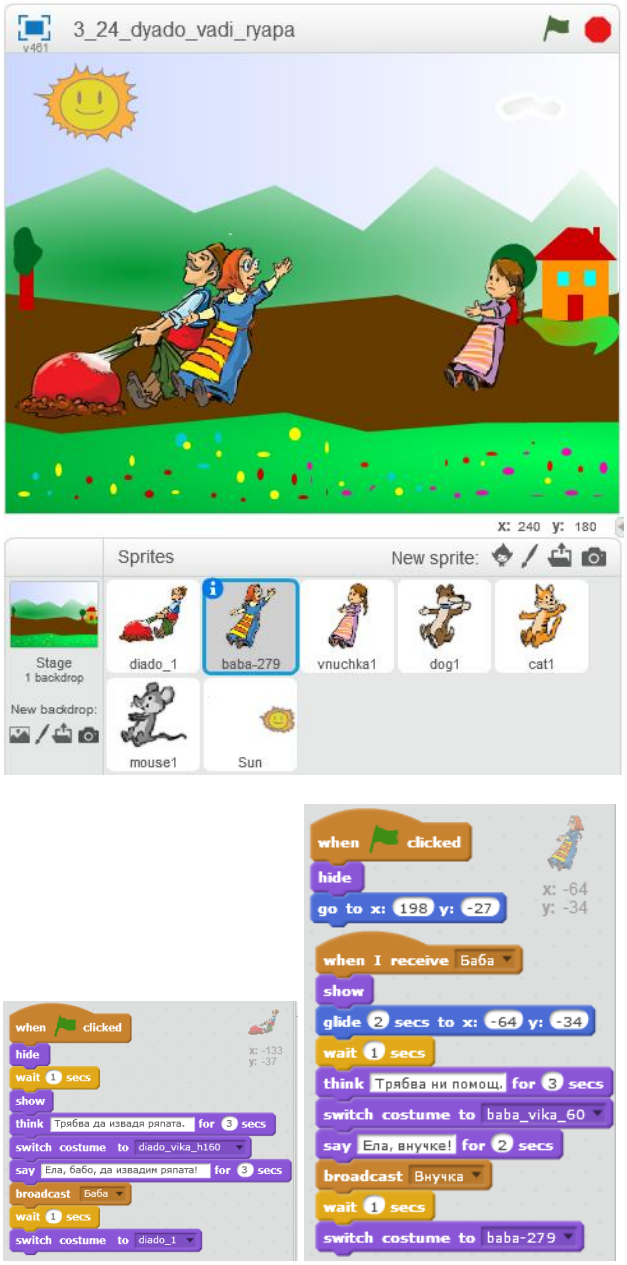

Figure 4. The tale "The Gigantic Turnip" [9]

About some barriers in usage of educational computer games by teachers in STEM

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***Abstract* - In this study we present the opinion of 114 Bulgarian teachers in STEM (mathematics, physics, chemistry and technology and entrepreneurship) concerning the barriers in using educational computer games in their teaching practice. There are various obstacles in the process of using educational computer games. They are associated with a high cost of existing educational games, the provision of content-quality games, technical equipment, the need for additional teacher training for the use of educational computer games, a time constraint within the classroom, the lack of match of curriculum games. We analyze the teachers' opinions with relevance to existing school policies for use of educational computer games, experience in use of educational computer games, teaching experience, age, school subject and school level – primary, low secondary or upper secondary school.**

Keywords – educational computer games, serious games, teacher's attitude, barriers

I. INTRODUCTION

Information technologies are part of the educational process on all educational levels. They can be presented in various ways: from the visual performance of different text and digital information to the use of different content educational games aiming at the achievement of certain educational objectives. Educational games not only facilitate knowledge acquirement and assimilation but also help to solve various hypothetic cases associated with reality. Recently the research on the application of serious games in education has been increasing. This tendency is shown in [1]. Authors consider the most modern topical trend in education computer game based approach and gamification. One of the factors for effective implementation of Educational Computer Games (ECG) in school practice is teachers' readiness and attitude [2]. Computer game based education in STEM motivates students and enhances their interest in science. At the same time, it is important to determine the barriers constraining the implementation of educational computer games in teachers' practice. This will direct teacher-training institutions, schools aiming at the implementation of innovative technologies and educational computer games developers.

In this paper we present the results of a survey on the barriers in using educational computer games in the teaching practice of teachers in mathematics, chemistry, physics, technology and entrepreneurship in Bulgaria. For the needs of the survey we have used the term educational computer games (ECG) - serious computer games with clear defined educational objectives and outcomes, related to the specific school subject or university course. The educational/didactical computer games are meant for training, learning, or assessment of competences and set of learning objectives [2].

II. RELATED STUDIES

Researchers pointed out different issues of teachers' attitude regarding educational computer games. Stieler-Hunt, and C.M. Jones [3] underline the teachers' role in the implementation of immersive digital games, they summarize that digital games in the classroom will not be "fully realized", until "negative teacher attitudes towards the use of immersive digital games in the classroom persist". For implementation of innovative pedagogical approaches teachers have to accept technological challenges. De Grovea et all [4] conclude that "use of digital games in a classroom is often looked upon with skepticism by teachers". Really it is necessity to find out the reasons of this skepticism. Baek outlines [5] six factors that hinder teachers' use of games in the classroom: "Inflexibility of curriculum, Negative effects of gaming, Students' lack of readiness, Lack of supporting materials, Fixed class schedules, and Limited budgets. In [1] studies regarding positive and negative factors regarding adoption of educational video games in Greece, USA, Turkey, Sweden, Finland, Belgium, France, and Taiwan are analyzed. As negative issues of acceptance and implementation of educational video games are mentioned classroom management and possibilities for curriculum integration.

Sanches-Mena and Marti-Pareno [6] point out four main barriers - lack of resources, students' apathy, subject fit, and classroom dynamics.

The study [7] conducted in Bulgaria shows that only 22% of the respondents – teachers in IT and Mathematics, use ECG for assessment. In [8, 9] attitudes of Bulgarian teachers toward the use of innovative educational computer games are presented. The authors summarize conditions for effective use of educational computer games: providing of technical equipment and free or low

The study is funded by Bulgarian National Scientific Research Fund, Contract DN-05/10, 2016

cost educational games; high quality of training of teachers to use ICT and educational computer games.

A study of the attitude of Bulgarian teachers who teach different subjects on all educational levels towards the use of educational computer games has been conducted according to a contract DN-05/10 with the Bulgarian National Science Fund. The study [2] is related to Bulgarian secondary school ICT and Computer science teachers' attitude towards educational computer games. There are compared opinions of teachers who use and who do not use educational computer games in their teaching practice. "Most important barriers for use of ECG by the ICT teachers – Too expensive ECG, Lack of time for preparing and becoming familiar with ECG, Lack of games with serious educational elements, Lack of information about where to find ECG with high quality." One of the research questions in this study is "Is there a statistically significant difference regarding barriers for use of ECG for teachers who use ECG and who do not use ECG?" The results show that statistically significant difference appears only regarding prices of the games and relevant games for the subject that they teach. "The prices of the games are too high. 76.9% of users of ECG agree or strongly agree that ECG are too expensive. 52% of non-users of ECG agree or strongly agree with the statement." "Use of ECG is not suitable for the school level that I teach. 78.4% of users of ECG disagree or strongly disagree and 58.7% of non-users of ECG disagree or strongly disagree with the statement."

The study about use of educational computer games in teaching and diagnostic of students with special educational needs is discussed in [10].

The attitude of STEM teachers in Bulgaria is discussed in [11].

III. METHODOLOGY

A. Target Group Description

114 teachers of mathematics, sciences, entrepreneurship and technology fall into the target group. 29 of them are primary school teachers, two of them teach in low secondary school as well. 69 are low secondary school teachers, 20 of them teach in high secondary school as well. 18 of the teachers work only in high secondary school.

12% of the teachers are men and 88% are women. The majority (46%) are at the age of 41 – 50. Over the age of 51 are 30% of the rest, 7% and 15% are respectively under the age of 31 and 41. The rationing of teachers according to their professional experience corresponds to the age rationing. 26% have 10 or less years of service; 39% have 11 – 20 and the rest 35% have more than 21 years of service.

B. Methods

The survey was conducted in the beginning of 2017/2018 school year using paper-based questionnaires. The opinions of teachers concerning the barriers in using educational computer games in their teaching practice are drawn together by means of a special study. It comprises sets of questions about the use of computer games; the types of games and the objectives they are used for; the efficiency of their use for the training process; problems related to the use of these elements in training; the need of additional training of the teachers related to the use of the games; existing school policies for use of educational computer games as well as issues featuring the demographic and professional position of the teachers.

The variables are mainly represented in a dichotomy or five-mark rating scale. The recorded rates allow calculation of general quantity characteristics for the individual variations of the studied variables. In certain analysis cases structural relative values are used. The studied total is small by size and not representative, so intensive (probability) parameters have been used because of their better informative value in the descriptive analysis [12]. Statistical hypothesis tests are also carried out.

IV. FINDINGS AND RESULTS

A. Problems with the Use of Computer Games

The use of educational computer games is constrained by certain circumstances related mainly to the provision of content-quality games, technical equipment and adequate teacher training (Table I). Teachers' opinion is that the high cost of the games constrains their application in the training process to a great extent (μ=3.7). Barriers constraining teachers in the use of computer games rated μ=3.4 are the lack of equipment and lack of time for preparing and becoming familiar with the games. The content-quality of the games further constrains their use. It has been found out that the games are short of "serious educational element", easily affordable games do not match curriculum and games are class-time constrained. Regarding these characteristics of the games and the awareness of their implementation the average rate is μ=3.2.

Teachers have not considered that the use of ECG devaluates their work or educational games are not compatible with the educational level they teach.

TABLE I. BARIERS CONSTRAITING TEACHERS IN THE USE OF COMPUTER GAMES

Barriers in the use of computer games	**Average rate - μ**
Lack of time for preparing and becoming familiar with ECG	3.35
High costs of games	3.69
Lack of games with serious educational element	3.23
Lack of information where to find high content-quality games	3.26
Lack of knowledge of game technologies and inability to use them	2.26
Lack of match-of-curriculum games	3.24
Lack of methodological training for ECG	2.62
Games are class-time constraint	3.22
Lack of equipment	3.36
Lack of IT-support	2.69
Parents` negative attitude toward the use of games	2.45
The use of ECG devaluates my work making it accessible to anyone	1.98
The use of ECG is not suitable for the school level I teach	2.16

Therefore, these "barriers" have low influence rates (μ rates about 2). This means that they do not influence teachers` attitude toward ECG usage in their teaching practice.

B. Attitude of Teachers Using and Teachers not Using Educational Computer Games. Existing School Policies and Barriers Facing the Teachers

Attitudes toward certain problems related to the barriers in using computer games in the educational process are different for teachers who use them or not, who teach in schools with or without existing policies for the use of games. The statistically significant difference test is based on the non-parametrical criterion of Kruskal-Wallis. The independence hypothesis (H_o) has been tested. According to it there are no differences in teachers' attitudes toward the barriers constraining the use of computer games or, if any, they are accidental.

With the majority of barriers there are no differences in teachers` attitude among teachers who use or not computer games as well as depending on existing policies for using the games in the schools they teach. Statistically significant differences (p=0.002) occur regarding the "Lack of methodological training for ECG" (Table II). Slightly over 18% is the rate of teachers who use the games and claim that this barrier constrains their use to a great extent (4 – 5 rates). Significantly greater (40%) is the rate of teachers who do not use games in their teaching practice but they consider that this barrier influences the use of the games to a great extent. With far less rates but statistically different is teachers` attitude distribution (p=0.017) regarding the influence of the barrier "lack of knowledge of game technologies and inability to use them". About 12% of those who use games claim strong influence of this barrier on their use in the teaching process. The rate of those who have not used them so far is 19%.

TABLE II. LEVELS OF SIGNIFICANT DIFFERENCE IN TEACHERS` ATTITUDE' TOWARD THE BARRIERS WITHIN DIFFERENT GROUPS OF TEACHERS

Problems with the use of games	**Asymp. Sig. (P)**	
	Use of games	***Policy available***
Lack of time for preparing and becoming familiar with the games	0.992	0.764
High cost of games	**0.056**	0.422
Lack of games with serious educational element	0.929	0.757
Lack of information where to find high content-quality games	0.417	0.216
Lack of knowledge of game technologies and inability to use them	**0.017**	0.278
Lack of match-of-curriculum games	0.559	**0.021**
Lack of methodological training for ECG	**0.002**	**0.037**
Games are class-time constraint	0.881	0.226
Lack of equipment	0.237	**0.029**
Lack of IT-support	0.274	0.420
Parents` negative attitude toward the use of games	0.209	0.416
The use of ECG devaluates my work making it accessible to anyone	0.508	0.113
The use of ECG is not suitable for the school level I teach	**0.051**	**0.050**

Significant difference occurs in the rates of teachers` attitude when it refers to the relevance of the game options and the educational level they teach. According to 13% of the teachers who use computer games the irrelevance is significant while the rate among those who do not use games is 20%.

Conditionally (p=0.056) differences in teachers` attitude occur also regarding the high cost of computer games. Based on their experience of the use of games, 70% of the teachers who use games in their practice consider that cost constrains their use to a great extent. Lower but still high (56%) is the rate of the teachers who do not use games but their opinion is that this barrier reduces game usage.

Statistically different is teachers` attitude toward the barriers among teachers who teach in schools with or without existing policies for use of educational games. Such a relation (p=0.021) occurs about the irrelevance of the games to curriculum. This is a serious problem for 49% of the teachers who teach in schools without existing policies for use of games in the teaching process. Such is teachers` attitude of 38% of the teachers who teach in schools with existing policies. Presumably existing policies stimulate the use of match-of-curriculum computer games.

The lack of adequate technical equipment is also differently assessed (p=0.029) by teachers. About 60% of the teachers in schools without existing policies for use of games point this barrier as a major problem. The respective rate of the teachers in schools with existing policies is 40%.

Another reason for the constrained use of computer games is the lack of methodological training to use games in the teaching process. This is the opinion of 24% of the teachers in schools with existing policies while the respective rate in the other schools is 40%.

The opinions of teachers in both types of schools differ (p=0.050) regarding their attitude toward whether computer games are suitable for the educational level they teach. The relative rates here are nearly equal, about 16%, but they are diametrically opposite in the five-rate scale of assessment.

While surveying the need of teachers` training in the field of educational computer games and the presumable barriers in their usage no statistically significant difference has been noticed.

C. Need for Additional Training

Certain problems with the use of computer games in teaching are related to teachers` training in this field. Teachers generally realize the importance of this training. The relative rate of teachers who need additional training is 68% among those who already use games in their practice. This rate is bigger among teachers who have not used computer games – 74%. 71% point that they need additional training regarding the use of computer games. The great number of teachers who need additional training implicitly shows that our schools lack in sufficient and functional policy for the use of educational computer games in the teaching process.

TABLE III. NEED (%) OF ADDITIONAL TRAINING ACCORDING TO DEMOGRAPHIC AND PROFESSIONAL POSITION OF TEACHERS

Age	**%**	**Teaching experience**	**%**
20-30	87,5	1 - 5	83,3
31-40	70,6	6 – 10	90,0
41-50	74,0	11 -15	75,0
51-60	64,3	16 – 20	68,2
61+	80,0	21+	63,2
Existing policies in school	**%**	**School subjects**	**%**
No policies	80,0	Mathematics	70,9
Partially	65,0	Physics	60,0
Existing policies	71,9	Chemistry	66,7
		Entrepreneurship	62,5

The relative rate of teachers who need additional training in computer games is biggest in the age group 20 – 30. About 88% claim such needs. When the rates of age are higher the rate of teachers who need additional training in computer games is lower. It is the lowest among teachers over 50. (Table III) The mainstream is very similar regarding teaching experience as it strongly depends on the age of teachers. The relative rate of teachers who need additional training in computer games is higher in schools without existing policies for this. It should be further pointed that additional training for teachers in using computer games in their teaching practice is essential.

V. CONCLUSION

The outcomes of this pilot survey define the major barriers in usage of educational computer games facing Bulgarian teachers in STEM:

- Lack of adequate technical equipment. However, it occurs in different degree in schools with existing policies for the use of educational computer games and schools without such policies.
- Inadequate training in educational computer games based teaching.
- High cost of certain games.
- Lack of content-quality match of curriculum educational games.

Teachers` attitude toward various barriers depends on school policies for innovative teaching approaches. Teachers in schools with existing policies for use of educational computer games face significantly smaller number of barriers with less intensity.

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Intuitive communication versus rational communication among students of computing at the Algebra University College

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Abstract - **Communication is not just what is said, it is also what has not been said; its efficacy reflects in the response we get. In formal education, cognitive processes and problem-solving are taught through the prism of rationality with an emphasis on logic and rational approach, according to which everything must be justified and argued. It also prevails that communicative skills can be learned if certain rules are followed. However, it is active listening, empathy and connecting with an interlocutor, that makes possible to influence the behavior of those we communicate with. The intuition is based on an inner feeling that enables us to make decisions without logical resonance, it represents wisdom that we often can not explain how we possess it. The aim of the research conducted among the students of computing at the Algebra University College was to determine whether students rely on the „ratio“ or on the "inner voice" while they communicate. The results showed that although students consider intuition should be taken with a dose of reservation due to possible non-objective influences and give priority to rationality in business-related actions, they also opine that the best results are achieved when intuition and rationality are combined.**

Keywords – communication, intuition, rationality, inner voice, ratio

I. INTRODUCTION

The ability to communicate has made us human and every day, either consciously or unconsciously, that ability helps us to reduce the "distance" between us and others. The fulfillment of our private lives, as our business success, is often the direct result of our communication skills. The noun „communication“ is derived from the Latin term c*ommūnicāre*, meaning "to share, to make common“[1]. Our communication skills are influenced by a number of factors, but their success is reflected in how much of 'ourselves' we have been able to share and make in common with our interlocutor. Communication is not just what is said, it is also what has not been said; its efficacy reflects in the response we get. Therefore, it is no surprise that today's attention is increasingly devoted to the development of our communication skills.

The attempt to understand the progress of humans to solve problems in an advanced and intelligent way intrigues researches from multiple disciplines, and it can be traced all the way back to Aristotle's era (384-322BC). Some of the approaches include finding a solution based on already known solutions i.e. *direct facts*, adopting the most possible solution or the rule of thumb, i.e. the *heuristic approach*, reducing a new problem to an existing or to similar, already known solutions i.e. *analogy*, making moves which bring us closer to the goal step by step i.e. *hill climbing*, while applying already known and well-defined solutions i.e. *algorithmic deduction*, using a systematic search of possible solutions i.e. *exhaustive search*, solving a problem via decomposing the whole problem into subproblems i.e. *divide-and-conquer*, reducing a problem to a known category and finding the particular solutions i.e. *analysis and synthesis*[2].

Those approaches are usually the base of formal education and they are taught through the prism of logic and rational mind according to which everything must be justified and argued. Also, it often prevails that all skills can be learned if certain rules are followed, including communication. However, it is active listening, empathy and connecting with an interlocutor, that makes it possible to influence the behavior of those people to communicate with. The intuition is based on intuitive mind, on an inner feeling that enables people to make decisions without logical resonance, it represents the wisdom whose presence within them they often cannot explain.

Many authors today also consider the role of leaders in education, inviting on „evoking greatness“ i.e. bringing out the best in educational leaders, because evocative coaches are not afraid to tune into the intuition channel, to bring imagination, inspiration, and integration into the coaching process[3]. The basic questions that should be answered, according to Timothy Gallwey, which appear when we put ourselves in the shoes of the person are: 'What am I thinking? What am I feeling? What do I want?' The answers to these questions allow us to have a richer picture of the three primary levels of the other person: thinking, feeling and will. It is important to remember that at best we can make an educated guess about how other people think and fees, and it is also important to keep ourselves open to feedback and new information and to be willing to adjust our picture of the other person's reality. The purpose of that skill, called *transposing*, is not just to gain insight, but to be more effective in our communication[4].

II. COMMUNICATION STYLES

Individuals use different types of communication styles to convey their messages to others. Communication styles are the subject of consideration for many authors and researchers, and in this chapter, we will list some of the basic styles they are used in:

A. *In the book Peoplemaking, first published in 1972, Virginia Satir brings five styles of communication*[5]*;*

- *Placating* – earliest method of communication that a child learns. A person says 'yes' though he/she wants to say 'no', in order to be accepted by others and agrees and the needs of other people, life, desires, and demands are more important than their own, which underscores the lack of self-esteem.
- *Blaming* – a second way of communicating a child learns ('he made me do it'). A person puts their own desires in front of the desires of others and the situation they are in while does not take responsibility or transfer responsibility for his/her own life and feelings to others.
- *Computing* - a person says "I'm calm, cool, and collected", live in their own head, do not show emotions nor reactions and have an intellectual, reasonable and authoritative approach through which they lecture others. He/she is inclined to be alone and although he/she has friends, the relations are superficial.
- *Distracting* – a person changes the topic of conversation, begins to talk about something else, pronounces words that do not make sense and jokes in an inappropriate way. The belief is 'I'm not important', 'you're not important' and the whole situation is not important. He/she is unable to make intimate relationships and is often labeled as the Joker.
- *Leveling* – this style differs greatly from the previous as it is the most integrative communication style. A person expresses what he/she wants, nothing is avoided and hidden and everything is in line with the reality of the situation. Themselves, other people and context in consideration are equally valuable. It is not necessary to be perfect but real.

B. *Some analyst of interpersonal communication divide people's behavior into one or a combination of these five styles (Baden Eunson):*

- *Passive* - people avoid expressing their opinions or feelings. They do not respond overtly to hurtful or anger-inducing situations so once they have reached their high tolerance for unacceptable behavior, they are prone to explosive outbursts, usually out of proportion. After however, they may feel shame, guilt, and confusion, so they return to being passive[6].
- *Aggressive* - people express their feelings, opinions and advocate for their needs in a way that violates the rights of others, and thereby are verbally and/or physically abusive. They try to dominate others, criticize, blame or attack others and speak in a loud and demanding way, interrupt others frequently, and are very impulsive. They use humiliation to control others[6].
- *Manipulative* – individuals that use this style of communication do not take other people's feelings, needs, opinions, wishes, and lifes into consideration, but they act in a manipulative way: they often flatter others, they use lies and other techniques to deceive others so that they can achieve their own hidden agendas.
- *Assertive* – assertiveness can be expressed as 'getting what you want from others without infringing on their rights'[7]. Individuals that use this communication style clearly state their opinions and feelings, and firmly advocate for their rights and needs without violating the rights of others. They value themselves, their time, and their emotional, spiritual, and physical needs and they are strong advocates for themselves while being very respectful of the rights of others[6].
- *Passive-Aggressive* – it may involve intentional inefficiency, moodiness, delay, anger, and similar behavior. Relationship with a person in this style may seem friendly, but indirect and hostile interactions make the environment with these people negative and stressful[7].

C. *Mark Murphy (2015), a recognized expert in organizational leadership and employee engagement, and his team have gone through two decades of research to come to the conclusion that there are four basic divisions of communication styles*[8]:

- *Analytical Communicator* – a person aspires to express information through a particular language and does not like unclear expressions. Usually, has little patience when others express many emotions and feelings. A positive side is that the person gives the impression of a knowledgable individual. The negative side is that a person may act non-emotional and cold to others.
- *Intuitive Communicator* – an individual is prone to looking at a big picture, moving directly to the point and avoiding a large number of details in the conversation that led to the point. The advantage is speed and thinking out of the box. A person sometimes has no patience when the situation requires dedication to detail, i.e there is a risk of missing the point. The most difficult is to agree with a person who is a functional communicator.
- *Functional Communicator* – a person thrives on details, processes, timelines, and plans and to process information step by step so nothing would be lost. The advantage is that no detail is missed. The negative side is potentially losing the attention of others, especially the person who is inclined to look at a larger picture without too many details, such as intuitive communicators.

- *Personal Communicator* – a person seeks emotional language as a way of connecting with others or revealing what other people think. The advantage is the ability to establish deep relationships with others while the negative side is that sometimes may be ridiculed as being too sensitive, especially by people who are reluctant to recognize the emotional aspect of the situation, which may get them upset or angry.

Murphy points out that none of the styles are necessarily better than others, but it is very important to choose the right style when the information is passed to a specific audience. Flexibility in dealing with communication styles helps to transfer information more successfully.

D. The meaning of your communication is the response you get[9]*",* and not what is said!

This is a great presupposition by the anthropologist Gregory Bateson which at the same time points to the complexity and simplicity of communication. It is important to emphasize that alongside what we communicate directly, there is a phenomenon of *metacommunication*. Metacommunication includes all nonverbal cues (tone of voice, body language, gestures, facial expression, etc.) which carry meaning that either enhance or disallow what we say with words. There's a whole conversation going on beneath the surface. Very often meta-communication can be described as*: what I said isn't what I meant*[10].

III. INTUITION AND INTUITIVE COMMUNICATION

A. According to Diane Brandon, there are eleven types of intuition („sixth sense"), which are[11]:

- *Presentiment* - people's feelings reduced to focusing their attention on something that can happen, whether good or bad.
- *Drowsiness in the abdomen* - a "weird" feeling coming from the belly. For example, a feeling of mild nausea when thinking about an upcoming obligation or event that creates a sense of discomfort.
- *"Yeah!" Moments of sudden surprise* - the state people find themselves in when an idea suddenly comes to their mind or something becomes perfectly meaningful, often referred to as the "light is turned on".
- *Vision* - the appearance of intuition in visual form. People can look like they actually see something with their eyes, and can be formed figuratively as an image in their mind.
- *Instincts* – although some people would never classify instincts under intuition, they are also one of the ways of reporting it. For example, if a person comes to some animal, instinct will tell her whether or not her to run away.
- *Irritable feeling that does not pass* - the feeling when something works right, but is constantly followed by the irritating feeling that tells them the opposite.
- *Touch* - intuition can also occur in the form of touch, which is called psychometry. Touching an item or another person can be a trigger to receive information.
- *Fragrance* - this form can occur in people when they receive information about a negative subject and may suddenly feel an unpleasant odor.
- *Hearing* - it can occur in the form of a sound or voice (including an inner voice) that can be literal or figurative and can only be in their mind as if they were imagined.
- *Physical signs* - the body has the ability to register and transmit information, so this form of intuition may involve signals such as gooseflesh what sends a message to a person whether something is good or bad.
- *Telepathy* - represents communication between two minds and may be common between two close individuals. For example, when people think of another person, and soon afterward they meet somewhere or call them.

B. The intuition-rationality tension

Although, people are rarely communicating in a way that they use only one communication model, the intuitive model, which is based on the inner feeling and the rational model, which is based on facts and logic stand out as the two most common extremes.

The intuitive approach was used until the Renaissance when the scientific community embraced the structured hypothetical - deductive model based on a rational and analytical approach. Afterward, it was abandoned because it was considered to be inferior to the new accepted model. Although that was the case for the following few hundred years, in the mid-20th-century new research appeared in the area of intuition and tried to find a way to harness this aspect of human existence. Areas, where intuition is considered to be valuable, are communication, decision making, knowledge management, leadership, problem-solving and creativity.

A rational and structured approach will undoubtedly yield results that we can predict and measure. The problem is when there is not enough time to consider all of the factors that affect the outcome of one's decision when there is rapid change, and one has not uncovered the unknown, the time is short, and a great deal is at stake, who will take responsibility for the decision? These kind of situations are ideal for recognizing leaders. For the most critical positions in our civilization, people who possess analytical and structured approach based on facts and reality are wanted, but people who know something that others do not, even if they cannot describe how they know it, are also desirable.

The tension between intuition and rationality in decision making is described by some authors as paradoxical[12]. Such paradoxical tension arises when two practices that seem logical individually are 'inconsistent or even absurd when juxtaposed'[13]. Rationality refers to an

analytical, systematic, rule-based, and explicit mechanism for decision making[14]. Rational decision making can be slow, time-consuming, and effortful, because of its systematic and structured nature, so it is not always appropriate for mastering the time pressure, complexity, and uncertainty of innovation decision making. When a decision-making process is based on intuition, decision makers consciously recognize a problem through the perception of relevant cues and patterns, non-consciously activate all the cognitive schemas associated with the problem, non-consciously make holistic associations across cognitive schemas, and consciously generate a solution[15]. The intuitive process includes problem definition, analysis, and synthesis, just like rational information processing, but these stages occur faster and are mostly non-conscious and deeply intertwined. Additionally, intuitive judgment is effectively charged and accompanied by a feeling of certitude and the perception that one's intuitions are correct, despite the lack of rational analysis[16].

C. *Intuitive communication* – is communication model that has the most ability to anticipate future events, situations, feelings, when a person has no clear and firm arguments for a decision but is firmly certain to think and act properly. Certain "unargumented" security in communication is the result of intuitive action[17]. As Murphy stated, those who use the intuitive model of communication are characterized by features such as enthusiasm, creativity, and determination.

D. *Emotional intelligence is a balance between the rational and the emotional brain.* Our style of communication is influenced by numerous factors, but we achieve the most when we combine all the aspects of our mind and establish a balance between the rational and the emotional mind. Emotional intelligence (EI) can be described as our ability to work with emotions (the way we perceive, understand, express and manage emotions). It enables us to accurately perceive other people and to use that information to build relationships with others.

5 major components of EI, according to David Goleman are[18]:

- *SELF-AWARENESS* – the awareness of how we feel all of the time, and understanding how those feelings are affecting the people around us.
- *SELF-REGULATION* - the ability to control our emotions and actions, developed by living our values, and by holding ourselves accountable when we make a mistake.
- *MOTIVATION* – the passion for work and meaningful contribution, beyond the material gainings. Highly motivated people put off short-term rewards for long-term success.
- *EMPATHY* - the ability to identify with other people and understand their wants, needs, and viewpoints.
- *SOCIAL SKILLS* – skills which help us work positively with other people, and manage conflict effectively.

E. *The intuition and rationality in higher education*

In order for teachers to encourage students to develop their full communication potential, ie intuitive as well as rational communication, they must first become aware and develop on their own intuition's skills such as self management (creative problem solving, handling conflict, managing pressure and stress, emotional intelligence etc.), communication skills (assertiveness, presentation skills, influencing skills, positive personal impact, dealing with difficult situations, negotiation skills etc.) and management&leadership skills (how to be a mentor, coaching, teamwork, team development, implementing and managing change, managing diversity, effective team briefing, managing people, action-centered leadership, performance management etc.)[19].

IV. THE RESEARCH METHODOLOGY

A. Research Goals and Methods

The research conducted among the Algebra University College students was concerned with the use of intuitive communication versus rational communication among computing students at Algebra University College, both in the private, as well as in the professional environment. The general research objective was to determine whether the students of computing predominantly use rational or intuitive communication style.

The research was conducted among the Algebra University College students during January of 2019 through an anonymous voluntary survey. The questionnaire had 9 questions. One of these questions included 8 statements and the students could choose if they considered the statements to be accurate or inaccurate, while for the other questions possible answers were defined with the degrees according to the Likert's scale of frequency.

For the analysis of the research results, a quantitative method was used. The data processing of the survey results was made through the Microsoft Excel tool.

B. Participants

Undergraduate Study Program	Applied Computing	Multimedia Computing
Total number of Students per Study Program (N)	111	13
Number of Students by Gender		
Male	98	10
Female	13	3
Number of Students per academic year		
First	100	13
Second	11	0

Table 1. The structure of the participants by Study Program, Gender and Academic year

The population sample included 124 Algebra University College students of undergraduate study programs: Applied Computing (Software Engineering and System Engineering) and Multimedia Computing. The structure of the surveyed students is presented according to the study program, gender and academic year. The majority of participants were Applied Computing (90%), male (79%) and first years students (80%) while among Multimedia Computing students 10 % were female and 8% were second years students.

C. *Research Results*

The general hypothesis of this research is that students predominantly use the rational communication style, and one of the fundamental questions is whether students also use intuitive communication and to which level, both in the private and in the professional environment.

The research results have shown that students often use intuition in everyday communication (42%) or periodically (40%), while only a few students never use intuitive communication (1%), or they use it rarely (11%). Only 6% of students use intuition every day in their communication.

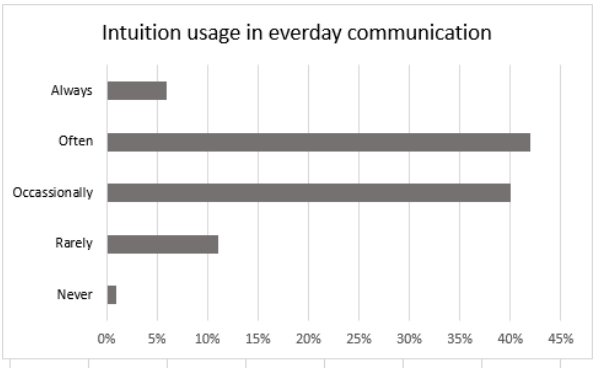

Chart 1. Distribution of the answers to the question: *How often are you using intuition in everyday communication?*

Regarding the question of how much they rely on intuition when contacting unknown people, results show that the highest percentage of participants (43%) do it often or periodically (27%), and always (12%). 15% of students rarely rely on intuition when contacting unknown people, and 3% never do it. The 46% of the students claim that intuition often helps them estimate whether the received messages or information are true (41%) or always (5%). To 37% of them intuition helps periodically, but to 12% rarely or never (5%).

In the professional environment, 52% of the students base their communication on a combination of intuition and rationality, but rationality prevails, while 29% of participants rely on the combination of intuition and rationality to the same extent. Only 9% of participants base their communication in the professional environment exclusively on rationality, and only 1% exclusively on intuition, while 9% use a combination of intuition and rationality, but intuition prevails.

It is interesting to notice that in the private environment, 31% of the students base their communication on the combination of intuition and rationality, but rationality prevails, while 38% base their communication on the combination of intuition and rationality to the same extent. Only 4% of participants base their communication in private life exclusively on rationality and only 1% exclusively on intuition. In addition, 27% use a combination of intuition and rationality, but intuition prevails.

For 15% of students in total intuition is an unreliable communication tool, of which 4% consider intuition very unreliable, while for the 31% intuition is a reliable communication tool, of which 2% consider intuition very reliable. Most of them consider intuition neither a reliable nor unreliable communication tool (54%).

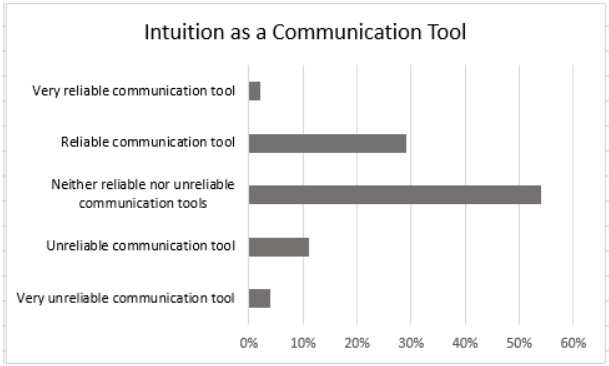

Chart 2. Distribution of the answers to the question: *According to your opinion, intuition is…?*

When it comes to communication in the decision-making process, intuition is more important than rationality only for 17% of students, and 83% of students disagree with this statement. When making any decisions only 6% of students consider that they should and could rely entirely on their intuition, but mostly they think that they should not and cannot rely entirely on their intuition when making decisions (93%).

For 60% of surveyed participants, intuition and rationality have equal importance in communication, but 40% of them disagree with that statement. 52% of the surveyed students always start from rationality, but if their intuition persistently says the opposite - they listen to it, while 48% do not.

When it comes to business, 91% of students give priority to rationality and 9% give priority to intuition. At the same time, 85% of participants consider that the best results are achieved when the combination of intuition and rationality is used, but 15% disagree with this statement.

Almost a quarter of the surveyed students consider that making decisions for the future is impossible to evaluate rationally but only with intuition (24%), while the vast majority (76%) believe that decision making for the future cannot be evaluated rationally but should be evaluated with the help of intuition exclusively.

90% of students estimates that intuition should be taken with a dose of reservation due to the possible

influence of emotions on it, and 10% disagrees with this statement.

Regarding other people, students estimated that they use intuition in communication occasionally (48%), or in most cases (38%), but some students think that other people use intuition rarely (11%), always (2%) or never (1%). According to the students' assessment, other people believe their intuition occasionally (43%), or in most cases (39%), rarely (15%), always (2%) or never (2%). It is not clear why students believe that other people use their intuition in communication more often than they believe their intuition.

Also, it is interesting to notice that although 60% of students consider that intuition and rationality hold the same importance in the communication process, with 85% of them believing that the combination of intuition and rationality gives the best result, 92% of students will still give preference to rationality in a professional environment. But it seems that more than half of the total number of surveyed students will listen to intuition if it persistently contradicts rationality.

D. Limiting elements of the research and recommendations for further research

All answers of the surveyed students represent only their assessment of their behavior, beliefs, and attitudes, and from the results of this research, it is not possible to determine the extent to which their opinions would be consistent with their behavior in real life. Also, the sample of participants is small and the method of distributing the survey was limited to sampling, so a recommendation for future research is to change these circumstances. In addition, in future research, in which more female students would participate, the distinction should be made between male and female students.

It would be advisable to consider longitudinal research of the development of communication styles of students and their integration communication style elements that have not been used so far, but which they have embraced under the influence of targeted education. Another recommended way of monitoring the development of communication skills and styles would be the project approach to solving tasks on courses and focus groups as an additional research method, so that a survey would not be the only method of data acquisition, in order to gain a more detailed insight into the mentioned area of interest.

V. CONCLUSION

The results of the conducted survey among Algebra Univerity College showed that almost half of the surveyed students use intuition in everyday communication while most of the students use it at least periodically. It further shows that they rely on intuition in contact with others and to estimate the truthfulness of received information. It is interesting to notice that half of them consider intuition as neither reliable nor unreliable communication tool that should be taken with a dose of reservation due to possible on-objective influences. When business is concerned, they give priority to rationality in business-related actions.

Although the main disadvantage of rational communication highlights the cold approach while intuitive communication lacks reliability, the research results verified that students think that the best results are achieved when intuition and rationality are combined. While both the rational and the intuitive communication style have their own advantages, by combining the elements of both, one attains the best objectives.

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The effects of integrating mobile technology for determining the boundaries of multiple integrals

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***Abstract* - Mobile devices such as mobile phones and laptops can have great impact on learning in classroom and on learning through homework assignments. The authors described the influence of the mobile devices (mostly mobile phones) as learning tools, on students' learning achievements of the two-dimensional functions, and in particular, double and triple integrals. The research was conducted at the University of Kragujevac and two groups were tested. In the experimental group students used their mobile devices and the online materials (which were made by their teacher in *GeoGebra*) to observe surfaces and graphs of multivariable functions and their intersections. For the students in control group, materials were presented without the use of mobile devices. Students' achievements were compared and analyzed. The impact of using mobile learning has been examined through the students' competence to correctly determine the domain of integration and limits for integration. Differences in students' motivation were also analyzed.**

Keywords - mobile devices, calculus, visualization, boundaries

I. INTRODUCTION

Experiences of many teachers have shown that learning and understanding multivariate calculus, double and triple integrals among other things, causes difficulties for students [1]. Some authors [2], consider visualizing and sketching figures in 3D and the relationship between graphical and algebraic representations in space as the most difficult part when it comes to determining multiple integrals.

In the research which authors present in this paper, process of teaching and learning multiple integrals, at the Faculty of Engineering, University of Kragujevac, Serbia is described and analyzed. When students practice multiple integrals, it's hard for them to connect algebraic and graphical representations, to select and to use appropriate representations etc [3].

The dynamic properties of many software packages enhance better visualization. *GeoGebra, Wolfram Alpha, PhotoMath, 3D Geometry, Geometry Pad* are just some of the applications through which teachers can prepare materials and use those materials while teaching multivariate calculus. Among all the listed applications, *GeoGebra* holds primacy and some research shows that. For instance, Korenova and Veres-Bagyi in their research [4] claime that 45% of teachers in higher education in Hungary uses *GeoGebra.* The same authors state the reasons for using digital technology: doing numerical calculations by students so that they may concentrate only on the problem; visualization and modeling of the problems and obtaining graphical representation of the given problem, which can lead students to the solution; as a source of educational materials etc. By using materials made in *GeoGebra* during the course of Mathematics 3, our students were enabled to manipulate the pictures, to rotate objects, and to observe the objects from another perspective when they practice multiple integrals and when they attempt to determine the boundaries of multiple integrals. The aim of this research was to examine the influence of the mobile learning through dynamic software environment on students' achievements. Also, influence of mobile learning on students' motivation was the topic of this research as well, because students' motivation was poor through the last few years.

II. THEORETICAL BACKGROUND

Some authors showed that the gain score between students who learned with the help of mobile devices and students who didn't use mobile devices was in favour of the first group. These results indicate that the use of mobile technologies make positive responses from students both in terms of how they perceive the mobile activities and how it improved their performance [5]. Cheung and Slavin [6] also find that technology produced a positive effect on students' achievement in comparison to traditional methods. They also indicate that effects vary by the type of educational technology used. Cochraine [7] indicated potential benefits of using mobile technologies for learning include: facilitating learning across contexts, facilitating contextual learning, and providing personalization in both personal and collaborative environments. When it comes to evaluation of mobile learning in mathematics, Crompton and Burke's [8] survey of mobile learning in mathematics showed that 36 of 48 studies reported positive learning outcomes. Similarly, in [5] review of mobile learning studies in mathematics, 77% of 31 studies reported that mobile technologies improved students' achievements. Students' impressions are that the use of mobile technologies is engaging and useful [9]. Those authors

concluded that students saw mobile technologies as useful mathematics tools because they facilitated visualization and encouraged collaborative learning. In many researches [9], [10] in learning environments, students have found mobile devices helpful in terms of facilitating visualization of math concepts. Students explained [11] that the activities made them recall the topics better and helped them visualize the concepts being learned as was the case in other mobile learning studies which matches with foundings in [9]. This is maybe expected reaction of student having in mind that videos, animations and other math manipulatives are typical learning materials that are used to help visualize math concepts both in mobile learning environments and computer-based environments. Some students [11], [12] felt that doing math with the help of mobile devices had helped them grasp abstract math concepts and this resulted with better memory of the learning contents. These students' impressions were supported by a significant improvement in their achievements and with significantly higher gains of the experimental group unlike the control group.

University students are using their mobile phones for communicating by voice, text, and, increasingly, digital photographs and videos.

M-learning is the adoption of any knowledge or skill through using mobile technology regardless of place and time. M-learning does not replace traditional learning but is just another way of learning using a new technology. MoLeNET claims that mobile learning can be broadly defined as "the exploitation of ubiquitous handheld technologies, together with wireless and mobile phone networks, to facilitate, support, enhance and extend the reach of teaching and learning". Mobile learning can take place in any location, at any time, including traditional learning environments such as classrooms as well as in workplaces, at home, at public places and in travel. Mobile technologies include mobile phones, smartphones, iPODs, handheld gaming devices, mini notebooks or netbooks and specialist portable technologies used in science labs, engineering workshops. Mobile learning involves connectivity for downloading, uploading and/or online working via wireless networks, mobile phone networks or both, and linking to institutional systems e.g. virtual learning environments (VLEs) and management information systems (MIS). The concept of m-learning (mobile-learning) has become popular in new instructional design due to the progress and increased usage of new devices and technologies like tablets and mobile phones.

Here are some of the main benefits from mobile learning [13]: Learners can interact with each other and with the practitioner instead of hiding behind large monitors; It's much easier to accommodate several mobile devices in a classroom than several desktop computers; It's possible to share assignments and work collaboratively; learners and practitioners can e-mail, cut, copy and paste text, pass the device around; Mobile devices can be used anywhere, anytime; These devices engage learners - young people who may have lost interest in education. The authors also list some disadvantages: Small mobile and PDA screens limit the amount and type of information that can be displayed; It's difficult to use moving graphics, especially with mobile phones.

Using a system of mobile learning is a bilateral process. On one hand are educators who must develop appropriate learning materials and be able to actively communicate with students; on the other hand are consumers who use the created learning material.

In a review of a mobile – learning literature (Alioona and Delialioglua) from 2015 the authors gave insight in research activities. There was no research from this part of the world, there were just a few researches that refer to higher education (5 from 30) and the most of them were small scale projects (16 of 30). When it comes to devices that were used in this projects smart phones were present in 73% cases.

III. METHODOLOGY OF RESEARCH

The research presented in this paper was conducted in order to investigate the influence of mobile learning on solving multiple integrals within calculus course. It is well known that the majority of students have difficulties with determining the double and triple integrals, and especially with determining the boundaries for the given integrals. The students used *GeoGebra* software, because it enables algebraic and graphical representations of surfaces, simultaneously.

The experimental approach was conducted and the students from experimental group learned with the use of mobile devices, while the students from control group learned face to face.

Sample (Participants)

In our research we considered two groups of second year students from the University of Kragujevac, Serbia, Faculty of Engineering.

- In control group there were 32 Mechanical engineering, Military-industrial engineering and Automotive engineering students in 2018/2019 academic year.
- In control group there were also 32 Mechanical engineering, Military-industrial engineering and Automotive engineering students in 2018/2019 academic year.

There were more students who took these courses, but in our research, we excluded them for a lack of presense to classes.

Instruments and Procedures

Students were divided before the start of the research into two groups for the exercises in multivariate calculus. Students from both the groups on Mathematics 3 course got the same pre-test, where their previous knowledge of integrals was checked. Mathematics education for the students from both groups up to that point was completly identical. The duration of pretest was 30 minutes and the maximum number of points was 30. The pre-test contained problems that required the understanding of the properties of definite integral, substitution rule, partial integration and definite integral application. The results of the students' pre-test were analyzed and compared. Since there were no significant differences between students accomplishments in the experimental and control group (mean difference: -1.376, p=0.35) we carried on with our research.

Both the groups had face-to-face theoretical calculus lectures from the same teacher, at the University and worked on exercises in two groups for three weeks. The control group practiced multiple integrals on traditional way, with chalk and board. For the experimental group, teacher prepared materials (Fig. 2, Fig. 3, Fig. 4, Fig. 5) freely accessible from every mobile device (laptops, tablets and smart phones) with an internet connection. On the practice lessons that addressed to multiple integrals students were introduced with the materials and that *GeoGebra* package got a mobile phones version. Experimental group worked on their project whenever and wherever the students wanted to practise and there were in contact with each other and with the teacher using e-mail, Skype, Viber or WhatsApp (Fig. 1). Students had the freedom to choose their colleagues with whom they communicated, consulted and jointly solved tasks.

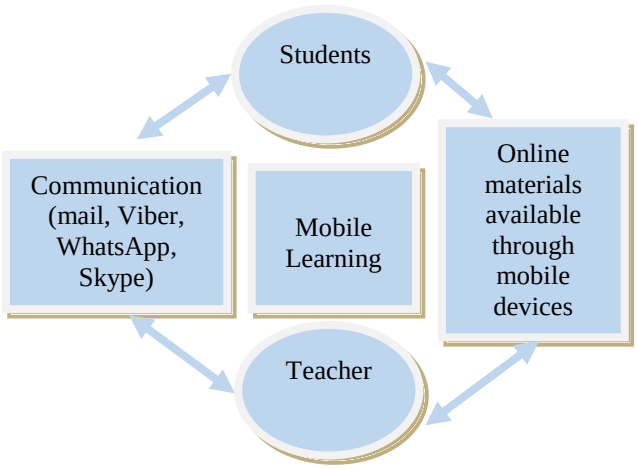

Figure 1. Schema of mobile learning

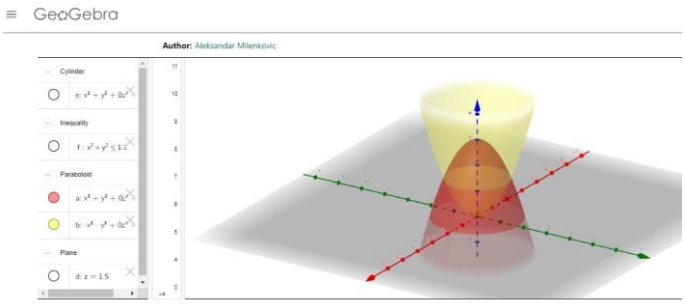

Figure 2. Paraboloids and their intersection in *GeoGebra*

If they wanted to work independently, they were not pressured to cooperate with other colleagues. In a word, students had complete freedom in choosing when and how to cooperate with other colleagues. Students from both the groups solved completely identical tasks in the classroom. For the experimental group, teacher prepared materials in *GeoGebra*, mostly in 3D graphics view. The materials followed the tasks that students had been worked on during the past few years and during this year within control group. So there were no difference between two groups in the tasks, just in the work methods.

Before solving the concrete tasks, teacher showed to experimental group the transition to polar coordinates, prepared in *Geogebra* and posted online on *Geogebra* website which illustrated the interior mapping of the circle into the interior of the rectangle, then mapping the interior of the circular ring to the interior of the smaller rectangle, etc. In the same manner teacher introduced cylindrical coordinates for change of variables, again using materials posted online which illustrated the transition from the one coordinate system to the other coordinate system. Also teacher showed materials that illustrates change with spherical coordinates.

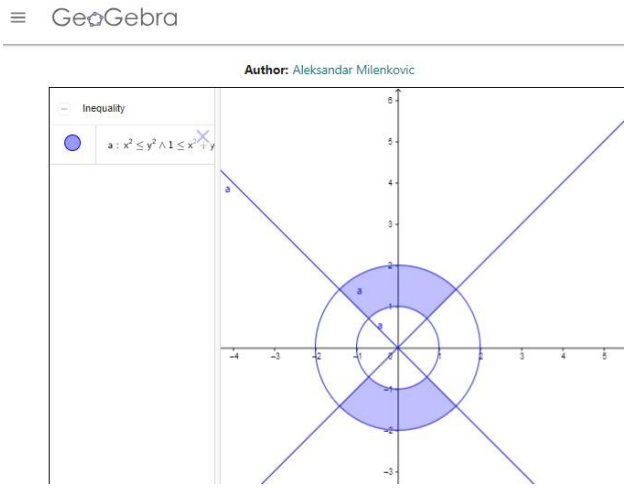

Figure 3. Part of the circular ring in *GeoGebra*

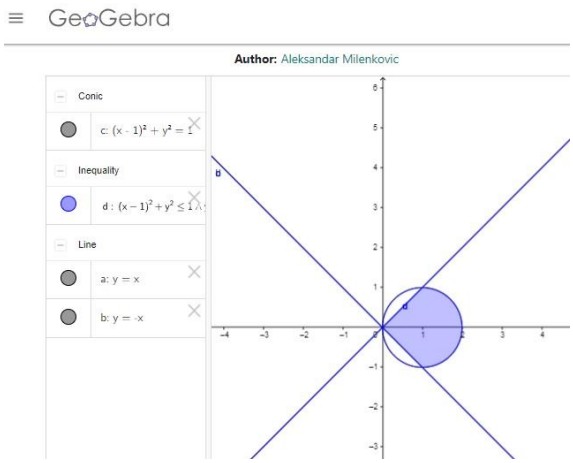

Figure 4. Part of the xOy plane determined by the circle and two lines in *GeoGebra*

The graphs prepared by the teacher contained curves, surfaces, planes, and their cross-sections in space; lines, circles and parabola in plane. Each surface was painted with different color, for better transparency. Appropriate intersections, projections of given intersections to the corresponding plane (mostly on *xOy* plane) were presented. Certain sets of points were immediately presented, while some parts of the graphics were hidden and revealed by the students through the exercise. For every example students tried on their own to determine boundaries for each variable. For that part of the problem, students were solving different equations and inequalities. The results obtained by the students from the experimental and the control group, on the exam, in solving the task related to the multiple integral were compared.

IV. RESULTS AND DISCUSSION

For statistical analysis authors used SPSS Statistics software package. We used Shapiro Wilk test for normality of the sample and then we took Mann-Whitney U test as a non-parametric statistical technique to analyze differences between two data sets (experimental and control group) because the values within the sample did not follow the normal distribution. Pearson's Chi-square test for independence was used to discover if there is a relationship between two categorical variables. All the calculations in the SPSS software were carried out at the level of significance of 0.05.

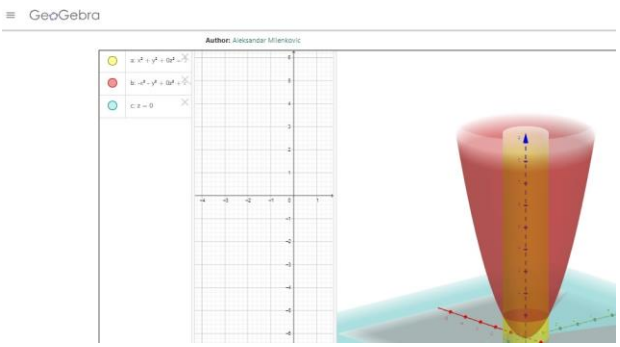

Figure 5. Cylinder and paraboloid and their intersection in *Geogebra*

For the feedback on the influence of the mobile learning on students' motivation, we compared the number of students from the experimental and the control group who tried to solve the multiple integral. From the results obtained in Table 1. and in Fig. 6, it can be noticed that, in contrast to the control group (in which 53,1 % of the students did not even try to solve the task), in the experimental group, 75 % of the students tried to solve the corresponding multiple integral. Assumption that there is statistically significant difference in the number of students of the experimental and control group who tried to solve the corresponding task was tested with the adequate analysis (Hi-square test). Based on the results obtained, there is statistically significant difference in the number of students of the experimental and control group who tried to solve the corresponding task (χ^2= 5,317, df = 1, p =0,04).

Table 1. The ratio of the number of students who tried to solve the multiple integral, depending on the group

Group	Did the student try to solve the double integral		Total
	No	Yes	
Experimental	8	24	32
Control	17	15	32
Total	25	39	64

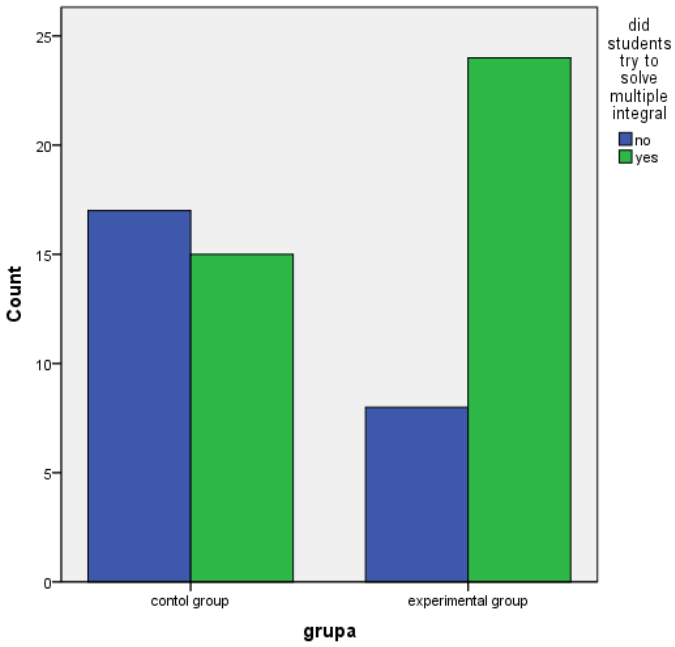

Figure 6. Frequency of solving multiple integral on a test, depending on the group

When it comes to comparing the number of students who have accurately determined the limits for solving the multiple integral from the experimental group and the control group, those differences are presented in Table 2. and Fig. 7. Unlike the control group in which 65.6% did not accurately determine the boundaries of the multiple integral, the results in the experimental group are better. In the experimental group, 62.5% students accurately determined the boundaries for which it was necessary to properly visualize the appropriate surfaces, to find their intersections, to determine the projections on the plane, to solve the corresponding equations and inequalities. Again, based on the students' results, we wanted to examine is there significant difference between the achievements of students who have been learning with the help of mobile devices and students who worked in a traditional way, both in order to precisely determine the boundaries of the multiple integral. As might be expected by the given results, Hi-square test showed that the difference in the number of students of the experimental group and control group that determined the boundaries of the multiple integral correctly, is statistically significant (χ^2= 4,004, df = 1, p =0,045) in favor of the experimental group.

Table 2. The ratio of the number of students who successfully determined the boundaries of the variables for multiple integral, depending on the group

Group	Did the student determine the boundaries for the multiple integral correctly		Total
	No	Yes	
Experimental	12	20	32
Control	21	11	32
Total	33	31	64

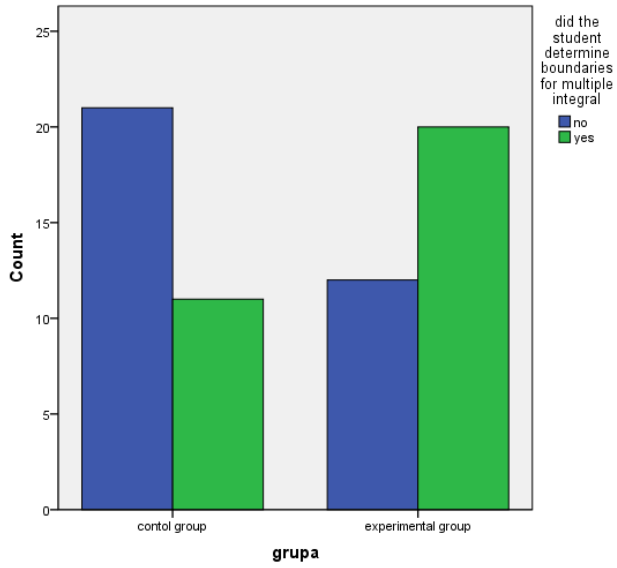

Figure 7. Frequency of exact determining the boundaries of the variables for multiple integral, depending on the group

Table 3. Means and medians of total number of points students scored while solving multiple integral

Group	Number of students	Means	Medians
Experimental	32	5.0462	8
Control	32	3.3438	0

Finally, we were interested in the extent to which students' success in determining the boundaries for multiple integrals affects the overall efficiency when it comes to solving the multiple integral. For this purpose, we compared the total number of points that the students from both groups scored by solving the multiple integral. As we mentioned earlier, the total number of points within the sample did not follow the normal distribution. Therefore, we used Mann-Whitney U test for comparing those results. On the basis of statistical data such as arithmetic means and medians of the number of points that students achieved while they were solving a multiple integral (Table 3), a significant difference can be assumed in favor of the students of the experimental group. However, the Mann-Whitney U test does not recognize this difference. Based on the results of the given test (Z= -1.644, p=0.1), we conclude that the difference between the experimental and control group is not statistically significant. This can be explained in a way by a small sample, small number of students who participated in this research, but also authors noticed that in most cases, students who have precisely determined the boundaries, did not have much difficulty in calculating the integral.

V. CONLUSION

In this research the influence of mobile learning in determining boundaries of multiple integrals with the help of materials prepared in *GeoGebra*, mostly in 3D, is analyzed. The second year university students from Faculty of Engineering, Kragujevac, Serbia, were considered, during their Mathematics 3 course in 2018/2019 and students' ability to determine boundaries for multiple integrals was examined. For the experimental group, teacher prepared materials freely accessible from every mobile device (laptops, tablets and smart phones) with an internet connection, while the control group practiced multiple integrals with chalk and board only (without the use of mobile devices).

The students from experimental group could organize their learning outside of the classroom, at their own pase, where, when and with whom they wanted, able to connect with teacher by mail, Skype, Facebook, Viber or WatsApp. During their exercise students had the opportunity to move and rotate images of surfaces and their intersections on their mobile devices (mostly smartphones) with the goal to precisely determine boundaries for the multiple integrals.

The results showed that the difference in the number of students of the experimental group and control group, who tried to solve the multiple integral is statistically significant. This result is in favor of learning the content of multiple integrals with the help of mobile devices, and that mobile learning enhances students' interest in mathematics and provides better students' motivation.

The differences between the number of students who precisely determined the boundaries of multiple integral is also statistically significant in favor of the students who used mobile devices while learning multiple integrals. This result must be emphasized because it represents the immediate impact of mobile learning presented in this paper.

At the end, there were no statistically important difference between two groups in the total number of points that students scored while solving multiple integral. One of the reasons is that students who determined boundaries of the integral correctly, generally did not have further difficulties in calculating the integral, which also indicates the importance of determining the boundaries of the multiple integral and point out that part of the task as crutial.

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Investigating Gender Gap in Computer Science Research Community

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***Abstract* - With the emerging information age, the worldwide concerns about the gender gap in computing careers are gaining more importance. Although there are many initiatives going on, still continues the presence of a notable absence of women in the field. Many of the papers analyze the reasons behind this phenomenon and give recommendations on how to increase the participation of women in computer science. The participation in some papers represents the gender gap in the number of students, in other the number of graduates or number of employees.**

The study presented in this paper includes a review of the research papers that tackle the issue of gender gap in computer science from various perspectives. It includes a concrete investigation of the gender gap based on the research publications by exploring the DBLP. We show the methodology for gathering these papers from the DBLP database, including their authors. The gained results are analyzed and presented, showing the gender distribution among the authors, through years and in different categories.

Keywords - CS, gender gap, DBLP, Computer Science Research Community

I. INTRODUCTION

Even though women are increasingly studying Science, Technology, Engineering, Mathematics at University, they are less often trained in research groups, are promoted more slowly, and are more likely to run off computer science careers.

The problem of gender inequity in science is not a novelty. It began to shift into the public eye since the year 1970 driven by the movement of Second Wave Feminism, which sparked a growing interest in the area. Nowadays, the topic has remained in the focus of the scientific community, despite many initiatives to encourage female scientists. Many research publications in the recent years point on the persistence of a gender gap in science leading to discussions about the primary reasons. The problem remains universal and deeply settled in the scientific world and is a subject of constant re-evaluation by research methods [7], [13].

Gender diversity and women's involvement in science can be expected to contribute to knowledge creation and scientific discoveries, female scientists remain a minority in multiple scholarly fields, such as those related to science, technology and mathematics, both as authors of scientific articles and as holders of senior positions in academia. Recent studies indicate, that women have represented less of full-time faculty members across various scientific domains. It is about a relatively limited gender diversity in terms of academic appointments at research universities, as gender parity continues to be elusive in terms of women's senior faculty and leadership position appointments. In many states, female scientists may struggle to have equal compensation, to stay in tenure-track career paths and to have a work-life balance, due to child-care responsibilities [9], [10].

This gender gap has also been found in relation to scientific paper authorship, that intergenerational effects are likely to lead to the unequal representation of women in some scholarly fields, such as technology and engineering, even though gender parity has been found to be improving in science in general and already present in some scientific domains, as part of growing gender equality in recent years [6].

In line with this, a study showed that the literature dedicated to the analysis of the difference in research productivity between the genders tends to agree in indicating better performance for men. For instance, through bibliometric examination of the entire population of research personnel working in the scientific-technological disciplines of Italian university system, a study confirms the presence of significant differences in productivity between men and women. The differences are, however, minor than stated in a large part of the literature, showing an ongoing trend towards decline, and are also seen as more noticeable for quantitative performance indicators than other indicators. On the other hand, the gender gap shows significant sectorial differences and regardless the commonly better performance of men, there are scientific fields in which the performance of women doesn't appear as inferior [3].

Academic publications remain the primary means of disseminating scientific knowledge and the principal measure of research productivity and therefore impact the career advances and visibility of women in computer science [1].

Many studies on gender have shown that female scientists tend to publish fewer publications than their male colleagues. This pattern has been found across many fields and nations [2],[4],[5],[12],[14]. In this direction we aimed to broaden our research beyond universities, countries or regions, and to give a contribution in terms of the female/ male ratio in terms of research publications in computer science based on the latest data available globally.

For the purposes of this research we have used DBLP Computer Science Bibliography. This service provides open bibliographic information on major computer science journals and proceedings. DBLP indexes more than 4 million articles and contains titles of articles, their authors, years of publication etc.

II. METHODOLOGY

The DBLP dataset is downloadable and represents a very interesting resource for investigating the trends in terms of research fields, most productive authors as well as evolution analysis of various aspects of research publications [8].

Further on, we used the Python library Gender-guesser to detect the author gender from author name, which shows accuracy of 97.34% [11]. This library sets a name to be unknown (name not found), andy (androgynous), male, female, mostly_male, or mostly_female. In our further work we have considered only those cases that are detected as female or male.

First analysis is made about most productive DBLP authors or in other words authors with largest number of publications. We have investigated twelve different categories, according to the DBLP partition: in the first category are authors with more than 750 papers, in the second category authors between 650 and 750 papers etc.

In our second analysis, we have created three datasets from the DBLP database, in json format (Figure 1).

{"title":["Parallel Integer Sorting and Simulation Amongst CRCW Models."],"author":["Sanjeev Saxena"],"year":["1996"],"journal":["Acta Inf."],"pages":["13"]},{"title":["Pattern Matching in Trees and Nets."],"author":["Hans Ulrich Simon"],"year":["1983"],"journal":["Acta Inf."],"pages":["22"]},{"title":["NP-complete Problems Simplified on Tree Schemas."],"author":["Nathan Goodman","Oded Shmueli"],"year":["1983"],"journal":["Acta Inf."],"pages":["8"]}

Figure 1. Part of json file about articles

These datasets contain data for three categories based on types of publications:

- articles (journal publications) - counting 1952444 papers.
- books - counting 15617 books.
- conference proceedings - counting 2361456 papers.

III. ANALYSIS

Below are presented the tables and the analysis of the ratio female/male on the data gained from the DBLP. The first analysis is performed from the perspective of the most productive authors and the second one is based on the type of the publications.

A. *Analysis of the female/male ratio based on the productivity of the authors*

In this part are presented the data that were gained from the DBPL library, based on the number of published papers. It is important to note that the study is based only on the number of published papers and it doesn't include the index of the authors or other elements form the DBLP.

As shown in Tab.I, the analysis includes 12 categories as defined in the DBLP. The criterion for categories is number of published papers by author.

The table includes columns for all the data selected by the Gender guesser library, but, in order to be more accurate on the ratio presented (last column)we have considered only the columns male and female which include authors which definitely are from the stated gender.

TABLE I THE DISTRIBUTION OF THE AUTHORS BASED ON THE MUNBER OF THE PUBLICATIONS

Category	Criteria	male	female	mostly_male	mostly_fema	andy	unknown	ratio female/male
1	>750	17	1	4	0	27	10	0.059
2	630-749	23	2	3	0	21	10	0.087
3	550-629	35	4	4	0	21	6	0.114
4	485-549	44	4	1	1	33	14	0.091
5	430-484	67	4	7	1	33	31	0.060
6	380-429	95	8	3	1	33	62	0.084
7	330-379	141	15	8	1	53	85	0.106
8	280-329	276	25	15	5	105	143	0.091
9	230-279	610	75	33	9	138	261	0.123
10	180-229	1223	162	70	15	297	525	0.132
11	130-179	2864	371	128	39	535	1114	0.130
12	80-129	8007	1256	379	108	1322	3316	0.157

The graphical view of the ratio between the female and male authors for all categories is presented in Fig.3

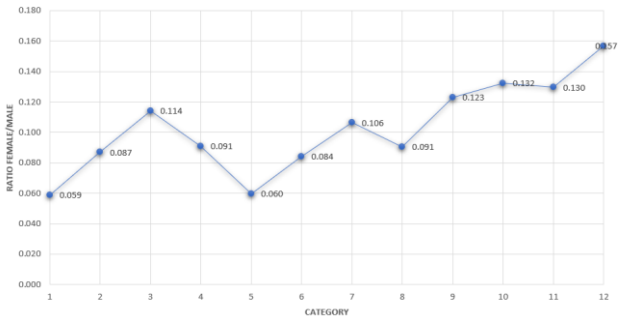

Figure 2. The ratio of the female and male authors among categories

As it can be seen in Fig.2, in the initial categories, which contain the most productive authors, the female male ratio is with lower values which shows a greater gender gap between the authors. As we move towards the categories with authors who are less productive the gap is decreased although not continuously. This fact was mentioned on several research papers for many fields [4],[6]. This confirms that the same trend is present in the computer science field as well.

B. *Analysis of the female/male ratio based on the type of publications*

Another aspect of our research was to analyze the gender gap between the authors based on type of publications: journal articles, books and conference proceedings. The investigation about the female participation in publishing computer science papers is made for each category particularly. In addition, in this part we have considered the year of publication. The idea

was to track the changing path of the gender gap among researchers through the years.

Fig.3, Fig. 4 and Fig.5 are graphical representation of the investigation realized.

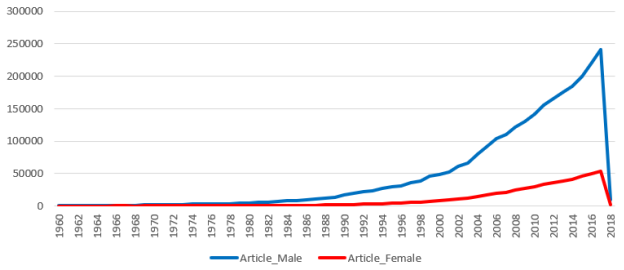

Figure 3. Evolution of the number of journal publications through years.

As it can be seen, these charts include data from 1960 till 2018. It is interesting to note that the gender gap, in all three categories, is slightly expressed until 1980. The radical increase of this gap is in the last 40 years. The drop at the and of the chart is due to the date when the data were extracted from the DBLP and it still didn't include the overall data from the last year.

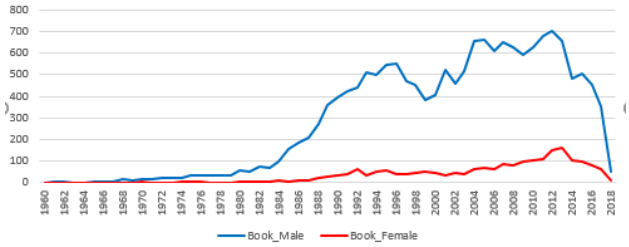

Figure 4. Evolution of the number of book publications through years.

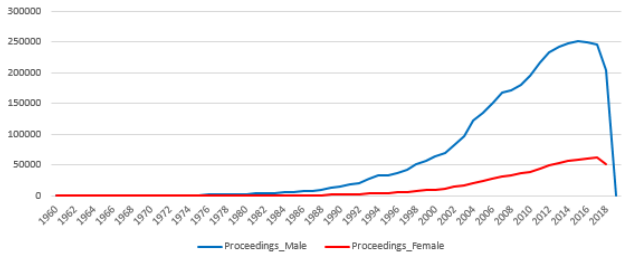

Figure 5. Evolution of the number of conference proceedings through years.

An overall graphical representation including all three categories and their change through the years is presented in Fig. 6. More precisely this figure includes the evolution of the female/male ratio for books, journal articles and conference proceedings. As it can be seen, while for the books category the gender ratio has some oscillations since books are published to a lower extend compared with articles and conference papers, for the categories of conference proceedings and journal articles the increase on the gender gap is continuous.

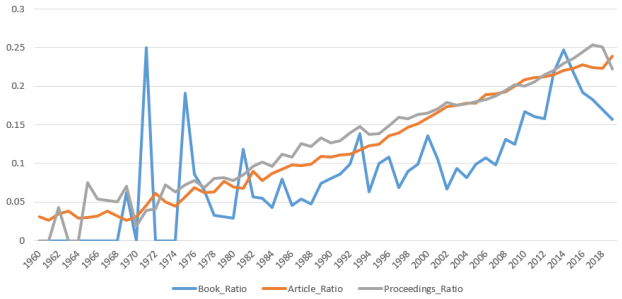

Figure 6. Female/male publishing ratio through years

IV. INVESTIGATION OF THE FEMALE RESEARCHERS AS COAUTHORS

As part of this study we also considered the role of the female authors as coauthors on a research publication. Hence, in addition to the previous analysis, we have produced a list of coauthors where at least one of the authors is female, aiming to better understand the interaction of the female authors with other authors.

The methodology included filtering the publications who had at least one author identified as 'female'. Further on, from this set, we have created separate subsets for research papers, depending on the total number of authors: one, two, three and so one. For each publication we have put a metric index, which shows the order number for the female authors on a publication as coauthor on a research publication. And then, for each subset we have calculated the average order position of the female authors.

For instance, in cases where the female author is the single author of a publication, the index is 1; in cases when the female author is a coauthor on a publication with two author the value of the index is 1.5 showing that the female author is usually on the second position.

This methodology was applied for all three DBLP categories: books, journal articles and conference proceedings. The results are shown on Fig. 7, Fig. 8 and Fig. 9 respectively.



Figure 7. Index of female researchers as coauthors in the category: Journal articles

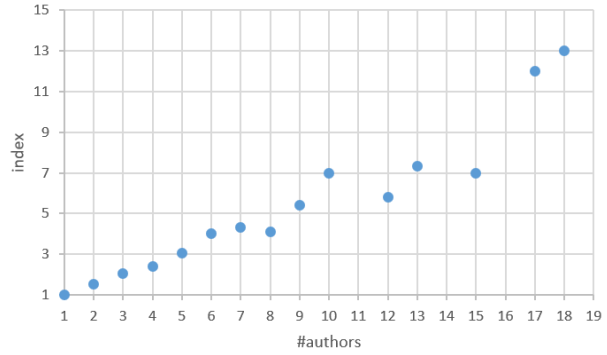

Figure 8. Index of female researchers as coauthors in category: Books

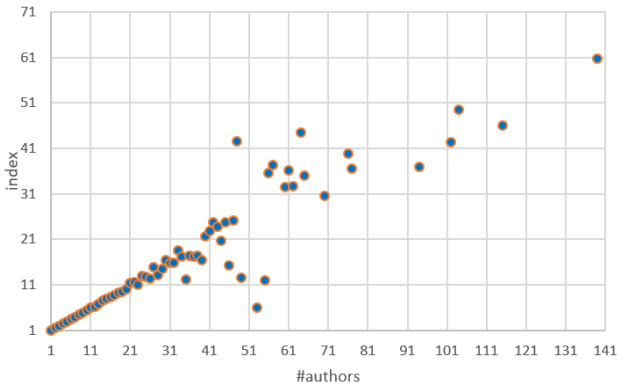

Figure 9. Index of female researchers as coauthors in the category: Conference proceedings

The last three charts that represent the data generated from this part of the study, due to the huge number of values generated do not include spot values, but however it can be seen that the order number of female authors in a publication in average is at the middle or in the second half of the list of the authors.

Also, the average value of the ratio of the position of the female authors in the list of authors versus the overall number of the authors list is:

- 0.629042183 - for journal articles
- 0.647245061 for books
- 0.62956506 for conference proceedings

As it can be noticed, in general, in all three categories the value of these ratios is around 0.6.

V. CONCLUSION

The publication rate between genders depends on a wide range of factors that cannot easily be measured, like the availability of research funds, teaching loads, technical equipment, support of research assistants, workload policies, faculty culture and working conditions, organizational background as well as talent and hard work.

However, this study does not focus on the factors but mainly on the investigation and quantification of the gender gap in the research publications in computer science field in several aspects and categories. At the same time the evolution of the ratio female/male publication through the years is presented.

At this point it should be noted that the analysis conducted, and the data presented are correct to a large extend but is conceivable that there is small percentage of authors whose names cannot be identified by the 'Gender Guesser' as female and neither as male and hence they were not included under female or male category during the study.

As the main activities in terms of future work we plan to:

- analyze the behavior of the genders in co-authorship community using social network analysis, for example how authors behave with authors of the same gender and the opposite gender; identify if there is a tendency that authors are clustered in groups of the same gender; identify influencers among female authors etc.
- to automatically identify fields of research for females using machine learning approaches to analyze papers written by them.
- to automatically identify the authors affiliation and investigate their distribution by countries.

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GitHub as backbone in Software Engineering course: Technology acceptance analysis

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***Abstract* - In the field of software engineering education, continuous adjustment of course content and technologies with real-working environment is crucial for developing students' skills that meet the needs of the labor market. The main goal of this paper is to present the research result regarding the use of GitHub in Software Engineering course which has characteristics of real-working environment: students are divided into up-to-five-member teams with adequate development roles and during the semester are working on project which encompasses full software development life-cycle. A pilot study was conducted in the end of the summer semester of academic year 2017/2018 on the sample of undergraduate students (N=78) whose study field is related to informatics. New measuring instrument was developed and consisted of scales related to the UTAUT (Unified Theory of Acceptance and Use of Technology) model, but also those related to learning value, learning satisfaction and ease of use to investigate in detail students' acceptance of GitHub in context of software engineering learning. Results of the study outlined following remarks: students find GitHub useful in team coding projects, its ease of use has positive effect on students' acceptance, as well as on learning satisfaction and learning value of software engineering in practice.**

Key words* - *GitHub, UTAUT, software engineering, technology acceptance

I. INTRODUCTION

As Information and Communication Technology (ICT) is inevitable part of modern education, concept of online social learning is intensively (re)shaping future ways of teaching and acquiring knowledge in Software Engineering courses. In this concept of social learning, peers (students) simultaneously consume and generate course content on different levels of interactions: peer-to-peer, student-to-instructor [1], but also connect with wider programming community using online collaborative social platforms as GitHub, social networks, YouTube channels, MOOCs [2] or Q&A sites like Stack Overflow [3]. In Software Engineering work environment, but also educational settings on universities, GitHub is one of the most popular social coding platforms which allows users (in this study: students) to keep tracking of their code, its versions and changes and to easily collaborate on open source software projects and activities. Microsoft's acquisition of GitHub in June of 2018 was a point-blank sign for 28 million of developers using platform that this giant wants to empower IT professional community throughout learning, sharing and working together to create software [4].

In educational context of Software Engineering, advantages of using GitHub (or similar version control and social coding platforms like BitBucket) are on the both sides involved: teachers use platform for course materials distribution, collecting project-coding assignments and creating collaborative environment for students' teams [5].

Both, theory and practice point out that GitHub as an collaborative and version control tool should be introduced in education process as it brings different benefits to the students such as transparency in learning and peer learning, access to technology, direct feedback and self-promotion [6], easy coordination and less work downtime [7], easy contribution to existing open-source projects that help to form personal opinion on their technological, quality or other aspects [8], it increased the number of interactions [9] and it is *de-fact standard* used in industry projects.

From students' perspective, most important GitHub's benefits are: transparency which allows learning from others and continuous monitoring other team members activities in every development phase, motivation in competitive educational context [10], access to technical knowledge, developer self-promotion [6], but also bridge to real-working environment (e.g. job ads listing GitHub experience as demanding technical skill for IT, or using GitHub as professional portfolio when applying for open positions) [5].

Even though GitHub is not a pioneering technology in education, still students are mostly unfamiliar with it due to instructors' lack of awareness of its benefits and relevance in real-working environment. In IT sector, social collaboration is important because it implies working with others to achieve a common goal, and consequently social worker is skillful in using such tools to manage job-related tasks and projects [11].

Technology acceptance models like UTAUT (*Unified Theory* of *Acceptance and Use of Technology)* or TAM (*Technology Acceptance Model*) are widely used to expand the understanding of technology actual usage and acceptance. Yet, GitHub's acceptance by students - its actual role/potential in the field of Software Engineering education and technical skills development - is still new and unknown research area.

UTAUT constructs regarding the usage and acceptance of technology are facilitating conditions, performance

expectancy, effort expectancy, social influence and behavioral intention [12]. Model has been used in various researches in educational contexts: e-learning, mobile learning, video lecturing etc.

Authors [13] stress that understanding of factors that are crucial for implementation of new instructional technologies in education should be looked thorough social influence, one of the constructs of UTAUT model. Among students, technology adoption is strongly influenced by peers and their opinions. Since GitHub is a collaborative social coding platform, social influence is relevant on different levels: peer-to-peer, teacher-to-student and wider developer community in general due to GitHub's transparency and opinions for self-promotion, communication and learning from others. Positive perception of social influence by peers positively relates to students' behavioral intention to use technology. UTAUT model was used in assessment of students' behavioral intention to use desktop video conferencing in distance course, but autonomy variable was added to extend the model and improve the predictive value of model. Results of this empirical study show [14] that students' behavioral intention to use such technology is driven by their expectations that outcomes of its use will help them in acquiring knowledge (academic performance in general), their peers and faculty members believe they should use it. Yet, technical problems that could interrupt students' learning should be resolved quickly.

Results of study [15] focused on LMS (*learning management system)* use examined UTAUT model extended with learning value show similar conclusions: students' intention to use LMS is positively related to their perception of its usefulness for academic activities. Moreover, in settings where use of technology is mandatory, students' intention to use LMS is influenced by teachers' and colleagues' explication of its benefits so social influence is crucial in every technology adoption process.

An extended UTAUT2 model suggested by [16] to examine acceptance software engineering tools in academic education. In this study students' acceptance of CASE tool used for IS modeling and supporting Agile practices was examined. Behavioral intention was mostly explained with performance expectancy which was strongly influenced by two independent variables from UTAUT2 model: effort expectancy and social influence. Taking into consideration new variables extending UTAUT2 model, Model Interchange variable had the greatest impact on students' intention to use CASE tool. Items related to assessment of this variable included tool's features as exporting and importing diagrams and models, integration of developed documentation with other tools, and implementation of project in different tool versions and editions with regard to backward.

This research was partially financed by the Grant of University of Zagreb for Science and Research in 2018 related to the use of smart technologies in students' learning ecosystem in order to predict learning results.

From the results of motioned studies, it can be concluded that performance expectancy and behavioral intention are positively related in context of students' acceptance of technology in educational settings. Regardless different context of technology use, UTAUT model can be used as baseline for determine students' acceptance and use of technology in Software Engineering education, but also additional variables should be added to explain more precisely predictors for collaborative platforms like GitHub. Researches constantly attempt to expand the model to find other determinants to predict variance in dependent variable, which in case of UTAUT is *behavioral intention* to use some technology. In this pilot study additional variables were included to go beyond original UTAUT model. Basis was extensive literature review in which collaborative social coding platforms were taken from the students' perspective. Therefore, learning value, learning satisfaction and perceived ease of use of technology were included. Variables are explained in *Measuring instrument* section.

II. METHODOLOGY

A. Context of the study

As a part of a continuous improvement of course content and teaching methodology we introduced the use of GitHub in our course on Software Engineering more than five years ago. The course is performed in the last semester of the bachelor's degree study program and it builds on the previously acquired knowledge in programming, object-oriented paradigm, database management and administration, business process modeling, user interface design and project management. However, the students had no prior knowledge on the use of GitHub in programming.

The course activities, which were finished before the study was performed had the goal of introducing the students with the theory and practice of software engineering and as such included the lectures and case-studies related to the use of GitHub and possible workflows, preparation and defense of laboratory exercises on the use of GitHub in practice and continuous work on practical assignment - project. While working on projects, students have been divided into up-to-five-member teams, were given a mentor who closely monitored, guided, feedbacked and finally evaluated their activities. Projects included the performance of full-scale software development life-cycle including the activities of user-requirement analysis and specification, design, development, testing, deployment and documentation of software product. For the first time during their bachelor's education students have performed such complex project.

Such educational setting offers students the insight into a real working environment where they will have to solve complex software engineering problems by leaning on team work, collaboration and direct feedback. Back-to-back with other important technologies, collaborative and version control platforms like GitHub also represent a base for implementation of highly popular DevOps practices like continuous integration, testing and deployment which

brings additional learning value and hopefully increases a learning satisfaction of students.

B. Problem and research goals

To fulfill discovered literature and research gap on using GitHub for specific Software Engineering learning and teaching activities, main goal of this case study analysis was to disclose if additional variables (learning satisfaction, learning value, perceived ease of use) can be integrated with UTAUT model as predictors of students' intention towards GitHub use in software development activities. UTAUT is very robust model and can explain up to 70% of variance in dependent, but appropriateness of new measuring instrument should be taken into consideration [16].

C. Respondents

Respondents in the study were undergraduate students (N=78) from one Croatian university who took the Software Engineering course. The majority or students (94.94%) were full time students, mostly aged from 21 to 23 years, while 7.62% were aged from 24 to 26. By gender, 60 male and 18 female students participated in this study.

D. Measuring instrument

Research was conducted by Google Forms online survey in the end of the summer semester after students finished their course and project activities. Participation in research was completely voluntary and anonymous. The findings of the research in this paper represent a more detailed analysis of the data from pilot study which was conducted in the 2017/2018 academic year. The results of first part of the research devoted to UTAUT model and collaborative learning were presented on another conference [17]. After a literature review, a new measuring instrument adjusted to GitHub context was built upon variables related to: (a) UTAUT model (*facilitating conditions*, *performance expectancy*, *effort expectancy*, *social influence* and *behavioral intention*) (b) learning value; (c) learning satisfaction and (d) perceived ease of use of technology. UTAUT constructs were adapted to GitHub context from more general research and tested measuring instrument for the *Acceptance of Software Engineering Tools in Academic Educatio*n [16]. Survey included socio-demographic questions and five-point *Likert*-type scale was used as attitude and opinion measure. Since UTAUT constructs included in study were described in detail in previous report, in this paper focus will be given on learning value, learning satisfaction and ease of use of technology. It is important to stress that all of the items in study were related to GitHub and students experience with using it for project activities. Students were not questioned about overall course satisfaction – focus was on GitHub which was clearly stated in purpose of study. Furthermore, in each item keyword GitHub was mentioned so students could easily assess their opinions upon this platform.

Learning value construct was adapted from study [15] where authors assumed that learning value influences the behavioral intention to use LMS. For this research, items were adjusted for GitHub context (*e.g. "Learning through program assignments / projects in GitHub is worth more than the time and effort I have invested in this activity.")* and construct consisted of four items.

Learning value from students' perspective refers to benefits gained from time and effort invested in learning and working on projects in particular environment. Comparing learning value to Venkatesh et al.'s (2012) price value definition, authors stress that if students' investment time and effort has positive learning value, students will have positive attitude for using technology [15] [18].

Learning satisfaction was often questioned in previous computer-mediated learning studies from the stand point for users' acceptance of technology and to determine students' attitude towards technology. Learning satisfaction construct consisted of five items (*e.g. "I am satisfied with my learning activities using GitHub.")* and were adapted to GitHub context from study [19].

Interesting aspect related to GitHub is peer-to-peer learning that in online environment leads to greater students' satisfaction [20] but still, positive learning environment is important. Students' satisfaction drivers are effective peer-to-peer interactions and student-to-instructor interactions that improve learning climate in online context [21].

Perceived *ease of use of technology* construct numbered six items (*e.g. "I make no mistakes using GitHub"*.) which were adopted and adapted from original Davis's TAM (Technology Acceptance Model) research to specific GitHub context. *Perceived ease of use* refers to ones' belief that using technology will be effortless. Since this construct is not part of original UTAUT model, it was included in research because Davis suggests that the ease of use of technology affects users' intention to use it [22].

Reliability of constructs included for analysis in this study were examined using *Cronbach's alpha coefficient.* This step in necessary because items in questionnaire were adapted from other studies and adjusted to specific GitHub context. It is crucial to determine whether for some constructs additional items should be included or excluded for future versions of measuring instrument.

It is important to note that internal consistency of UTAUT constructs was analyzed and reported in our previous study. In the case of *Learning satisfaction* (α=0.806) and *Perceived ease of use* (α=0.851) Cronbach's alpha coefficient values were higher than the suggested benchmark value of 0.70 [21]. Cronbach alpha value for *Learning value* construct (α=0.640) was below 0.7 which reveals that additional items should be included in future research.

III. RESULTS AND INTERPRETATION

A. Regression analysis

For data and statistical analysis IBM SPSS Statistic 23 was used. Regression analysis was conducted to reveal how dependent variable – behavioral intention of students using GitHub can be explained remaining variables from

UTAUT model with and additional ones included in study: learning satisfaction, learning value and perceived ease of use. Calculated multiple correlation coefficient (R) for *behavioral intention* was R=0.778 indicating a good level of prediction. Regression model is shown in *Table I*. The coefficient of determination (R^2=0.606) indicates that 60.6% (R^2=0.606) variability of dependent variable (behavioral intention) can be explained with independent variables included in study.

TABLE I. MODEL SUMMARY- BEHAVIORAL INTENTION (N=78)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.778[a]	.606	.566	2.21804

a. Predictors: (Constant), Facilitating conditions, Performance expectancy, Effort expectancy, Social influence, Learning value, Learning satisfaction, Perceived ease of use.

To determine which variables can be used as predictors for students' behavioral intention, from further analysis can be concluded that *Perceived ease of use* (p=0.003) and Learning satisfaction (p=0.034) are statistically significant variables that can be used for predicting students' intention towards the use of GitHub. In case of other variables included in the study, p>0.05 so they cannot be considered as predictors of dependent variable *behavioral intention* (see *Table II*). From the proposed model, behavioral intention varies on two independent variables as follows: *behavioral intention = 0.932 + (0.139*perceived ease of use) + (0.228*learning satisfaction).*

TABLE II. STATISTICAL SIGNIFICANCE OF INDEPENDENT VARIABLES AND ESTIMATED MODEL COEFFICIENTS [A] (N=78)

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Constant	-.932	2.116		-.440	
Facilitating conditions	-.105	.093	-.117	-1.138	.661
Performance expectancy	.056	.094	.084	.591	.259
Social influence	.362	.116	.335	3.125	.556
Effort expectancy	-.100	.127	-.099	-.786	.077
Perceived ease of use	**.139**	**.071**	**.200**	**1.958**	**.003**
Learning value	.308	.143	.234	2.158	.054
Learning satisfaction	**.228**	**.127**	**.272**	**1.796**	**.034**

A. Dependent Variable: Behavioral intention

TABLE III. DETERMINING THE STATISTICAL SIGNIFICANCE OF THE MODEL (N=78)

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	529.122	7	75.589	15.37	.000[b]
	Residual	344.378	70	4.92		
	Total	873.5	77			

a. Dependent Variable: Behavioral intention
b. Predictors: (Constant), Facilitating conditions, Performance expectancy, Effort expectancy, Social influence, Learning value, Learning satisfaction, Perceived ease of use.

Overall regression model corresponds to data analyzed in this case study (p<0.0005) and numerical expression of dependent variable behavioral intention from UTAUT model is: F(7,70=15,37,p<0.0005,R^2=0.606). Independent variables that are statistically significant (p<0.05) are *perceived ease of use* and *learning satisfaction*.

B. Discussion

Results of this study reveal that variables from UTAUT model (*Facilitating conditions, Performance expectancy, Effort expectancy, Social influence*) are not statistically significant predictors for variance of depended variable – *behavioral intention* of students to use GitHub for academic purposes if in regression analysis additional variables are included.

On the other hand, *perceived ease* of use and *learning satisfaction* proved to be as predictors for students' behavioral intention, and regression model in general explains 60,6% of variability of dependent variable (behavioral intention) with independent variables.

Even though perceived ease of use and learning satisfaction revealed as statistically important and their internal consistency is good, comparing the results of our previous study on the same data set opens several questions that should be discussed. Results of our previous study, where only UTAUT model variables were included in regression analysis, *performance expectancy* and *social influence* revealed to be statistically significant variables that can be used as predictors for *behavioral intention* [17]. Adding independent variables that seemed relevant from literature, changed the predictors of variability of behavioral intention. Also, results of regression analysis of this study explained 60.6% variability of the dependent variable (scores of the *Behavioral Intention Scale*) in the regression model and in previous (UTAUT-only) score was 50,4%.

In the context of the results examined in this and previous studies, some changes in measuring instrument and research model should be done. The main reasons that may be cause are complex learning, yet social collaboration environment, different technologies students use in classrooms, but also their motivation.

IV. CONCLUSION

From the results of this pilot study in which UTAUT was used as backbone to reveal students' acceptance of GitHub, several conclusions revealed:

- variables outside UTAUT model may have an important role in understanding students' actual intention to use social coding platforms. In our study perceived ease of use from TAM and learning satisfaction turn out to be statistically relevant;
- measuring instrument should be improved throughout interviews with students to determine what is important in academic settings and GitHub adoption;

- sample from pilot study is very homogenous and new developed measuring instrument should be tested and checked in other environments (for example - other university).

Analysis from pilot study so far only clarify how complex the learning environment in Software Engineering is from students' perspective, but also instructor's role, especially setting up course environment should be included in future study.

As far as future work is concerned, great challenge may be number of Software engineering courses where GitHub is used in similar work-imitation academic settings where instructor is focused on students' learning satisfaction, learning value and peer-to-peer learning.

Other limitations arise from purposive sampling – this study included point of view of students from one course so results cannot be generalized. Since the purpose of pilot study was to determine if chosen variables were adequate for extending the UTAUT model for exploring predictors of student's acceptance of GitHub in more mature phase of research the range of generalization of the results will be widened. In this study another part of results from pilot study was analyzed and in future research with new and validated measuring instrument gathered data will be applicable for generalization and comparison with similar researches in IT educational context of using software development supporting technologies.

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Analyses of possibilities of Flipped Classroom in Teaching Computer Science Courses

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***Abstract*—The flipped classroom is the new educational model in using technology to impact and enhanced education. From the published research on Flipped classroom concluded that has not been rigorously evaluated as a pedagogy but case studies are emerging. This research study focused on analyzing possibilities of flipped classroom in Computer Sciences particularly focusing on its implementation in 3 (three) courses: Programming. Object Oriented Programming and software engineering. Measured are Motivation of lecturer and motivation of student, increased attendance, better grades, access to learning materials, learning at own peace, better understanding, higher-level cognitive skills. Also flipped classroom impact on the learning outcomes has been investigated: Knowledge and understanding, Applying knowledge and understanding, Making judgment, Communications skills. Four broad categories of instructional approaches for use in an flipped classroom have been identified: (a) individual activities, (b) paired activities, (c) informal small groups, and (d) cooperative student projects. The research study is based on the theory of Bloom's revised taxonomy of cognitive domain. In order to analyze this, a case study experiment was realized and insights as well as recommendations are presented.**

Keywords— Flipped classroom, programming robotics, effectiveness of learning, flipped classroom paradigm

I. INTRODUCTION

The main objective of this research are the following analyses:

- Quantitative empirical analyses of flipped classroom
  - Analyse the efficiency of knowledge transfer
  - Increased information communication and manipulation
  - Increased accessibility to learning
  - Does it reduce bias and student retention
  - Measure impact in active learning towards passive one
  - Measure motivation
  - Higher-level cognitive skills
  - Measure impact on Learning Outcomes

The main aim of the research study is to investigate and assess the impacts of the flipped classroom model of student learning in several Computer Science courses like: Programming, Object Oriented Programming and Software Engineering. Flipped classroom is an approach to learning where swapped are the arrangement of knowledge imparting and knowledge transfer comparing to traditional teaching and learning. Assessment of learners on their attitudes, motivation, and effectiveness when using flipped classroom compared with traditional classroom has been realized. Also the assessment of whether it has any advantages ere over the traditional teaching methods in computer sciences has been investigated. There is a difference between a Flipped Classroom and Flipped Learning. These terms are not interchangeable. Flipping a class can, but does not necessarily, lead to Flipped Learning. Four broad categories of instructional approaches for use in an flipped classroom have been identified: (a) individual activities, (b) paired activities, (c) informal small groups, and (d) cooperative student projects. The research study is based on the theory of Bloom's revised taxonomy of cognitive domain. This taxonomy provides six levels of learning provided in the research methodology section.

The technological innovations and different collaboration tools have changed the face of education [2]. Using new technologies students can organize their learning process independently and become an active learner instead of the passive learner [8]. As a relatively new model of instruction, educators understandably desire evidence that the Flipped classroom model has a positive impact on important student outcomes, including achievement and engagement.

This situation forces the education paradigm to change from traditional instructor-centered to student-centered classroom. Therefore, technology plays a big role in this change by using its various online/offline tools and devices. We have been evidencing that the modern technology plays a significant role in our education system.

II. BACKGROUND RESEARCH

According to [1] the flipped classroom is a pedagogical method that helps educators to utilize the technology as a tool to increase the quality of the student learning experience as defined by [4]. The basic concept of the flipped classroom is to deliver teacher-created short video lectures to students before class time. Students can watch and learn the video

content usually at home. In class time, students work on their classwork or homework with instructor's more personalized guidance [10]

Traditional teaching has a limited time to repeat the lecturing in class time. But flipped classroom gives the control to students. They can review, replay, rewind, and fast-forward the video as needed [3]. Thus, students feel free to learn the lesson content anytime, and any missed classes can be watched with lower stress repeatedly [7]. That carries the individual learning facilities out of the classroom walls. Also students come to the class with questions regarding the topics. The important part of the flipped classroom is to convert the class time into a time to discuss deeper questions about the topic and student-teacher can work together to engage in collaborative learning. Teachers make more efficient use of class time [11]. Students can complete classroom activities and get assistance from the instructors. That gives the teachers the role of a learner-facilitator, because as explained in [8] "[this] opens more time in class for the teacher to go deeper into a topic which allows students to develop a better understanding of the content, and the students are doing their homework in class where the teacher is available to help if they get stuck." [8]

III. RESEARCH METHODOLOGY

The research study methodology used was empirical research. Used quantitative methods where the pparticipants of this research are divided in two groups of first year students. One of the classes are assigned as a control group, and other was assigned as the experimental groups. Initially it was taken a preliminary survey from all groups. Have utilized the learning management system Google Classroom. Each group register to their own online group called "Programming". After registering, students could access the online posted materials in this course. The main materials are high quality recorded topical videos, presentation files, and worksheets. Also required some physical tools like flash drives, CDs, tablets, Smartphone's and computers.

Students watched short tutorial videos which will cover the main lesson topics at home. This videos are published on the YouTube. The video lengths are less than 10 min. Students are able to follow the instructor's lecture along with the video by re-playing or pausing. To be sure that the video is watched by the students, they will have to take some notes on the video contents to present the teacher. Additionally, at the end of each video lecture there are a small quiz to review the student comprehension.

The study of flipped classrooms was based on the theory of Bloom's revised taxonomy of cognitive domain. This taxonomy provides six levels of learning. The explanation is arranged from the lowest level to the highest level:

1. Remembering: in this stage, the students try to recognize and recall the information they receive; they also try to understand the basic concepts and principles of the content they have learned.
2. Understanding: the students try to demonstrate their understanding, interpret the information and summarize what they have learned.
3. Applying: the students practice what they have learned or apply knowledge to the actual situation.
4. Analyzing: the students use their critical thinking in solving the problem, debate with friends, compare the answer with peers, and produce a summary. The students obtain new knowledge and ideas after implementing critical thinking or a debate in group activities. In this level of learning, the students also produce creative thinking.
5. Evaluating: assessment or established peer-review knowledge, judge in relational terms; in this stage, students are evaluating the whole learning concepts and they could evaluate or make judgment on how far they successfully learned.
6. Creating: the students are able to design, construct and produce something new from what they have learned [4]

In implementing flipped classroom, remembering and understanding as the lowest levels of cognitive domain are practiced outside the class hour [7]. While in the classroom, the learners focused on higher forms of cognitive work, including applying, analyzing, evaluating, and creating.

IV. RESULTS

In the research study questionnaire there are 9 questions cross-checking students different aspect of flipped classroom. Each question is capturing different perspective. There were 64 participants students that filled in the questionnaire.

TABLE 1 . FLIPPED CLASSROOM COMPARISON WITH CLASSICAL CLASSROOM IN 3 (THREE) COMPUTER SCIENCE COURSES

Q1. Compare and show your preference between flipped classroom and classical classroom?		
	Flipped classroom	Classical Classroom
1. programming	59%	41%
2. object oriented programming	57%	43%
3.software engineering	54%	46%

Analyses and Description of the results from Table 1:

According to learners feedback we can see that lerners preference is higher for flipped classroom compared with classical classroom.

TABLE 2 . EFFICIENCY OF FLIPPED CLASSROOM COMPARISON

Q2. The Flipped Classroom (FC) was more efficient for me?					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. programming	78%	13%	3%	5%	1%
2. object oriented programming	67%	22%	4%	6%	1%
3. software engineering	59%	25%	7%	8%	1%

Analyses and Description of the results from Table 2:

According to learners feedback we can see that lerners preference is higher for flipped classroom for which they consider is making them more efficient and 78% of the respondent learners for the curse programming have strongly agreed if compared with classical classroom.

TABLE 3 . INCREASED INFORMATION COMMUNICATION AND FREEDOM OF MANIPULATION

Q3. Flipped Classroom (FC) has Increased information communication and freedom of manipulation?					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. programming	27%	41%	17%	11%	4%
2. object oriented programming	21%	39%	20%	17%	3%
3. software engineering	37%	49%	12%	2%	0%

Analyses and Description of the results from Table 3:

According to learners feedback regarding lerners Increased information communication and freedom of manipulation they consider is making them more efficient and overal 68% they evaluate it positivly for programming course. 60% of the learner respondents evaluate it positively for the object oriented programming course and 86% of the reposndents evaluate it positevly for the software engineering course. In total the respondent learners have evalauted hihger level of increased information communication and freedom of manipulation of flipped classroom when compared with classical classroom.

TABLE 4 . INCREASED ACCESSIBILITY TO LEARNING

Q4. Flipped Classroom (FC) Increased accessibility to learning?					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. programming	34	43	8	13	2
2. object oriented programming	29	39	14	17	1
3. software engineering	39	47	14	0	0

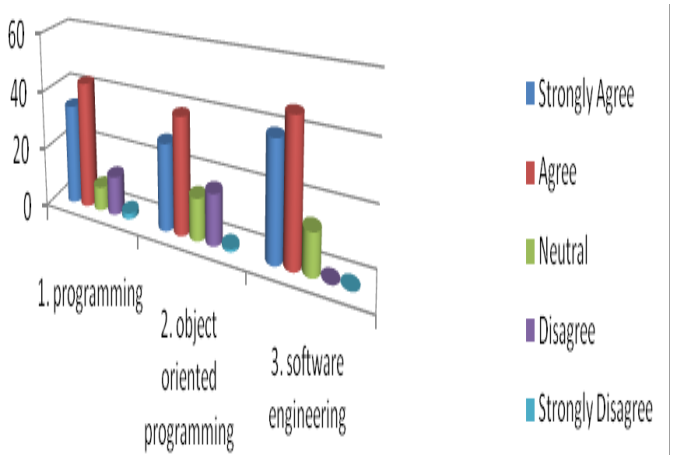

Figure 4 . Increased accessibility to learning

Analyses and Description of the results from Table 4 and Figure 4:

According to learners feedback regarding lerners opinion that Flipped Classroom (FC) Increased accessibility to learning they consider is is poisitive and overal 77% they evaluate it positivly for programming course, 68% for object oriented programming and 86% for the course software engineering.

TABLE 5 . POTENTIAL BENEFITS OF FLIPPED LEARNING

Q5. What are the potential benefits of flipped learning?	
Motivation of Lecturer	23.15%
Motivation of Student	29.85%
Increased attendance	4.46%
Better Grades	5.70%
Access to learning materials	12.45%
Learning at own peace	2.82%
Better Understanding	10.56%
higher-level cognitive skills	5.19%
Others	5.82%

Anbalyses and Description of the results from Table 5:

According to learners feedback regarding What are the potential benefits of flipped learning the learner respondents consider the following: Motivation of Lecturer 23.15%; Motivation of Student 29.85%; Increased attendance 4.46%; Better Grades 5.70%; Access to learning materials 12.45%; Learning at own peace 2.82%; Better Understanding 10.56%; higher-level cognitive skills 5.19%; Other factors 5.82%.

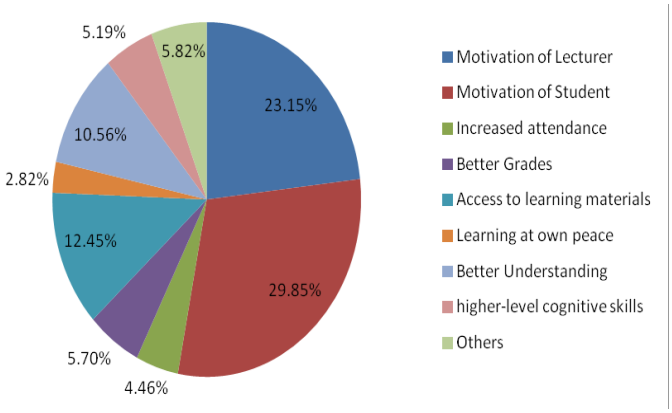

Figure 5. Potential benefits of flipped learning

TABLE 6 . REDUCE BIAS AND STUDENT RETENTION

Q6. Flipped Classroom (FC) Reduce bias and student retention?		
	Reduce Bias	Reduce Student Retention
1. programming	44%	48%
2. object oriented programming	38%	42%
3. software engineering	34%	27%

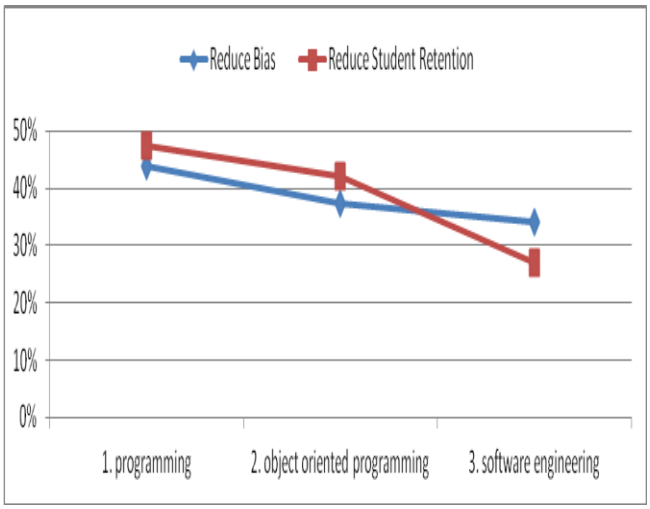

Figure 6 . Reduce bias and student retention

Analyses and Description of the results from Table 6:

According to learners feedback regarding the issue that **Flipped Classroom (FC) Reduce bias and student retention** the learner respondents consider that positivly but not more then have of the respondets does not agree entirely. For programming course only 44% agree that it reduces the bias and 48% agree that it reduces the student retention. For object oriented programming only 38|% of the respondets consider it reduces bias and 42% that it reduces the student retention. For Software engineering only 34% of the respondets consider that it reduces the bias and 27% that it reduces the student retention.

TABLE 7. PERFORMANCE USING FLIPPED CLASSROOM

Q7. How do you rate your performance using Flipped Classroom in these courses?	
Performance	100
programming	34
object oriented programming	31
software engineering	23
Other	12

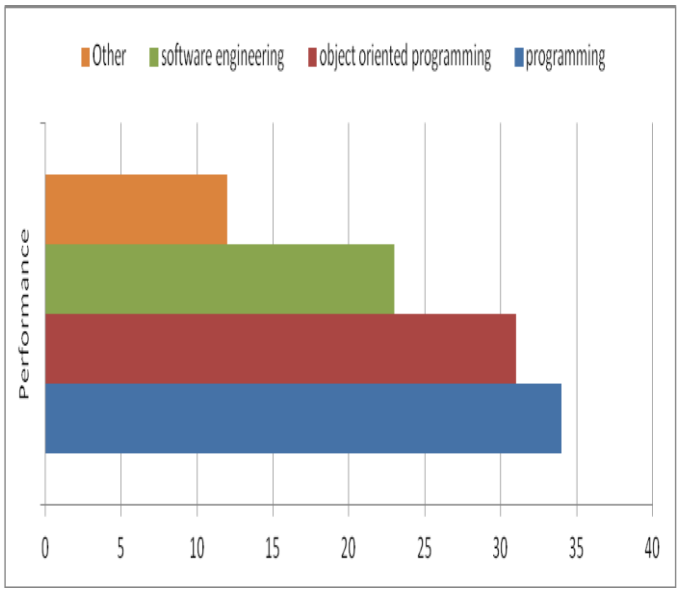

Figure 7. performance using Flipped Classroom

Analyses and Description of the results from Table 7:

According to learners feedback regarding the **rating their performance using Flipped Classroom in these courses** the learner respondents consider that positivly but not more then have of the respondets does not agree entirely. For programming course only 34% agree, For object oriented programming only 31% of the respondets consider it increased

their perfomrance and 23% that it increased their performance in the course software engineering.

TABLE 8 . MEASUREMENT PASSIVE LEARNING TOWARDS ACTIVE LEARNING

Q8. Measurement passive learning towards active learning using Flipped Classroom?		
	Active Learning	Passive Learning
1. programming	62%	38%
2. object oriented programming	59%	41%
3. software engineering	54%	46%

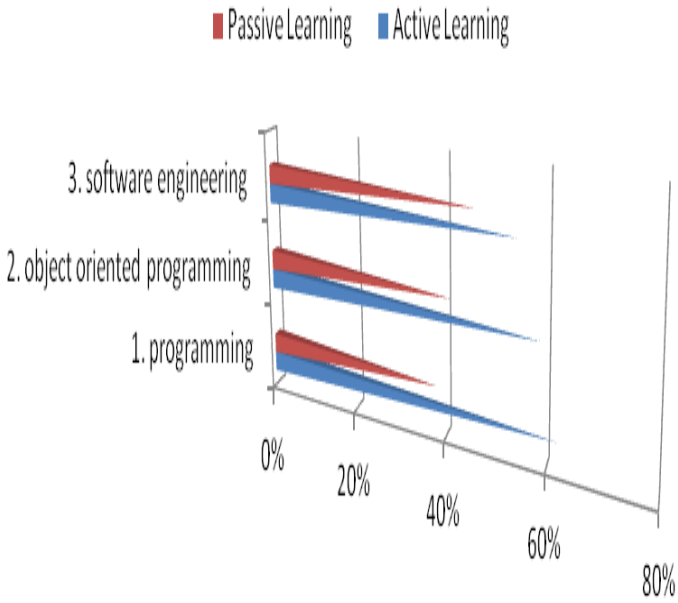

Figure 8 . Measurement passive learning towards active learning

Analyses and Description of the results from Table 8:

According to learners feedback regarding the **rating Measurement passive learning towards active learning using Flipped Classroom in these courses.** The learner respondents consider that positivly and for programming course for flipped classroom helped in active learning 62% and 38% in passive learning aspect. For object oriented programming flipped classroom helped in active learning 59% and 41% in passive learning aspect.

TABLE 9 . IMPROVMENTS THAT FLIPPED CLASSROOM HAS OVERAL ON LEARNING OUTCOMES

Q9. Improvements that Flipped Classroom has overall on learning outcomes?	
Fields	**Flipped Classroom**
Knowledge and understanding	52%
Applying knowledge and understanding	33%
Making judgment	12%
Communications skills	3%

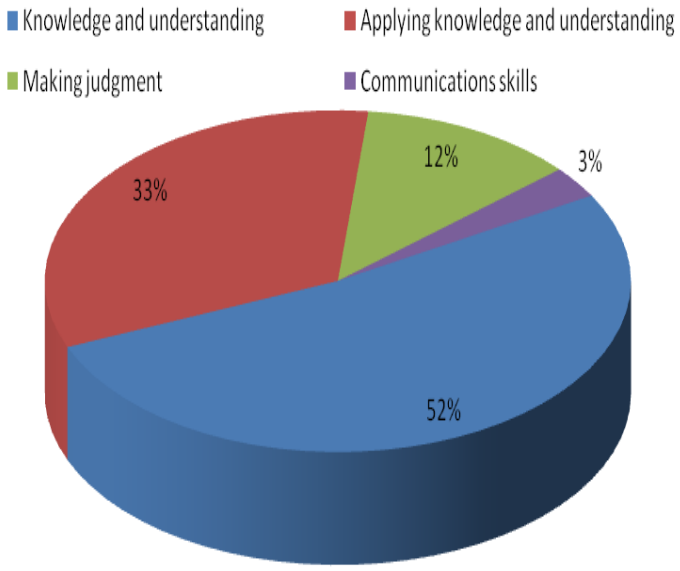

Figure 9 . Improvments that Flipped Classroom has overal on learning outcomes

Analyses and Description of the results from Table 9:

According to learners feedback regarding the **rating Improvements that Flipped Classroom has overall on learning outcomes in these courses.** The learner respondents consider that positivly and for **Knowledge and understanding** 52% and for **improving Applying knowledge and understanding** 33%. For **Making judgment** 12% of improvment and 03% consider improvment from flipped classroom regarding the **Communications skills** aspect.

V. CONCLUSION

Concluded that flipped classroom has positive impact in the analyzed courses: Programming. Object Oriented Programming and software engineering from Computer Science field.

The importance of this research study is that it may help educators to realize that teacher- student integration is possible to be improved in class time by class activities. Because, doing homework or class work in class time together provides a teacher with communication opportunities with their students.

Students sometimes learn from online video channels themselves. They follow the people who commonly titled as YouTubers who create and upload videos frequently [5]. For example, some YouTubers create a video series to instruct the programming languages chapters respectively. Students can

subscribe the channel and get involved in the online video lessons. Taking benefits from this addiction, the Flipped classroom may fill out the teacher-student gaps by online course materials and communications.

The issues identified where:

- To lecture the theory & practice in short class time, generally one class hour (45 min). In this regard curriculums are weak.
- Some students may not have the chance to use a computer at home. They may have smartphone or tablet simulators but using them is a totally different experience.
- Students are more motivated when learning using flipped learning

With all the observations, interviews, analysis of the research data and teaching experience have found many tangible results. The most important one is the finding that the flipped classroom pedagogy meets today's modern educational needs. Nowadays, technology is so widely used among people that educators need to keep up with it. Particularly students want to try new methods and they really like using technology in their education.

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User evaluation of an adaptive language learning system prototype

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***Abstract* - In order for a piece of educational software to be accepted and continuously used by the target group of users, it needs to cater for the majority of their needs and deliver its services in a user-friendly way. That is why it is crucial to evaluate user satisfaction with a system during its developmental phase, so that issues may be dealt with even before it is introduced into day-to-day use.**

The paper at hand presents the results of examining user satisfaction with a prototype of Language Learning System (LLS) – an adaptive, web-based system for language learning developed at our institution – using an adapted version of a previously developed and verified questionnaire. It reports on the strengths and weaknesses of the system in question with a special emphasis on its content (tests, language tasks, learning materials and feedback opportunities), adaptive capabilities, and the overall graphical design, and, where appropriate, suggests ways for improvement. The results further reveal certain usage and study patterns of students and their general attitudes regarding computer aided language learning. A total of twenty university-level students, who were systematically preparing for a language comprehension test over a period of three weeks, participated in the study.

Keywords – software evaluation, user satisfaction, adaptive educational system, computer assisted language learning

I. INTRODUCTION AND LITERATURE OVERVIEW

The use of information and communication technology (ICT) for learning and teaching is by no means a novelty today. Educational practitioners employ it on daily basis in a myriad of different fields and subject matters at all levels of education, including primary and secondary education, college and university level, as well as various modes of life-long study. The modes of implementing ICT into the educational process range from supplementing the traditional face-to-face teaching model at the one end of the spectrum, to courses that are delivered entirely online at the other. The former requires the teacher to be immediately present and manage the whole educational process first-hand, while in the latter approach the presence of an instructor is minimal (loosely leading the students through the course) or lacking altogether (in the case of autonomous educational software).

Recent data suggests that in the case of fully online courses the number of learners that lose interest in the study and drop out before its completion is rather high. According to a relatively recent study conducted on 221 Massive Open Online Courses (MOOCs), completion rates vary significantly (from 0,7 to 52,1% in the observed courses) with a median value of only 12,6% [1]. Another multi-national study, examining only MOOCs from the STEM area, reports that the number of those who enrolled into and completed at least one MOOC is even smaller and just barely exceeds 3% of students [2].

Reasons for such a high drop-out rate are multi-faceted and may be attributed to various qualitative characteristics of the course. These include personal (e.g., lack of time or motivation), institutional (e.g., institutional policy or issues concerning the recognition of the study certificate), technology-related (e.g., lack of and inability to obtain appropriate tools or software that is not user-friendly) and course-related reasons (e.g., discrepancy between the announced course content and the real course content). The overall student- or instructor-perceived quality of the course depends on the intricate interplay of these characteristics. Some authors suggest that in order to reverse these numbers and decrease attrition rates in online courses, it is important to continuously monitor and analyze user satisfaction, subsequently taking appropriate action to increase it and maintain it at a satisfactory level [3].

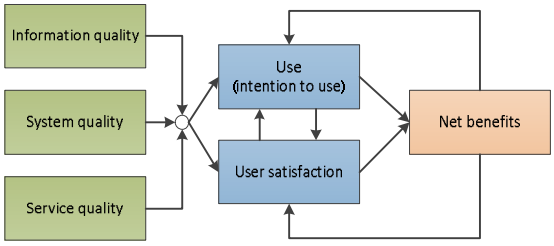

Figure 1. Reformulated DeLone & McLean IS Success Model (adapted from [5])

The concept of user satisfaction is an integral part of the widely used and cited DeLone & McLean Information Systems Success Model [4] and its later reformulation [5] (shown in Figure 1). The model has been long applied not only for evaluating information systems in the narrow sense of the term, but also for evaluating information systems in the broader sense which encompasses e-learning and e-business systems and software [3] [6]. The main premise of the model is that by using a particular system the user forms a set of opinions regarding the system. The subjective experience then translates into user's satisfaction or dissatisfaction with various

characteristics of the system and, in turn, feeds back into the continuation of system use [5]. Both use – as an objective notion – and user satisfaction – as a subjective notion – depend on three dimensions of quality: (1) information quality, (2) system quality, and (3) service quality. High levels of user satisfaction and increased use lead to a variety of benefits, e.g., financial gain for the software owner, increase in completion rates, or better knowledge gain.

Relevant literature reports on research based on the DeLone and McLean model confirm its validity. Although different authors and studies define various number of factors that make up user satisfaction, they tend to assign them similar (if not the same) names. Extra factors that do not appear in the original model, but are present in individual studies, can be attributed to specific circumstances and characteristics of the learning environments under examination. Thus in [6], factors termed service (i.e., assurance, tangibility and responsiveness), information (i.e., presentation, structure, interactivity, language, delivery mode) and system (i.e., course website; software) quality are claimed to contribute to the overall e-learning quality. In [7], continuance satisfaction is said to rest on five factors, namely information quality, task-technology fit, system quality, utility value and usefulness. Three factors are also identified in [8]: course (planning, contents, resources), technology (accessibility, usage of multimedia elements, design) and interaction (communication, teamwork). It is interesting to note that user satisfaction research within the field of education largely focuses on students, while only a handful of scientific papers address satisfaction from the instructor's viewpoint (as is the case in, e.g., [9]).

The paper at hand reports on our approach to evaluating a piece of educational software by assessing user (student) satisfaction. We take the DeLone & McLean model and its three dimensions of quality as the main starting point. A specially designed questionnaire was developed with the purpose of collecting data from a small sample of system users about their experience and views on the prototype version of Language Learning System (LLS) – an adaptive, web-based e-learning system for language learning developed at our institution. The paper summarizes and discusses the obtained results.

The rest of this paper is organized as follows. Section II outlines the main characteristics of the adaptive e-learning system prototype being assessed. Section III describes the measurement instrument and the main setup of the study. The results of descriptive statistics are systematically presented and briefly discussed in Section IV. Section V concludes the paper and suggests directions for future work.

II. E-LEARNING SYSTEM DESCRIPTION

LLS is an adaptive, web-based system for assessing and developing English language competences through the reading skill (simplified architecture given in Figure 2). It is intended for university students who are intermediate to advanced learners of English and actively use their first or second foreign language for various purposes, including written communication with foreign exchange students or professors, reading core literature for their courses, or reading any type of documentation (e.g., instructions for using a piece of software or study programs in English). Students at our Department are considered to fall into that category, and were taken as the target population at the time of developing the system.

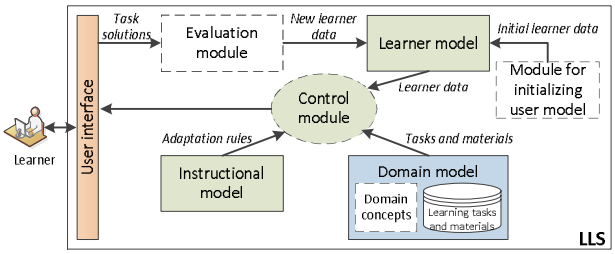

Figure 2. LLS's basic architecture (adapted from [10])

The system follows the traditional architecture of intelligent tutoring systems with its four basic models (student model, domain model, instructional model, and user interface) complemented with three modules (module for initializing user model, evaluation module, and control module) responsible for implementing the adaptive behavior of the system [10].

The system's domain model consists of 381 linguistic concepts (lexical, grammatical and semantic) that are to be acquired by the learner or have already been mastered. These are divided into three levels according to the Common European Framework of Reference for Languages (CEFR), namely B1, B2 and C1 levels, which correspond to the target audience's current level of linguistic ability as well.

Each learner is catered for individually by the system, depending on the available data stored in the student model, and is able to offer three main activities/services: (1) guided learning, (2) revision or (3) learning statistics. The stored data leads the system in selecting the most appropriate task for the learner to do (a reading assignment consisting of a text and multiple-choice comprehension questions) or it delivers study materials for a concept that has proved to be particularly problematic for the learner (explicit learning). In this way, the system adapts its behavior to each learner and leads him towards mastering the linguistic concepts of one level and, ultimately, to a higher level of the CEFR. Besides adaptive learning, the learner is able to reread study materials about a concept that has been studied previously, or view his progress in the learning statistics section. If the learner requests a new reading comprehension task to solve, the system delivers the most appropriate task (given available learner characteristics) containing the concept in question.

LLS is implemented as a web application, accessible using any web browser. The implementation was based on the classic LAMP framework (Linux, Apache, MySql, and PHP) for developing dynamic web pages. The implementation platform of choice was Phalcon with its MVC (i.e., model – view – controller) architecture. The application is readily available across different devices, from smartphones to laptops and personal computers. Its

front-end implements the template based on the leading web technologies like HTML5, CSS3, JQuery and JQuery Mobile, which makes it able to adapt to screens of different sizes as well as touchscreens.

Even though the system is currently in the prototype phase of development, it is fully functional and ready for use. It will, however, be enriched with tasks related to the listening skill once it enters everyday use.

III. INSTRUMENT DESIGN AND DATA COLLECTION

A seven-part questionnaire was used in order to gather data about user satisfaction with the LLS (parts are marked as *Intro* and *A – F*). Several items from a questionnaire used in a previous study on user satisfaction with an e-learning system [11] were taken as the basis for this study, either in their original form or adapted to meet the needs of the new research context. The majority of items, however, were newly introduced.

The introductory part of the questionnaire gathered general demographic data about participants, namely their sex, age, level of study, year of study, and study program.

Second part (A) of the questionnaire was aimed at collecting data about usage habits and patterns of participants, e.g., how frequently they accessed the system, where they accessed it from, what device they used most often, which service they used most often (guided learning, revision or detailed statistics), and what were the most useful modules of the system. This part of the questionnaire was implemented using 6 multiple-choice items that required selecting only one option.

The three parts of the questionnaire that follow were directed towards analyzing attitudes and opinions of participants regarding the overall implementation of the system. This is comparable to what DeLone & McLean termed *user satisfaction* in their model. First of the three parts (B), comprised of 17 items, was concerned with the content, presentation and structuring of learning materials (i.e., revision materials), appropriateness of selected texts, comprehension questions and feedback messages, and learning statistics. As can be observed, these make up *information quality* part of DeLone & McLean's model. Issues identified in this part of the questionnaire reflect the changes that need to be introduced in the domain model of LLS (marked blue in Figure 2).

Second of the three parts (C), made up of 7 items, scrutinized visual and navigational characteristics of the model, such as user interface, color combinations, usage of fonts, and layout of items on the screen. These represent what DeLone & McLean call *system quality*. All the issues identified in this part will be reflected in the changes made to the user interface model of LLS (marked orange in Figure 2).

The last part (D), consisting of 7 items, explored system's flexibility, namely its adaptive features and the ability to cater to students with different levels of knowledge, which may be taken to make up *service quality*. Shortcomings identified here will trigger changes in three parts of LLS, namely its instructional model, learner model and controller module (marked green in Figure 2).

Next part of the questionnaire (E), consisting of 6 items, served to examine attitudes and preferences of participants concerning online language learning using LSS as compared to the traditional way of learning. These were also intended to help in the analysis of the results obtained from parts B, C and D of the questionnaire.

Questionnaire items in parts B to E were formulated as statements, each accompanied by a 5-point Likert-type scale to offer participants the possibility to express the degree of their agreement or disagreement with a given statement (5 – completely agree, 4 – mostly agree, 3 – neither agree nor disagree, 2 – mostly disagree, 1 – completely disagree).

The final part of the questionnaire (F) was implemented as an open-ended item that prompted students to list all the changes that need to be introduced in the system in order for its quality to increase. There were no restrictions set on student answers, so they could have listed whatever they thought was important.

Questionnaire items from parts B, C and D are given in Appendix A, accompanied with the basic descriptive statistics that includes both mean value of users' answers and standard deviation for each item.

A. Questionnaire administration

In order to gather the necessary data, the questionnaire was administered to the participants following a three-week period of unlimited use of LLS and all its services. They were instructed to make the most of the assigned period in order to prepare for a comprehensive test examining their reading skills. All the participants reported to have solved at least 20 reading comprehension tasks and consulted a varying number of revision materials using the system, and use of all system services was confirmed. The questionnaire was administered anonymously in pen-and-paper format and took approximately 10 minutes to fill in.

B. Participants

The data used in this study came from 20 students (N=20) enrolled into various programs at the Department of Informatics, University of Rijeka. A small sample was deemed satisfactory for preliminary research purposes (see Table I).

TABLE I. PARTICIPANTS BY YEAR OF STUDY AND SEX

Undergraduate level						***Graduate level***			
1st year		*2nd year*		*3rd year*		*1st year*		*2nd year*	
F	M	F	M	F	M	F	M	F	M
4	0	0	1	4	0	1	5	3	2

At the time the questionnaire was administered, 55% of the participants were studying at the graduate level. Also, there were more female (60%) than male (40%) participants in the study. The average age of participants was 22,8 years, with ages ranging from 19 to 26 years.

Further analysis reveals that only 5 participants (25%) were enrolled into the double-major study program. Three

among them had a foreign language as their second major, but none of them English.

All the participants were considered to be part of the core target group of system users (as described earlier in Section II).

IV. Results and Discussion

The results obtained using the questionnaire were analyzed in the following way. A participant is considered to agree with a statement if he opted for either of the two highest values of the given 5-point Likert-like scale (namely, 4 or 5). Conversely, he is considered to disagree with a statement if he opted for either of the two lowest values of the scale (1 or 2). If he selected the middle value (3), he neither agreed nor disagreed with the statement and is thus considered to be neutral.

A. Usage habits and attitude towards learning with LLS

The first four items of part A of the questionnaire yielded several important results about the way LLS was used during learning.

Firstly, the majority of students claim to have accessed the system occasionally (55%). In this way, they studied for longer periods of time on a lesser number of occasions. Only 15% of participants have adopted the continuous learning approach characterized by shorter periods of study on a larger number of occasions. The rest were those who decided to cram their study time in a very small number of learning session, or even a single one.

Secondly, the results reveal that all the participants preferred learning while they were at home, regardless of the fact the system was readily available over the web so as not to restrict them to one location. They have done so using primarily their laptop computers (60%) or personal (desktop) computers (35%). This we attribute to the nature of the learning task itself: it seems easier to read texts and search for relevant information using larger screens without possible outside distractors (such as, e.g., background noise), especially if the texts are longer and require a certain level of concentration, as is the case on the B2 and C1 levels of the CEFR.

Thirdly, the most often used service of the system proved to be guided learning (95%). The same service was chosen as the most useful by 60% of participants, while the rest opted for revision. The former confirms that the system was used as intended by original design (developing linguistic skills through continuous activity, occasionally aided by explicit learning). The latter suggests a strong focus of some learners on explicit over implicit learning, which is rather often in the Croatian educational system. Most participants (85%) agreed that all the services provided by the system are useful, while the reminder (15%) failed to see learning statistics as being useful or even motivating for learning (the latter is their intended purpose).

The analysis of results further suggest that the participants, in general, enjoyed using the system (95%), and can describe their learning experience as being a positive one (90%). All of them found their learning experience with the system to be useful and the majority would recommend the system to be used in a hypothetical course for learning language at a distance (85%). However, there seems to be some concern among the participants about how fast and efficient learning is when using the system: less than half (45%) believe that they learn language faster using the system (as opposed to the traditional, classroom-oriented approach), exactly half (50%) consider they learn easier, while the rest are mostly neutral in that regard. Such results may be a reflection of the educational paradigm the participants are used to. In addition, they may be attributed to a lack of experience with distance learning. We believe that continuous education and practical demonstration of the benefits of the adaptive approach to e-learning, together with practical use of LLS over a prolonged period (during which more substantial learning results may become obvious to learners), may lead LLS users to form more positive attitudes about the speed and efficiency of learning when neither teachers nor fellow students are immediately present.

B. Information quality

In this subsection, the results concerning information quality are given separately for each of the three main services provided by LLS, namely (1) revision materials, (2) guided learning materials, and (3) statistical information.

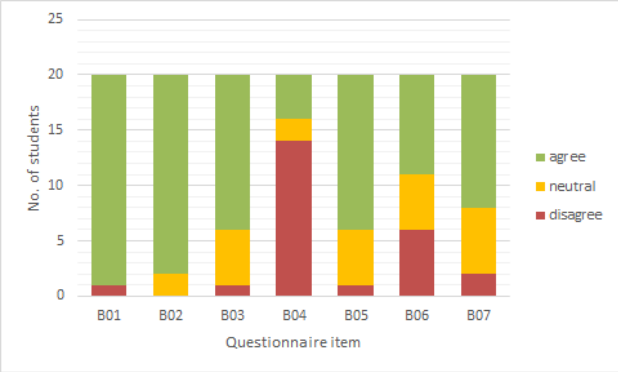

Figure 3. Quality of revision materials

When asked to consider the quality of the content of revision materials in general, 95% of the participants agreed that it is high (B01 in Figure 3). When, on the other hand, they were asked for a more in-depth analysis of the characteristics of revision materials, students agreed that the content presented to learners is clear (90%, B02), well-structured and following a logical train of thought (70%, B05), and can be perceived as well-rounded units (70%, B03). Moreover, most of the participants believed that the content itself does not overburden the learners with details (70%, B4). However, the results also reveal a potential issue that arises when considering the benefits of revision materials (B06 and B07): even though 45% of the participants consider the materials to be motivating for learning, the majority of them are either neutral (25%) or not motivated (30%), and cannot agree with the claim that the content was actually useful (40%). A possible solution might be to introduce more multimedia elements into learning

materials, and make the link between learning about a concept and applying new knowledge more visible (currently, this is not done explicitly, but implicitly).

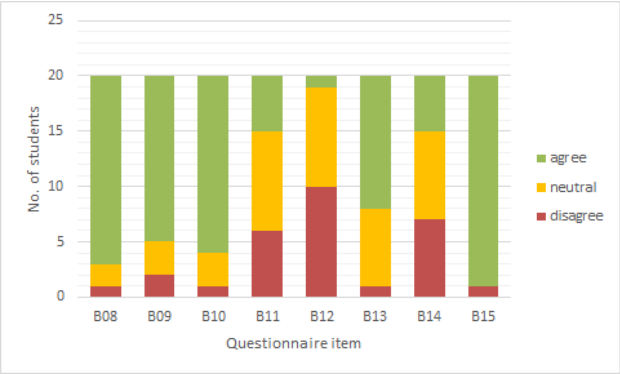

Figure 4. Quality of guided learning materials

Student opinions and attitudes regarding materials presented during guided learning are, by large, positive (Figure 4). The participants agreed that the texts and questions accompanying different tasks were diverse and interesting (85%, B08), and the topics corresponded to their interests (75%, B09). Furthermore, the level of the presented questions corresponded to the participants' perceived level of ability as they were considered neither too difficult (B11) nor too easy (B12). This may be seen as an indicator that LLS has lived up to the intended standard of catering individually to students based on their current level of skill, instead of working beyond or below that level. Even though the participants are convinced that multiple choice items are a good way of assessing reading comprehension (80%, B10), they expressed the need for introducing additional question types (95%, B15), such as gap filling. Feedback given to learners after each task may be seen as a potential challenge because 40% of the participants do not think that showing only correct answers to questions (as the only means of feedback) is enough (B13). Moreover, only 35% are against introducing more detail (B14).

The last service offered by the system – learning statistics – is considered to be clear and easily understood by 70% of the participants, but, overall, the participants do not perceive the need to add more statistical indicators to the existing ones (only 10% in support of more detail).

C. *System quality*

When it comes to assessing the overall quality of the system's graphical design, a large majority of participants (90%) agreed to describe it as high (C01 in Figure 5). More specifically, the interface was seen to be user-friendly (C02), while the selected color scheme was not drawing attention away from what is important – learning (C03). However, there were individual cases in which the participants specifically reported poor visibility due to the color of the background, which needs to be examined further.

As the fonts used in the system were carefully selected to facilitate reading on a computer screen, the participants reported no particular obstacles or challenges during learning (C04 and C05). In fact, 80% of them reported that the selected fonts did not hinder reading, while 85% believe that the choice of font made during the implementation of the system was a good one.

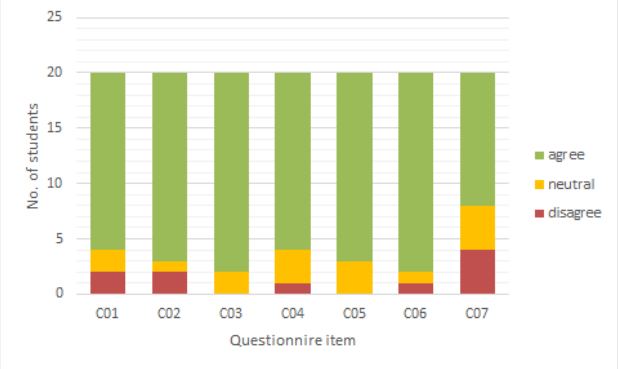

Figure 5. System quality

The participants also agreed (90%, C06) that the layout of elements on the screen during activity with the system is appropriate for the given context of learning, but at the same time welcome a slight change in the layout so that the reading passage and comprehension questions are shown side-by-side on the screen instead one above the other (C07).

D. *Service quality*

Figure 6 contains the results obtained from the part of the questionnaire designed to evaluate LLS's service quality.

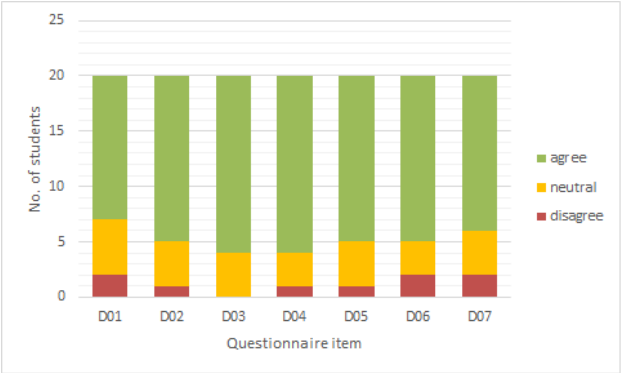

Figure 6. Service quality

As can be observed from the results for items D01, D02, and D03, namely the high percentages of agreement, the system's adaptation mechanism managed to respond to the varying needs of the learners (75%). It was seen as offering them equal opportunities regardless of their level of knowledge (80%) through an individualized learning path relevant for each of them. Furthermore, the process of such learning was a satisfying one for them (80%, D04), with an exception of only 5% claiming decidedly not to be satisfied with the support they got from the system.

As for the observed benefits of learning with the system (D06), even though the majority (75%) has noticed some positive effects on their learning, there are still those who have not (5%) or are unsure. Incidentally,

the latter are mostly those who have accessed the system rarely, which might shed some light on such findings.

V. CONLUSION

In this paper, we presented a study that evaluated LLS, an adaptive software for language learning, taking user satisfaction (DeLone & McLean model of IS success) as the starting point. The study was conducted using a specially devised questionnaire administered to a small sample of target audience learner following a three-week period of using the system prototype. The results have revealed that, in general, there do not seem to be any major issues with the system as it currently stands, so it can be implemented into day-to-day use once the observed challenges have been dealt with.

After adding the listening skill to the system, this questionnaire will be administered once again to a larger group of participants who have used the system for a significantly longer period of time. Such a comprehensive study will include a detailed factor analysis, which was not done previously given the small sample size.

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APPENDIX A.

TABLE II. QUESTIONNAIRE ITEMS AND MAIN DESCRIPTIVE STATISTICS

Item ID and text	*M*	*SD*
B01 Generally speaking, the content of learning materials is of high quality.	4,35	0,91
B02 Learning content is presented in a clear way.	4,55	0,67
B03 Each learning material represents a well-rounded whole.	4,05	0,92
B04 Learning content is too detailed.	2,35	0,96
B05 The content of each learning material is well-structured and logically presented.	4,00	1,05
B06 The content of learning materials motivated me to learn.	3,35	1,24
B07 Learning materials presented to me were very useful.	3,80	1,12
B08 Learning tasks (both texts and questions) were varied and interesting.	4,15	0,96
B09 Text topics were interesting and suited my interests.	3,95	0,92
B10 Multiple choice questions are an appropriate way of assessing reading comprehension.	4,15	1,01
B11 Reading comprehension questions were too difficult for me.	2,90	0,83
B12 Reading comprehension questions were too easy for me.	2,35	0,85
B13 Feedback I get after solving a task are suitable.	3,70	0,78
B14 Feedback I get after solving a task should be more detailed.	2,85	1,01
B15 Other types of questions should be included as well (e.g., gap filling, matching, etc.) .	4,65	0,73
B16 Learning statistics marking my progress is clear and	4,00	0,89
B17 Additional statistical data should be included in the system.	2,35	1,11
C01 Generally speaking, graphical design of the system is of high quality.	4,15	0,96
C02 System's user interface is user-friendly.	4,20	0,93
C03 Colour combinations used in the system do not draw attention away from the content.	4,60	0,66
C04 Fonts used in the system make reading easier.	4,20	1,03
C05 Fonts used in the system are well-chosen.	4,45	0,74
C06 The way texts and questions are presented is appropriate for the context of online learning.	4,40	0,97
C07 I would prefer if the questions were side-by-side with the text.	3,50	1,20
D01 The system caters equally to users with different levels of knowledge.	3,75	0,89
D02 Content is adapted to my needs.	3,95	0,97
D03 The system recommends a learning path based on my level of knowledge.	4,30	0,78
D04 I am satisfied with the way the system guides me during learning.	4,05	0,97
D05 Generally speaking, learning guidance is a useful mechanism for helping to select new learning/revision materials.	4,20	0,93
D06 Learning guidance had a positive effect on my learning process.	3,95	1,07
D07 Learning/revision materials I was offered seemed senisible/logical with regards to my current level of knowledge.	3,90	1,09

Analysis of clustering algorithms for group discovery in a web-based intelligent tutoring system

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***Abstract* - DITUS is a web-based intelligent tutoring system developed and used at our institution as an additional learning platform. To make the system even more adaptive we expanded its architecture with several modules that perform educational data mining tasks such as clustering, to discover groups of students that use the system in a similar manner, and high-utility sequential pattern mining to discover efficient learning paths through the knowledge domain. The results of these modules enable the system to offer hints to students on which knowledge units to learn before or after the currently selected unit. One of the main pre-conditions of the quality of hints is the clustering phase in which we discover groups of students that are using the system in a similar manner in terms of learning activity and efficiency. In this paper, we analyze the results of several well-known clustering algorithms on our datasets, to determine which one is best suited for the needs of our system.**

Keywords - intelligent tutoring system, clustering, educational data mining

I. INTRODUCTION

Intelligent tutoring systems (ITSs) are valuable teaching tools not only for distance education but also as a complementary teaching/learning tool in traditional (face-to-face) education. They are often used in teaching well-defined domains (e.g., math, physics, etc.) and are mostly standalone desktop applications. On the other hand, the number of web-based ITSs is much smaller [1], especially for teaching in ill-defined domains [2]. Ill-defined domains consist of a number of knowledge units (KUs) that do not have a strictly defined order in which they have to be taught/learned, but instead the system relies on a domain expert to define the structure of the domain. At our institution, we developed one such system, called the Department of Informatics TUtoring System (DITUS) to serve as an additional learning platform.

Our web-based intelligent tutoring system (WITS), described first in [3] and in [4], currently provides teachers with functionalities for creating KUs, teaching materials, various types of questions for assessing acquired knowledge, and an editor to create the KU hierarchy. Each KU is described by a start and a threshold value, which students reach by answering the questions correctly. Furthermore, the system features a descriptive statistics module for students and teachers [5]. To improve the system's overall efficiency further, we proposed a new architecture that added educational data mining (EDM) features like clustering and sequential pattern mining (SPM) [6][7].

A valuable source of data for our system lies in the records of student interactions with the system. By interactions, we mean all the students actions within the system that we store in the interactions database such as: log-in time (starting point for measuring time spent), log-out time (stop point), performing a learning action, performing a repetition action (explained later in this paper). We apply educational data mining (EDM) processes [8][9][10] to these records and use the obtained information to enrich the system's student model and improve the tutoring model. In order for improvements to take place, we added several new modules to the tutoring module. The first one was an integration layer [11] that creates a continuous communication channel to DM tools Weka [12] and SPMF [13] which are used to execute DM algorithms on data gathered within our ITS. Second was the module for clustering students based on their activity and learning progress. Finally, a SPM [14] module that is used to discover frequent patterns (FPs) students take through the knowledge domain.

This paper focuses in particular on the second module – clustering of students based on their activity (ways of using the system) and efficiency (correctness of answers to questions presented by the system and speed of advancement) levels. In order to help guide the students during their progress through the knowledge domain the system first clusters students that use the system in a similar way and consequently determines which cluster represents the highest achieving students, average achieving ones, etc. Then the SPM module finds productive learning paths through the knowledge domain for each group/cluster of students. Finally, the tutoring module offers students hints on which KU to learn next or before a selected one. Cluster ordering and discovered productive FPs of each cluster are used to guide students from a lower grade cluster towards the activity levels and learning paths of a higher-grade cluster, thus improving the students' learning experience and overall results.

An important aspect of this system is that it performs automated student model improvements [15] by running both clustering and SPM routines at scheduled intervals

while the students are progressing through the knowledge domain and increasing the size of the interactions dataset.

II. Related work

Student clustering is an important research topic in EDM. There are a number of approaches to clustering: connectivity-based, centroid-based, distribution-based, density-based, etc., and an even larger number of algorithms that can be applied on student data. In [16] Milligan published an overview of the clustering analysis critical steps. In cluster analysis, the fundamental problem is to determine the optimal number of clusters, which has a deterministic effect on the clustering results. This well-known optimization problem has received significant attention. A variety of methods for this problem have been analyzed by Gordon [17], where the author divided them into two categories: global and local methods. The local methods are intended to test the hypothesis that a pair of clusters should be amalgamated. They are suitable for assessing only hierarchically-nested partitions. With global methods, the quality of clustering given a specific number of clusters, g, is measured by a criterion, and the optimal estimate of g, ^G , is obtained by comparing the values of the criterion calculated in a range of values of g. Some of these methods analysed were: Calinski and Harabasz's method, Hartigan's method, Krzanowski and Lai's method, Silhouette statistic and the Gap method. Their performance has been analyzed by Tibshirani et.al.[18] and Symons [19]. Our method implements the silhouette statistic approach.

Once a clustering model is selected, it can be evaluated through various statistical methods [20] or a number of other, more complex methods [17], while the interpretation depends on the research area and the nature of data. Our method relies on descriptive statistics to sort the clusters based on cluster members' activity levels as well as their learning efficiency.

III. Research environment and methodology

Each student has his/her own personal approach to using the system. Some students copy the learning materials, study them offline and then come back to answer the questions later, others try to learn from the bottom up or from the top down, yet others try to brute force the system by answering the questions until they find the right answer. Students that learn offline can skew the results somewhat because they appear as highly efficient. Honor students mostly display this behavior, which would be highly efficient even if they did not learn offline. This is not a great concern because the main goal of the system is to help struggling students find a more efficient learning path through the knowledge domain. The best students will always create the smallest number of interactions.

To be able to engineer features that will exactly model the way the students interact with the system we need to extract the raw data from the database of student interactions using SQL queries. After we acquired the data, we engineered four features that represent each student. The process of feature engineering and the exact mathematical expressions we used are beyond the scope of this paper but some explanations are provided in the rest of this chapter.

The first three features: learning (L), repetition (R) and time spent (T) are called activity features and represent each student's interactions with the system.

The (L)earning feature is engineered from a number of raw data values extracted from the database of all student interactions with the system. It's basis is the number of learning actions (one of the main functionalities of the systems) a student has performed up to this point. A learning action consists of: a) reading the learning materials and b) answering one question about each of the KU's that are one level below the current one in the knowledge domain hierarchy. In this way, we check if the student understands the underlying concepts. If the student answers incorrectly, he/she is redirected to learning about that KU and the process begins again. In the engineered feature L, the number of learning actions is calculated in relation to the number of KUs completed (learned) and number of KUs started (not completed but completeness index > 0) at that moment.

The second feature – (R)epetition – is based on the number of repetition actions, which is the other main functionality of the system. A repetition action consists of selecting a KU and answering questions related to this KU, without presenting the learning materials. This functionality enables students to complete a KU faster, especially it they have previous knowledge about it. A similar calculation as described for the L feature is performed to get the engineered feature value R.

The T(ime) feature is based on the sum of time spent interacting with the system, also calculated in a way that takes into account the number of KUs completed and started at the moment the EDM process of clustering is started. While the activity features represent the way a student interacts with the system, the fourth, effectiveness feature (E) represent his/her success in answering questions about each knowledge unit being learned within our system. Before sending them to Weka, the values of the mentioned features are standardized[21] which results in average values being close to zero, the lowest being negative and so on.

As mentioned in the introductory part of the paper, a new module called "the integration layer" has been developed earlier to enable communication with two DM tools. In this way, re-implementing any specific algorithm into our application has been avoided, which ensures that data can be analyzed by a DM expert on another machine running the same DM tools, with absolute confidence that the results will be the same (where it is possible, depending on the algorithm). An important advantage of this architecture is that the administrator can easily change and use any clustering or SPM algorithm provided by either tool. In our system, we communicated with Weka to run the kMeans clustering algorithm using the Euclidian distance. Upon completion, the algorithm returns a set of clustering models with rising number of clusters k=2, 3, etc., to the DITUS system.

Clustering is usually observed from different standpoints having in common the notion of grouping or

discovering groups in a dataset. In general, clustering can be seen as a multi-objective optimization problem, therefore many different approaches can be used to solve it, e.g. connectivity based (hierarchical), centroid based (kMeans), distribution based (Expectation Maximization), density based, etc. The goal of this paper was to test different clustering algorithms in order to determine the best algorithm for the needs of our system. To do so we considered all the clustering algorithms offered by Weka. From the eight possible algorithms, we selected four:

- kMeans (Euclidian distance)
- kMeans (Manhattan distance)
- Farthest First
- Expectation Maximization (EM)

The distance measure used in kMeans can affect the obtained results. The Euclidian distance is one that is most commonly used (it is also the default option in Weka) and it is based on the Pythagorean Theorem. Its main drawback is that if one of the input features has a relatively large range it can overpower other features in the dataset. Manhattan distance is the sum of the absolute differences of coordinates of two points. It should give results that are more robust.

Farthest-first traversal of a bounded metric space is a sequence of points in the space, where the first point is selected arbitrarily and each successive point is as far as possible from the set of previously selected points. The same concept can be applied to a finite set of geometric points, by restricting the selected points to belong to the set or equivalently by considering the finite metric space generated by these points. For a finite metric space or finite set of geometric points, the resulting sequence forms a permutation of the points, known as the greedy permutation. It is often adapted for creating clustering models by minimizing the maximum diameter of a cluster.

In statistics, an expectation–maximization (EM) algorithm is an iterative method to find maximum likelihood or maximum a posteriori (MAP) estimates of parameters in statistical models, where the model depends on unobserved latent variables. The EM iteration alternates between performing an expectation (E) step, which creates a function for the expectation of the log-likelihood evaluated using the current estimate for the parameters, and a maximization (M) step, which computes parameters maximizing the expected log-likelihood found on the E step. These parameter-estimates are then used to determine the distribution of the latent variables in the next E step. EM is often used to create clustering models especially if the features have a Gaussian-like distribution.

We used one dataset from our DITUS system consisting of 32 rows representing 32 students with student ID value and another 4 columns (aforementioned feature values) modeling them. Weka was setup to ignore the student ID column. Here is the dataset in ARFF[22] format (the native format for the Weka software package):

```
@relation c_39_7_model_99c3ffd3b464f8190432

@attribute STUDENT_ID numeric
@attribute LEARNING numeric
@attribute REPETITION numeric
@attribute TIME numeric
@attribute EFFICIENCY numeric

@data
461,-0.65,0.75,-0.52,0.71
457,-0.43,-0.04,-0.36,0.75
442,1.49,-0.9,0.46,0.49
427,-0.68,0.22,1.11,0.73
454,-1,-0.96,-1.6,0
420,0.14,-0.87,0.25,0.72
455,-0.88,0.22,-0.76,0.72
447,0.51,-0.48,-0.33,0.46
465,0.2,-0.93,0.2,0.71
446,0.33,1.52,0.67,0.38
417,1.06,-0.9,1.18,0.46
438,1.14,-0.75,0.3,0.29
452,0.49,-0.93,-0.56,0.43
473,-1,-0.96,-1.6,0
458,-0.01,-0.16,-0.92,0.5
414,0.2,-0.9,0.56,0.72
503,3.69,0.4,1.49,0.47
419,-0.89,0.61,0.28,0.5
476,0.18,-0.96,-1.09,0.75
501,0.2,0.24,1.45,0.27
444,-0.71,1.61,1.59,0.6
459,1.78,-0.84,0.49,0.38
467,-0.56,1.84,-0.35,0.21
453,-0.58,0.87,-0.01,0.54
460,-0.54,2.9,-0.4,0.25
413,0.54,-0.93,2.19,0.55
433,-1,-0.96,-1.6,0
430,0.08,-0.93,-0.84,0.64
423,-0.82,0.25,-1.05,0.76
498,-0.7,0.99,0.52,0.41
466,-0.74,0.52,0.76,0.24
443,-0.82,0.43,-1.49,0.91
```

Where needed, we manually set the expected number of clusters to 2, 3, on to 7 (that is the current maximum number of clusters in the DITUS system) and run the algorithm. The results with the added cluster affiliation column where copied to an Excel file and joined with the raw values that we based the four engineered features on – the number of Learning actions, Repetition actions, Time spent and Efficiency. The reason for that was to facilitate the interpretation of results. Parts of the acquired results are displayed in Figure 1 (results for k=3) and Figure 2 (results for k=5). The first set of columns represent the results from kMeans (Euclidian), the second one kMeans (Manhattan), the third one Farthest First and the last one EM. The first column represents students ID, the second one the cluster affiliation, and the next four represent the raw values of learning (L), repetition (R), time spent learning (T) and efficiency (E) acquired from the database.

Finally, we compared and analyzed the results.

IV. DISCUSSION

The results displayed in Figure 1. show that kMeans with Euclidian distance grouped students that had used Learning and Repetition in a balanced way, had spent less Time using the system and had high(er) Efficiency in the cluster marked "0". Students with higher number of Larning and Repetition actions that took more Time thus having lower Efficiency where grouped in the second cluster. The students that almost exclusively used the Learning functionality (which takes longer to advance through the knowledge domain) in the third. There are some outliers in each cluster. Outlier values of engineered features usually appear when students brute force the system, e.g. use the repetition functionality to answer questions without reading them, until the question appears enough times that they guess the answer. The same question does not appear consecutively but the questions database is limited so with enough tries the same question will appear eventually. Outlier detection in the engineered dataset BEFORE the clustering step is a feature we are currently developing and adding to our system.

In the context of this analysis we use the term "outlier" to describe a student (a set of four values) that stands out from other value sets in the cluster.

When compared to the second column (the results of kMeans with Manhattan distance) we can see that there number of members is similar but there is almost no overlap – most students are assigned to different clusters and the patterns are less clear than in the first column. In the third column, the results of FF show a clear separation of inactive students (cluster 2) and slow students (cluster 1) while all the students in between make up cluster 0 (with some outliers).

It is very important for our system to discover inactive students as well as slow students correctly because this will positively affect the hint generation. In the fourth column, the results of EM again show the correct grouping of inactive students.

The members of cluster "0" could be described as group of students that used the system in a balanced way (learning and repetition functionalities) while cluster "1" consist of users that favored the slower Learning functionality. Students that use the system in a balanced way tend to have higher efficiency and less time spent in the system. That is why this group represent our "ideal" student. To correctly identify this group is the best result we expected from the clustering phase.

The results displayed in Figure 2. show the first time kMeans with Euclidian distance correctly identified inactive students (it did not succeed in this for k=2,3 and 4) and grouped them in cluster "3". We can also see clear patterns – cluster "0" can be described as "ideal" (balanced, fast, highly efficient), cluster "1" as "balanced but slower", cluster "2" as "unbalanced" (favors the Learning functionality), and cluster "5" as "unbalanced but efficient" (high number of correct answers). Overall, the results represent clear(er) patterns than the results in Figure 1. In reality, the DITUS system most often selects models with k=3, but in the future we plan to enable the teacher to be able to intervene in this step. The second column the patterns are also quite clear with some outliers. The third column displays very different results with much less clarity except the "inactive" and "unbalanced" clusters "2" and "3". These results would not help our tutoring module in providing efficient hints for most of the students. The fourth column (EM) has the exact same results as in the first (kMeans with Euclidian distance). Overall, when considering all results (for k=2,…,7) we can conclude that EM displayed the most robust and clear results, grouping students with much clearer usage patterns. The algorithm currently being used in the DITUS system – kMeans with Euclidian distance was second in our list of overall results. FF had clearer results than kMeans with Manhattan distance measure

V. CONCLUSION

In this paper, we gave a short introduction to the architecture of the DITUS system which has been under development for a number of years. The clustering phase, which precedes the SPM phase and the hint generation, is of crucial importance for the quality of hints presented to students. If we do not succeed in discovering groups of students that use the system in distinct ways the performance of our hint selection algorithm will be diminished. Our results show that the algorithm we use (kMeans with Euclidian distance) has good overall results, surpassed only by the EM algorithm. In our future work we will perform further research on more datasets and try EM in the following semester and evaluate the final results.

Figure 1. The results for k=3
ID = STUDENT_ID, , K = NUMBER OF CLUSTERS, UCENJ = LEARNINGS (RAW VALUE), PON = REPETITIONS (RAW VALUE), VRIJ = TIME (RAW VALUE (SECONDS)), EFIK = EFFICIENCY

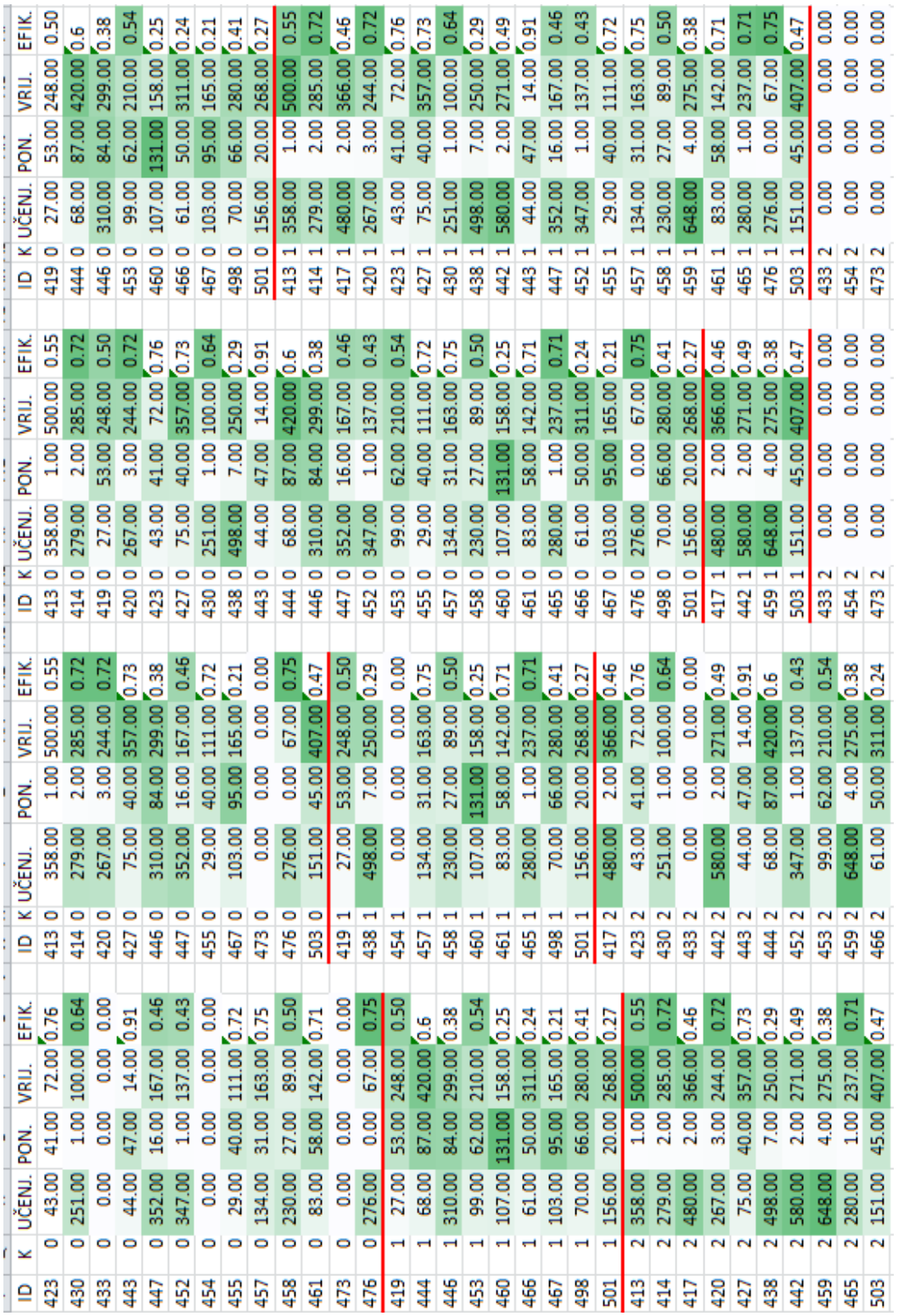
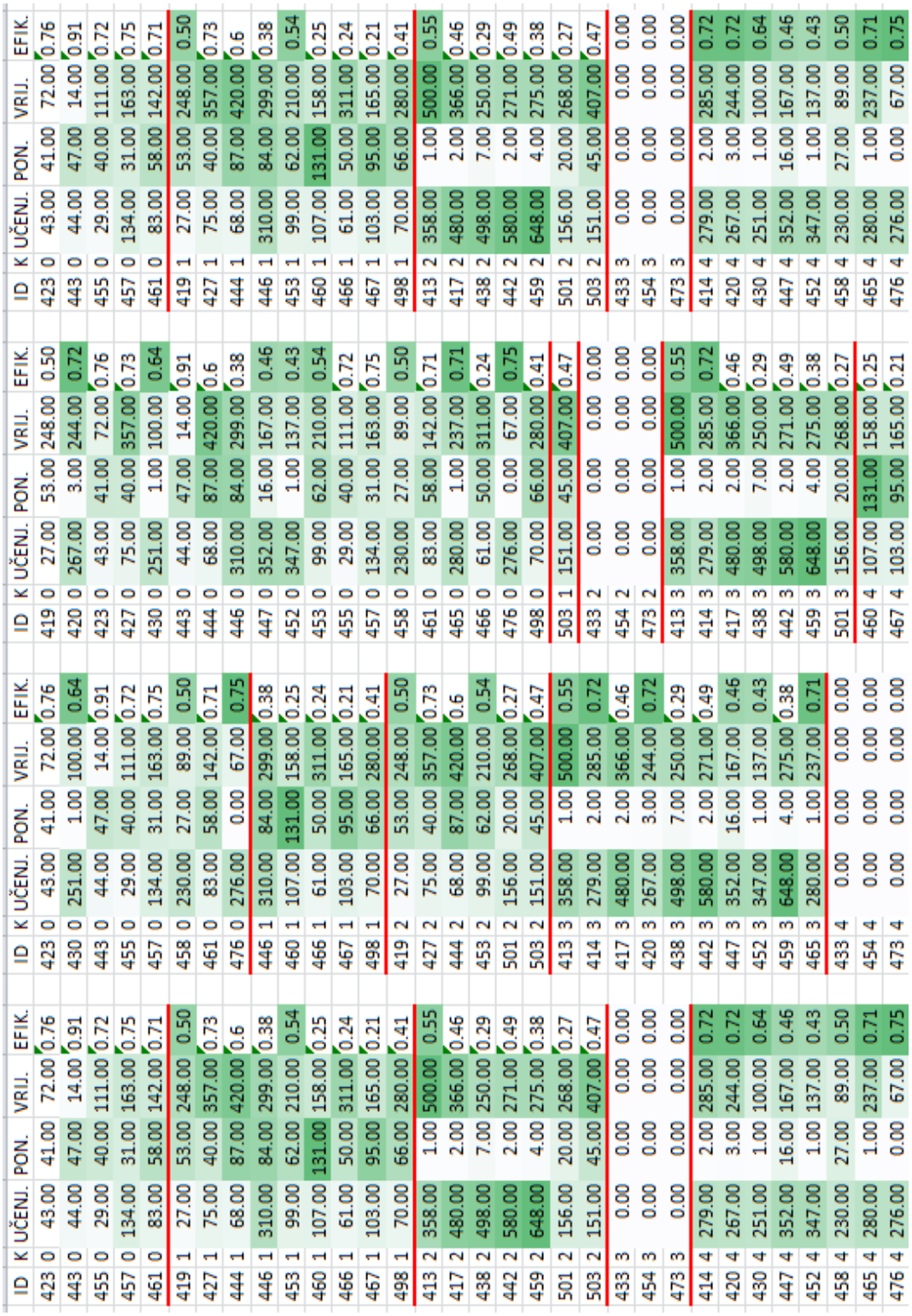


Figure 2. The results for k=5

LEGEND:

ID = STUDENT_ID, , K = NUMBER OF CLUSTERS, UCENJ = LEARNINGS (RAW VALUE), PON = REPETITIONS (RAW VALUE), VRIJ = TIME (RAW VALUE (SECONDS)), EFIK = EFFICIENCY



ID	K	UČENJ.	PON.	VRIJ.	EFIK.	ID	K	UČENJ.	PON.	VRIJ.	EFIK.	ID	K	UČENJ.	PON.	VRIJ.	EFIK.	ID	K	UČENJ.	PON.	VRIJ.	EFIK.
423	0	43.00	41.00	72.00	0.76	423	0	43.00	41.00	72.00	0.76	419	0	27.00	53.00	248.00	0.50	423	0	43.00	41.00	72.00	0.76
443	0	44.00	47.00	14.00	0.91	430	0	251.00	1.00	100.00	0.64	420	0	267.00	3.00	244.00	0.72	443	0	44.00	47.00	14.00	0.91
455	0	29.00	40.00	111.00	0.72	443	0	44.00	47.00	14.00	0.91	423	0	43.00	41.00	72.00	0.76	455	0	29.00	40.00	111.00	0.72
457	0	134.00	31.00	163.00	0.75	455	0	29.00	40.00	111.00	0.72	427	0	75.00	1.00	357.00	0.73	457	0	134.00	31.00	163.00	0.75
461	0	83.00	58.00	142.00	0.71	457	0	134.00	31.00	163.00	0.75	430	0	251.00	1.00	100.00	0.64	461	0	83.00	58.00	142.00	0.71
419	1	27.00	53.00	248.00	0.50	458	0	230.00	27.00	89.00	0.50	443	0	44.00	47.00	14.00	0.91	419	1	27.00	53.00	248.00	0.50
427	1	75.00	40.00	357.00	0.73	461	0	83.00	58.00	142.00	0.71	444	0	68.00	87.00	420.00	0.6	427	1	75.00	40.00	357.00	0.73
444	1	68.00	87.00	420.00	0.6	476	0	276.00	0.00	67.00	0.75	446	0	310.00	84.00	299.00	0.38	444	1	68.00	87.00	420.00	0.6
446	1	310.00	84.00	299.00	0.38	446	1	310.00	84.00	299.00	0.38	447	0	352.00	16.00	167.00	0.46	446	1	310.00	84.00	299.00	0.38
453	1	99.00	62.00	210.00	0.54	460	1	107.00	131.00	158.00	0.25	452	0	347.00	1.00	137.00	0.43	453	1	99.00	62.00	210.00	0.54
460	1	107.00	131.00	158.00	0.25	466	1	61.00	50.00	311.00	0.24	453	0	99.00	62.00	210.00	0.54	460	1	107.00	131.00	158.00	0.25
466	1	61.00	50.00	311.00	0.24	467	1	103.00	95.00	165.00	0.21	455	0	29.00	40.00	111.00	0.72	466	1	61.00	50.00	311.00	0.24
467	1	103.00	95.00	165.00	0.21	498	1	70.00	66.00	280.00	0.41	457	0	134.00	31.00	163.00	0.75	467	1	103.00	95.00	165.00	0.21
498	1	70.00	66.00	280.00	0.41	419	2	27.00	53.00	248.00	0.50	458	0	230.00	27.00	89.00	0.50	498	1	70.00	66.00	280.00	0.41
413	2	358.00	1.00	500.00	0.55	427	2	75.00	40.00	357.00	0.73	461	0	83.00	58.00	142.00	0.71	413	2	358.00	1.00	500.00	0.55
417	2	480.00	2.00	366.00	0.46	444	2	68.00	87.00	420.00	0.6	465	0	280.00	1.00	237.00	0.71	417	2	480.00	2.00	366.00	0.46
438	2	498.00	7.00	250.00	0.29	453	2	99.00	62.00	210.00	0.54	466	0	61.00	50.00	311.00	0.24	438	2	498.00	7.00	250.00	0.29
442	2	580.00	2.00	271.00	0.49	501	2	156.00	20.00	268.00	0.27	476	0	276.00	0.00	67.00	0.75	442	2	580.00	2.00	271.00	0.49
459	2	648.00	4.00	275.00	0.38	503	2	151.00	45.00	407.00	0.47	498	0	70.00	66.00	280.00	0.41	459	2	648.00	4.00	275.00	0.38
501	2	156.00	20.00	268.00	0.27	413	3	358.00	1.00	500.00	0.55	503	1	151.00	45.00	407.00	0.47	501	2	156.00	20.00	268.00	0.27
503	2	151.00	45.00	407.00	0.47	414	3	279.00	2.00	285.00	0.72	433	2	0.00	0.00	0.00	0.00	503	2	151.00	45.00	407.00	0.47
433	3	0.00	0.00	0.00	0.00	417	3	480.00	2.00	366.00	0.46	454	2	0.00	0.00	0.00	0.00	433	3	0.00	0.00	0.00	0.00
454	3	0.00	0.00	0.00	0.00	420	3	267.00	3.00	244.00	0.72	473	2	0.00	0.00	0.00	0.00	454	3	0.00	0.00	0.00	0.00
473	3	0.00	0.00	0.00	0.00	438	3	498.00	7.00	250.00	0.29	413	3	358.00	1.00	500.00	0.55	473	3	0.00	0.00	0.00	0.00
414	4	279.00	2.00	285.00	0.72	442	3	580.00	2.00	271.00	0.49	414	3	279.00	2.00	285.00	0.72	414	4	279.00	2.00	285.00	0.72
420	4	267.00	3.00	244.00	0.72	447	3	352.00	16.00	167.00	0.46	417	3	480.00	2.00	366.00	0.46	420	4	267.00	3.00	244.00	0.72
430	4	251.00	1.00	100.00	0.64	452	3	347.00	1.00	137.00	0.43	438	3	498.00	7.00	250.00	0.29	430	4	251.00	1.00	100.00	0.64
447	4	352.00	16.00	167.00	0.46	459	3	648.00	4.00	275.00	0.38	442	3	580.00	2.00	271.00	0.49	447	4	352.00	16.00	167.00	0.46
452	4	347.00	1.00	137.00	0.43	465	3	280.00	1.00	237.00	0.71	459	3	648.00	4.00	275.00	0.38	452	4	347.00	1.00	137.00	0.43
458	4	230.00	27.00	89.00	0.50	433	4	0.00	0.00	0.00	0.00	501	3	156.00	20.00	268.00	0.27	458	4	230.00	27.00	89.00	0.50
465	4	280.00	1.00	237.00	0.71	454	4	0.00	0.00	0.00	0.00	460	4	107.00	131.00	158.00	0.25	465	4	280.00	1.00	237.00	0.71
476	4	276.00	0.00	67.00	0.75	473	4	0.00	0.00	0.00	0.00	467	4	103.00	95.00	165.00	0.21	476	4	276.00	0.00	67.00	0.75

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Influence of Gamification Reward System on Student Motivation

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***Abstract* - In the last couple of years, gamification has been increasingly used in education in order to motivate and encourage student engagement and interaction in class lectures, but also E-learning. In this paper, gamification usage is analyzed through online tool called Kahoot that has been used on the Information and Communication Technologies (ICT), a course that is part of the 1st semester on Undergraduate program on Zagreb School of Economics and Management (ZSEM). Two student groups were analyzed – ICT course held in Croatian and ICT course held in English. Based on the overall semester score in Kahoot, students from Croatian ICT course were awarded with extra percentages as a reward for their activity and engagement in class. In the English ICT course, which is by the program and syllabus equal to Croatian ICT course, students were not rewarded with extra percentages as gamification was only perceived as a knowledge revise tool during the semester. Another difference between the groups is the diversity in the English ICT course, as there were also international exchange students mixed with the enrolled ZSEM students on English program. The paper presents analysis of extrinsic and intrinsic student motivation from both groups and provides correlation analysis of gamification results with students' final grade and survey elements regarding student motivation perception and the importance of receiving a reward after the game.**

Keywords – Gamification, motivation, reward system, education, information and communication technologies

I. INTRODUCTION

According to Deterding [1] gamification is using game design elements in non-game context. [2, 3] One of the most widespread areas of gamification application is education. Over the past 10 years, gamification has been intensively used in education to motivate students to be more active in class. [4, 5, 6] In the paper "The model for introduction of gamification into e-learning in higher education", authors described the great possibilities of using gamification not only in the classrooms, but also in the field of E-learning. [7] By using gamification, teachers are closer to students, students are motivated to learn through fun by staying focused for a longer period of time.

With the development of smart phones, a number of applications have been developed that enable gamification in education – which is easily accessible for students and lecturers. [8, 9, 10] This paper will use a very widespread and user friendly game-based learning platform – Kahoot. [11, 12]

In the paper "Influence of Gaming on Student Motivation in the Educational Process in the Courses of Different Fields" the authors analyzed the use of Kahoot on the same student sample – however, the courses were of different areas, such as technologies and legal discipline. [13] Results have shown that students are highly motivated to learn through Kahoot whether it is a course directly related to new technologies such as ICT (Information and Communication Technologies) or social subjects such as legal courses. [14]

According to Honey & Mumford, there are four main pillars related to gamification: the elements of the game, the motivation, the rewards and the adaptation to the users' profile. [15]

Gamification is closely related to intrinsic motivation and it presents 4th motive on Glasser's list of motives [16, 3], students are keener on playing and competing if there is some kind of a symbolic award. [14] Depending on the content, gamification uses different reward mechanisms, but the most common ones are: Leaderboards, Prizes and Achievement. [17]

In the paper, "The role of competition and reward regarding student motivation in the gamification process of different age groups", the authors analyzed student motivation in gamification and their perception regarding rewards – depending on the age group [18]. The analysis was based on the sample from first year students, fourth year students and lifelong learning student group. All of the students were motivated with Kahoot, however, older students are more intrinsically motivated and are more focused on their progress, while younger students have more interest in the competition with peers and are more willing in gaining some sort of reward.

This paper is constructed into four main parts: Gamification on ZSEM, Research Methodology, Student Perceptions, Research Results and Conclusion. The paper first explains the usage of gamification on ZSEM and the methodologies used in order to evaluate gamification impact on students. The following part of the paper focuses on the research results and its analysis for conclusion interpretation.

II. GAMIFICATION IN CLASS ON ZSEM

A. Gamification on ICT course

ICT course is about teaching students how to use new technologies and how to deal with certain changes within the appropriate time frame. That is why gamification is very suitable for this type of class as it uses modern technology for learning – such as Kahoot. Kahoot is used for repetitive learning and exam preparations. [13]

For this research, two ICT groups of students were analysed – Croatian group and English group, meaning that there was one group held in Croatian language to ZSEM full time students, while other group was held in an English language. The English group had some of ZSEM full time students which took the English program and also, some of international Exchange students who enrolled the ICT in English, making the group full of diversity and different cultural dynamics.

Students that were part of the Croatian group were told at the beginning of the semester that they will be rewarded depending on their gamification Kahoot scores, while the other, English group were told that gamification was only used as a revise learning tool – no rewards based on scores. Moreover, the Croatian group were also awarded for if they contributed to this research with a filled survey, while English group of students were only ask to help and contribute.

B. ICT Croatian group

As mentioned, ICT Croatian group had a certain reward system based on Kahoot scores. In Table I, it is visible that first place is awarded with 1.5%, and students that were from 2nd – 5th place are awarded with 1%. The rest of the students get a symbolic award of 0.5% for participating in the Kahoot game.

TABLE I. KAHOOT AWARD SYSTEM ON ICT FOR CROATIAN GROUP

Kahoot placement	**Extra percentage award system**
1st place	1.5%
2nd – 5th place	1%
Symbolic activity award	0.5%

C. ICT English group

As it has already been clarified, the English ICT group did not earn any rewards during the semester as they were informed that gamification is used only as a revise lecture tool. This was made in order to determine how motivation was built in this way and if any, what kind of a motivation was it and how they can be compered – intrinsic and extrinsic.

The diversity in the group was also promising as the background of the group is more dynamic – however, it may also influence the research results drastically.

III. RESEARCH METHODOLOGY

The research was based on student survey results and Kahoot results, where one of the variables are personal student perception regarding gamification and another being real measurable student quiz results.

The goal is to explore student perception and the influences regarding motivation in class. By questioning, measuring and analyzing the relationship of the received results, the insight into student motivation can be measured and class intensity adapted for the purpose of learning.

Although the satisfaction factor of this generation in using Kahoot or any kind of gamification is high, other elements should be analysed as well in order to get a clear picture and vision of gamification impact on students. That is why the analysis and correlation between survey elements and Kahoot results were made.

IV. STUDENT PERCEPTION

The collection of survey results was in purpose of understanding the student perception on motivation. Two key questions from the survey were used – regarding their motivation level and the level of reward importance, measured on a Likert scale of 1 to 5. In the next section, further analysis is made on those questions from the survey.

These results are created for further analysis with the Kahoot results, however, the results may be impacted by the different scenarios that were placed for both Croatian and English ICT groups. Also, the diversity of the international English group creates a certain limitation on interpretation of the results.

A. Survey

Both Croatian and English ICT groups were examined through survey regarding gamification. Croatian ICT group has a total sample of 60 students that had any Kahoot results, while English group has a sample of 22 students, although, with more international diversity. Students that didn't play or had an overall score of 0 were not analysed because there were couple of internet connectivity issues during the game for some students. After all Kahoot games that were played throughout the semester, making a total of 5 games for both groups, students participated in a survey in order to see their

perception regarding motivation and reward system in gamification. In the Croatian ICT group, there were 17 students, making 28,3% of the Kahoot sample, which also filled a survey, while in the English ICT group there were 13 students, making it a 59,1% of the English Kahoot sample.

At the end of the survey, the last question was referred to students as a comment section, being positive or negative. Most of the answers were positive and encouraging gamification as part of the class – even some of them had a recommendation of implementing it as a part of the grading system (not as extra percentage).

From the survey, the important results for this research were extracted to visualise the difference in gamification student perception – from Croatian ICT group and English ICT group. An average function was calculated for every question element from the survey – students' perception regarding satisfaction, motivation, rewarding system and competition factor when using Kahoot. The Likert scale was from a mark of 1 to 5.

Table 1 shows averages of the survey elements, where it is clear that marks are similar, and relatively high, for satisfaction (4,8 and 4,6) and the importance of the competition factor, which is a bit lower – but still similar (3,8 and 3,9).

TABLE II. SURVEY ELEMENTS – MEAN CORRELATION

Survey elements	CRO	ENG
Satisfaction	**4,8**	**4,6**
Motivation	**4,6**	**3,9**
Reward	**4,8**	**3,7**
Competition	**3,8**	**3,9**

As scenarios are different for both groups when considering reward systems, students' perceptions are drastically different in the elements of motivation and reward. Croatian ICT group has marked motivation factor with a high 4,6, while English ICT group has a mark perception of 3,9.

Because of the significant difference in survey results, motivation and reward are entering further analysis. This also states that there is a difference in student perception regarding gamification, which would be interesting to compare with

B. Survey - Motivation

In order to assess students' motivation and the impact on it through gamification, students from Croatian and English group have different opinions as the scenarios are different too.

In Figure 1, 70,6% of Croatian ICT group marked their motivation with a mark of 5, 17,6% with a mark of 4 and 11,8% with a mark of 3 – creating an high average value of 4,65%. The median and mode of Croatian ICT group are a high and strong mark of 5.

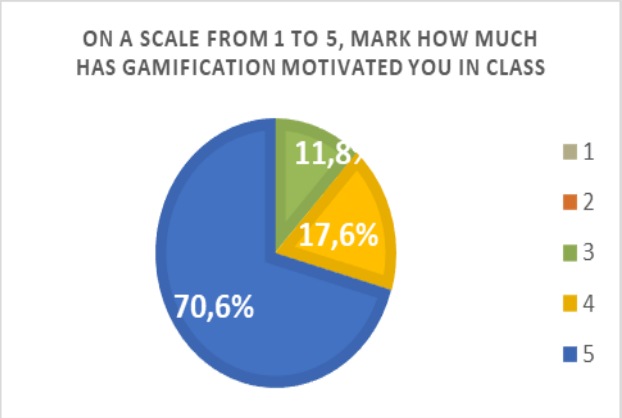

Figure 1. Kahoot motivation question – Croatian group

In Figure 2, the situation with the English ICT group is a bit different – which reflects the difference in scenarios of gamification usage in class (reward or no reward). 21,4% of English ICT grouped marked their motivation with a mark of 5, 50% with a mark of 4 and 28,6% with a mark of 3 – creating an average of 3,9. With other indicators such as mode and median, it is clear that the mark in this segment is 1 point below than the Croatian ICT group – making a mark of 4 for English ICT group.

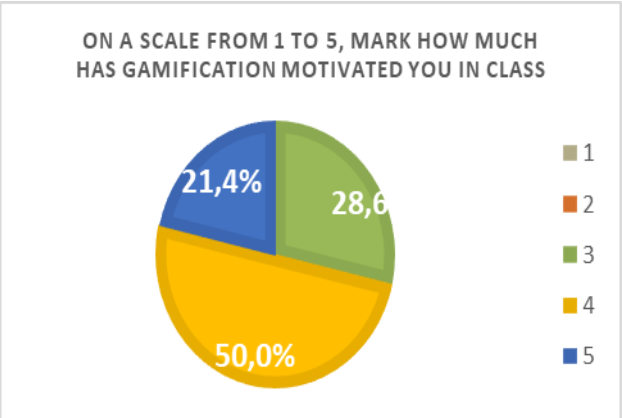

Figure 2. Kahoot motivation question – English group

C. Survey - Reward

Reward system plays a certain role in motivating and empowering student learning.

In the Croatian ICT group, 76,5% gave a mark of 5 regarding their perception on the importance of earning a reward in a game – while the rest gave a solid mark of 4, as it can be seen in Figure 3. Also, as more than 75% were already answered with the mark of 5, the median and mode also present the same mark of 5.



Figure 3. Kahoot reward question – Croatian group

Figure 4 shows different marks from the reward question on behalf of English ICT group – which had a scenario of using gamification as a revise tool, not for additional points or any kind of reward for playing. The importance of the reward shows 21% of answers as a mark of 5, 36% for both marks of 4 and 3 (creating a ponder of 72% altogether) and 7% with an importance mark of 2.



Figure 4. Kahoot reward question – English group

Students perception is clearly different when they face a certain scenario that applies as a rule for the whole semester – student perception on motivation and reward is bigger if they know about the reward system. However, the diversity of the international English group may also impact the results as there are different background points such as culture, education system, maturity, etc. There was also a certain difference in age since some of the exchange students were older and graduate students, while ICT as a course is part of the 1st year undergraduate program.

V. Research Results

In the next research headings, first analysis will cover both surveys and Kahoots' absolute and relative values, following with the correlation analysis of the Kahoot relative values and final students' grades. Afterwards, Kahoot relative values and survey important elements – motivation and reward system. This paper is using both absolute and relative values in order to present the data in the best way, so the correlation between the groups is using absolute Kahoot results and within the groups' relative Kahoot results.

A. *Absolute Kahoot values*

Kahoot results depend on the correctness of an answer and the time taken for clicking the answer – the faster answer is pressed, more points is awarded. As both ICT groups used 5 Kahoot games, all of the results, or absolute values, were summed for every student. Using this approach, every student collected a certain number of points from the Kahoot games and the average absolute values for Croatian and English ICT groups could be compared. The averaged absolute value for Croatian ICT group is 19.757,97, while for English was 10.979,82 – almost half of the Croatian groups value.

This presented gap between Croatian and English average absolute values shows how students with bigger motivation had better results in the Kahoot games. This result proves how earning a reward positively motivates students to do better.

B. *Relative Kahoot value and student grades*

Relative Kahoot values were adjusted from absolute values so it would be considered more accurate when calculating results within each group.

Figure 5 and 6 show the scatter plot for Croatian and English ICT groups where it correlates student success in Kahoot with their final grades. Both figures show that the higher score in Kahoot equals a bigger probability in having a better final grade.

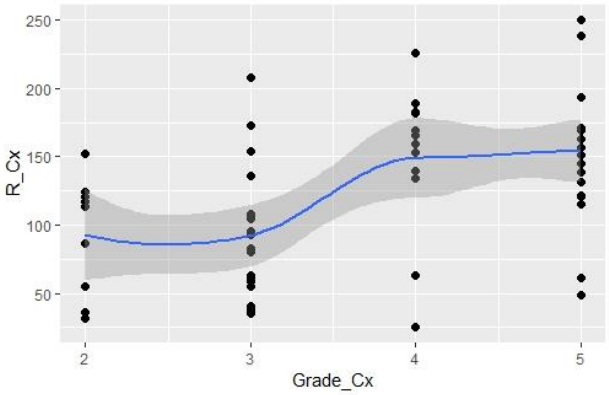

Figure 5. Kahoot relative values and students grades - Croatian group scatter plot

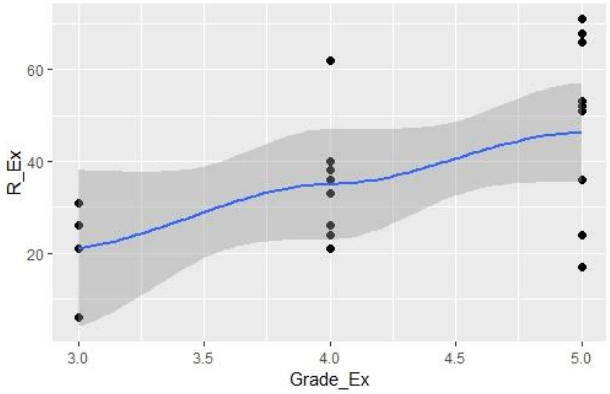

Figure 6. Kahoot relative values and students grades - English group scatter plot

The correlation for Croatian group is moderate (0,48), and so is for English – but slightly higher (0,52). However, there are also a lot of other elements that may influence the final grade of any student.

In order to examine the data set more detailed, the set was separated on male and female students in each group. Tables of boxplots (Table III) and Boxplots (Figure 7 and 8) were created to show the difference between minimum, median, mode, maximum, 1st and 3rd quartile values of both groups (in relative values). It is interesting to see the difference between groups based on gender. In Croatian ICT group, females' values exceed males, while in English group the situation is reversed.

TABLE III. STATISTICS OF BOTH GROUPS FOR BOXPLOT

	ICT CRO Relative value	ICT ENG Relative value
Minimum	25,00	6,00
1st Quartile	75,75	24,00
Median	121,50	34,50
Mean	123,47	37,55
3rd Quartile	163,75	51,75
Maximum	250,00	71,0

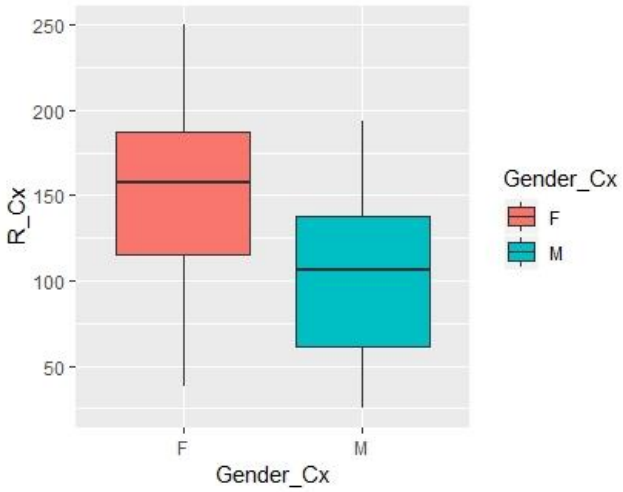

Figure 7. Kahoot relative values and gender - Croatian group box plot

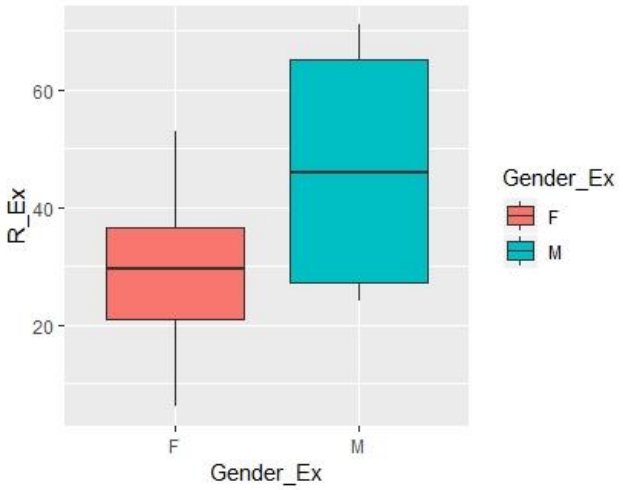

Figure 8. Kahoot relative values and gender - English group box plot

C. *Relative Kahoot values and motivation*

The correlation between relative Kahoot values and motivation marks are different for both groups. Figure 9 shows a perfect scatterplot of Croatian ICT group with high significance – the higher the motivation, the better Kahoot scores.

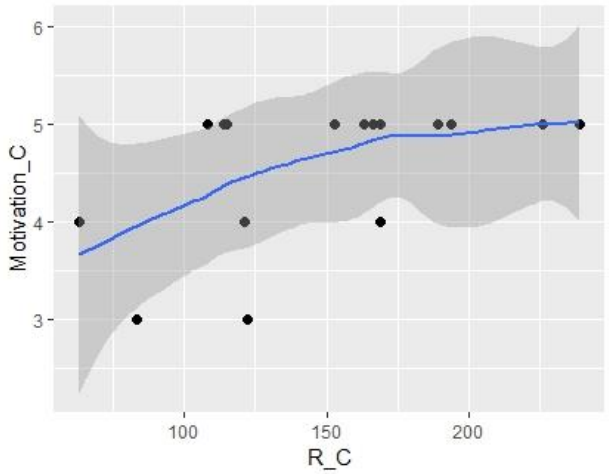

Figure 9. Kahoot relative values and motivation - Croatian group scatter plot

However, the correlation between relative Kahoot values and motivation marks for English ICT groups is of low significance as it is mostly scattered – due to the scenario of gamification usage and interantional diversity. Figure 10 shows the English ICT group scatter plot regarding motivation and relative values. The correlation level for both cases is at the lower moderate border, Croatian group with a 0,54 and English 0,36.

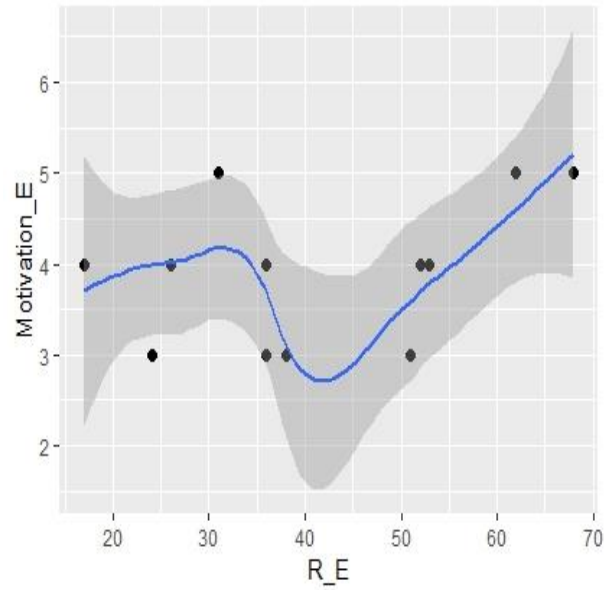

Figure 10. Kahoot relative values and motivation - English group scatter plot

D. Relative Kahoot values and reward

The correlation between relative Kahoot values that a student earned by playing and their perception on the importance of a reward system is also different for both groups.

The Croatian ICT group, as shown in Figure 11, shows the strong importance of a reward system as there is no mark under 4.

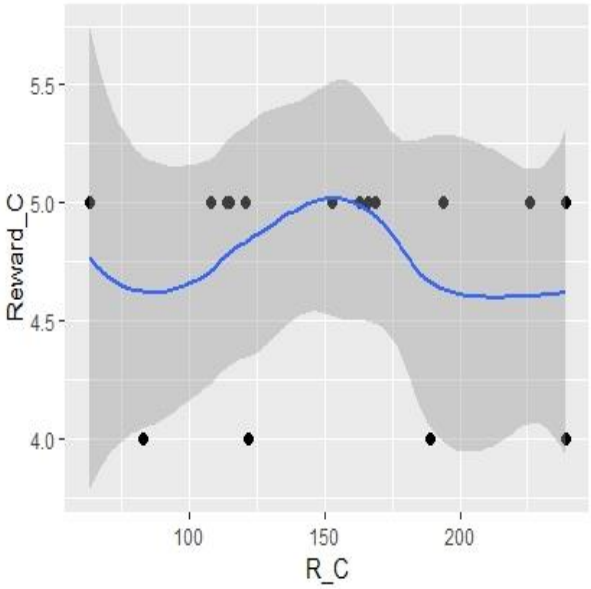

Figure 11. Kahoot relative values and reward - Croatian group scatter plot

For the English ICT group in Figure 12, the data is again scattered as it depends mostly on the diversity and the scenario chosen for rewarding students.

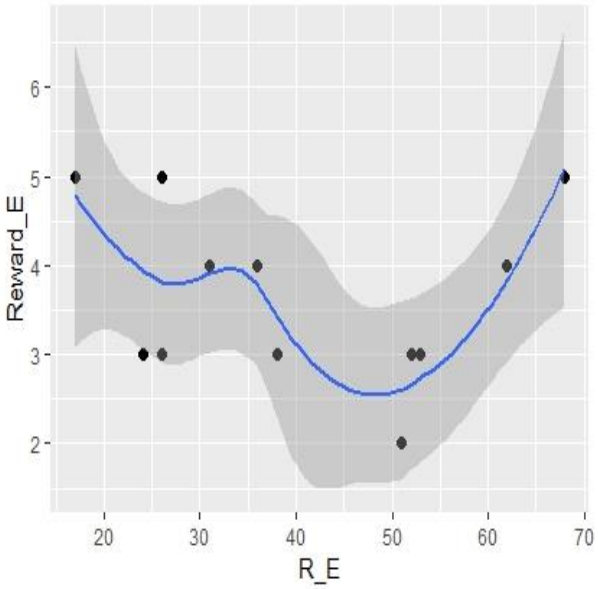

Figure 12. Kahoot relative values and reward - English group scatter plot

The correlation level for both cases is negative and very low, meaning it is not significant. Croatian student group had -0,036 and English -0,13.

VI. CONCLUSION

This paper shows how reward system in gamification influences student motivation regarding course activities through semester. It was evident how student perception towards motivation and rewarding system questions from the survey is different for Croatian and English ICT group because of the difference in reward system scenario. Meaning, Croatian group of students had higher marks than English group regarding motivation and the importance of some kind of a reward – because they had a reward scenario, unlike the English group. The higher motivation was also visible in the mean comparison of both groups absolute Kahoot values, as Croatian group had almost twice as bigger of the wanted mean. This result clearly shows how students do better in the Kahoot as they know they will be rewarded for it - revealing their true motivation – extrinsic motivation. The relationship between Kahoot score and final student grade is still in a positive correlation, as expected. However, the correlation of certain elements in the English group was a bit scattered and had no consistency because of the international diversity – the difference in cultural aspect, educational aspect, maturity aspect (some of the students were graduate level on an undergraduate course), etc.

For further research, it would be interesting to see gamification usage and successfulness through different tools, such as having a student profile throughout the semester which is growing by completing certain tasks and activities for earning Badges. The correlation of student profile success in gamification and final grades should provide decent insights on the student motivation perception.

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A Web-Based System for Personalized Learning Path Tracking of Doctoral Students

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Abstract - **High-quality training of doctoral students for valuable and thorough scientific research imposes high academic standards. The new academic generation of young scientists needs to be trained in creativity, critical thinking and autonomous intellectual conclusions. Doctoral students need to find suitable conditions for work, so that they can become independent researchers who at an early stage take responsibility for the scope, direction and progress of their projects. This defines the main purpose of doctoral education, which needs to be led at a high academic and methodical level. The highly acclaimed and well-popularized doctoral information system, developed at the University of Ruse, provides a wide array of possibilities for personalized learning path tracking. This enables the status of each doctoral student to be determined accurately and timely. The software allows for keeping detailed portfolios for each participant, and makes generation of various progress visualization tools, such as reports and graphs, effortless. Generating reports quickly and efficiently is an important benefit, compared to the conventional manual methods widely used in educational institutions. The paper explores the developed software system, and provides some sample analysis based on personal learning paths of doctoral students enrolled in the recent few years.**

Keywords - personalized learning path, doctoral, education, software, web

I. INTRODUCTION

The advancements of information and communication technology and of the World Wide Web has led to the digitalization of society in nearly every aspect. Long gone is the time when discussions on the need or benefits of information systems designed to track and augment education in higher education institutions were relevant.

Doctoral students of the digital age expect to be able to use information technology in their everyday research. Some interesting observances have been made in [1] about the use and adoption of information services and web-based environments for research work.

The strive towards improving the quality of service [2] for doctoral students in higher education schools, securing verified and reliable information about their education and activity and the need for evaluation and improvement of the activities related to the planning of educational and administrative work with doctoral students, effective feedback and coordination of the interoperability between administrative structures, scientific supervisors and doctoral students, impose the use of a specialized Web-based software solution to serve all information flow needs related to doctoral degrees [3, 4].

A survey has been conducted on the different approaches and tools employing services and practices that contribute to the doctoral degree process [5, 6] – at the beginning, when a degree position is opened, as well as in tracking and administration of the following stages of the educational process [7]. The available information resources and systems are strictly specific, depending on the particular requirements of each scientific organization and the legislative framework of each country. A complete global study of doctoral education around the world has been conducted in [8], and some useful ideas and suggestions for its improvement have been discussed. A four-quadrant supervisory style management grid based on the Blake and Moulton Managerial Grid Model has been proposed in [9], aiming to improve the style of management of doctoral students; it is currently in use in Australia.

During the development of the Web based System for Doctoral Students at the University of Ruse, the design has mainly been aimed at its biggest potential user groups, namely doctoral students and their scientific supervisors. This has ensured the focus was aimed towards building a high-quality user-centered information system, where the driving forces of the education process itself – doctoral students and their supervisors – are placed.

II. BACKGROUND

The comparison and analysis of different viewpoints [10, 11] about the multidimensional phenomenon that is the individual educational path leads to the summary that in the system of continuous, multi-level education, this term can be described as a process of acquiring a specialized education or degree, with targeted, continuous pedagogical support [12, 13].

Individual learning paths are closely connected with the selection of a future researcher [14, 15], the awareness of personal responsibility for their choice, and the formation of an initiative for their own development [16, 17].

The strive towards improving the quality of service for doctoral students in higher education schools, securing verified and reliable information about their education and activity and the need for evaluation and improvement of the activities related to the planning of educational and administrative work with doctoral students, effective

feedback and coordination of the interoperability between administrative structures, scientific supervisors and doctoral students, impose the use of a specialized Web-based software solution to serve all information flow needs related to doctoral degrees.

An original Web-based software system, which strives to aid the administrative division dedicated to doctoral students, the scientific supervisors and the students themselves, is presented in the paper; the system aims to be useful at all stages – admission, education, monitoring, reporting and automation of all activities related to doctoral degrees at the University of Ruse, while also complying with legislative documents and norms.

The innovative software system for management and reporting of the educational and administrative activities related to doctoral degrees deployed at University of Ruse has contributed to the optimization of the process of tracking, reporting and coordination of all entities involved - research units, the university-wide department for doctoral students, scientific supervisors and doctoral students. The system's information database is being used for research and analysis of the critical factors, which ensure the standardization and unification of the informational processes and the optimal distribution of the resources of different types of doctoral degrees.

The system for doctoral students has been in active use since 2016, with 312 doctoral students, 189 candidates, and 216 scientific supervisors' profiles registered to date. A detailed profile is maintained for each doctoral student currently enrolled in one of the degrees offered by the university. The new competitions for doctoral degrees are scheduled and announced via the system, giving candidates the ability to apply for these degrees and track the admission process entirely online; the online admission strictly complies with the time slots and deadlines outlined in the university's internal regulatory framework.

III. EXPOSITION

A. User Interface and Profile for Doctoral Students

As far as documentation is concerned, the education of doctoral students is monitored and regulated using a well-developed and applied system of standard document types (personal learning plan, training curricula, reports, etc.). It is important to note that, taking into account the existence of a wide array of universities and scientific/research organizations, each with its own internal documentation used for the organization of doctoral education, this system is somewhat liberalized. Even so, problems related to the systematization of the information from the development path of the doctoral student.

Summarizing each separate position of the preliminary systematization represents the original idea, and is a true roadmap of the path, which the doctoral student needs to follow in their work on their dissertation. The roadmap details each particular activity and can be thought of as a "passport" of sorts of the future research.

After a study of the main processes related to the admission and education according to the Bulgarian Law for Higher Education was conducted, it was summarized that the information system needs to support entering and maintaining of the following information:

- Data about doctoral students;
- Data about academic staff, serving as scientific supervisors
- All required documents and their supporting data;
- Data about the currently active admission competitions;
- Reports required by the Ministry of Education and Science
- An individual work plan for each doctoral student:
    - Type of doctoral degree;
    - Date of enrollment;
    - Term deadline;
    - Date of dissertation finalization;
    - Dissertation topic;
    - Scientific supervisor(s);
    - Basis for admission/acceptance;
    - Mid-degree exam data;
    - Dissertation defense data.

The scientific work of a doctoral student should also be tracked:

- Conference participations;
- Developed projects or project participation;
- Specializations;
- Published articles;
- Participation in the undergraduate learning process – conducted seminar-type/laboratory workshops

The quality of a research product is a function of a multitude of factors, which are consistently applied and of a synergistic nature. The generated high values of quality up to a point can be "spent" in a subsequent stage and therefore will not multiply into a collecting effect.

The web based system supports and maintains profiles of doctoral students, and thus allows storing, updating and displaying up-to-date information of their current state and the activities that they need to execute in relation to their doctoral degree. The system provides the capability to publish every doctoral student's individual learning plan, with the option for themselves and their scientific supervisors to view and track deadlines and important stages related to periodical reporting and the overall conformity to the procedure. It also allows students to view the administrative documentation, maintained by the university's Department for doctoral students in accordance with the legislative requirements. Information about educational credits is also collected and summarized, ensuring that academic mobility is also supported.

A doctoral student's profile is shown on Fig. 1. It is separated into several different panels. The profile stores data and documentation related to the particular student's degree. The main panel allows for monitoring the latest activity related to the particular doctoral degree. The progress bar, for example, is a notably useful function through which the time period of the doctoral process can be tracked in a visual manner.

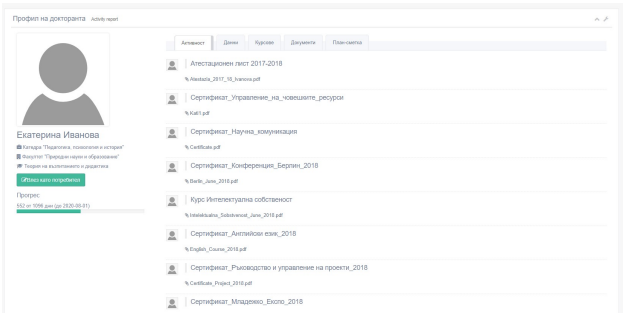

Figure 1. A Doctoral Student's profile

The panel for tracking the various courses the doctoral student is enrolled in and must complete is presented on Fig. 2. The following information is stored for each course:

- Course name;
- Lecturer's name;
- Start and end date;
- Educational credits.

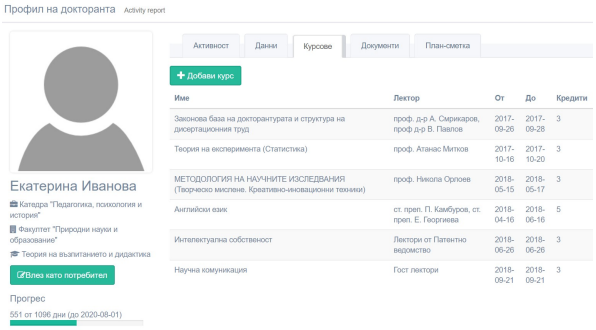

Figure 2. Course tracking panel in the doctoral student's profile

All functions and capabilities available to doctoral students are presented on Fig. 3.

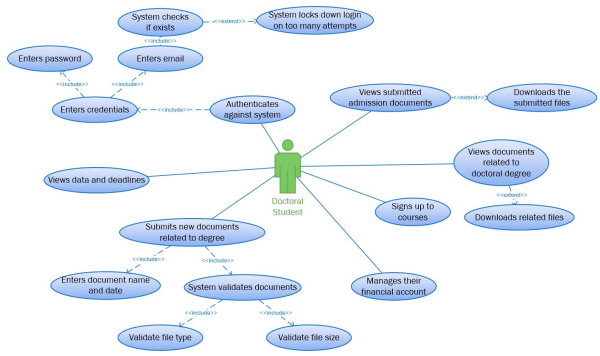

Figure 3. A Use Case Diagram representing the interaction of doctoral students with the system

As well as managing their documents, signing up for courses and progress tracking, doctoral students can manage their financial account, making sure that they are up to date on the funds received and spent in relation to their research.

B. *User Interface and Profile for Scietific Supervisors*

It should not be forgotten that the first mentor, reviewer and the person who should encourage each doctoral student is their scientific supervisor.

Along with doctoral students' profiles, a profile for each scientific supervisor is also maintained in the system. Supervisors have two main panels available, which they can use to view and manage their assigned doctoral students; they can also manage any degree and competition proposals from their profile page. If such need arises, scientific supervisors also have a limited ability to monitor and edit their doctoral student's electronic profiles.

A sample profile of a scientific advisor is presented on Fig.4. They can see and manage the two doctoral students assigned to them.

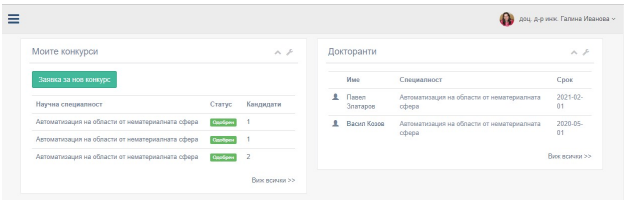

Figure 4. A scientific supervisor's profile

All of the functionality available to scientific supervisors is shown on Fig. 5.

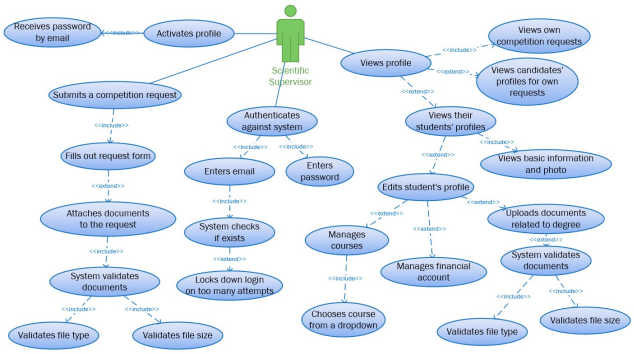

Figure 5. A Use Case Diagram representing the interaction of scientific supervisors with the system

Using their profile page, the scientific supervisor has control of most aspects of the whole doctoral degree process – from publishing a doctoral degree competition to degree finalization. Their profile also contains a history of all doctoral students assigned to the particular supervisor who have graduated.

C. *Personal Learning Path and Tracking*

During each doctoral student's enrollment, it is required that an individual learning plan is developed by students and their supervisors, and verified by the corresponding scientific organization. This document is individual to each of the doctoral students, but, to make the process easier, at the University of Ruse there exists a sample plan, which can be used as a guide for doctoral students and scientific supervisors preparing the plan. The document should outline each activity that the doctoral student needs to perform in order to pass the minimum requirements (defined by the legislative norms). An example graph - spiral of development – is presented on Fig. 6. Such a graph can be drawn for each doctoral

student, based on the planned activities and deadlines in the individual plan.

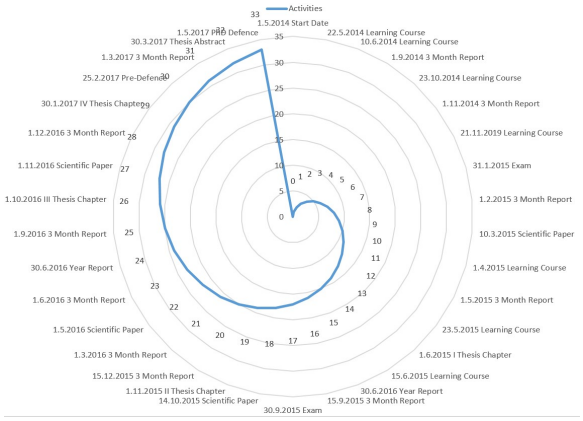

Figure 6. A spiral diagram of a doctoral student's development

Full-time doctoral students are enrolled for a three-year period, at the end of which they must present and defend their work. The minimum number of activities included in each individual plan are about 30 and are presented on Fig. 6. These can include educational courses, reports, conference participations (with scientific articles or papers), writing of the different chapters of the dissertation (Bulgarian dissertation usually include four chapters), defenses and presentations (a preliminary – internal - and a final one – external). Unfortunately, a small percentage of doctoral students actually manage to defend their dissertation work in the allocated three-year period. The system stores data about every essential activity along with its expected date of completion. On Fig. 7, a model of a trend graphic is proposed; this model can be used to track the doctoral student's overall progress. A trend diagram can be plotted based on each individual plan; the doctoral student should try to follow the trend curve as closely as possible. If their plot is below the trend curve, this should be a signal to them and their scientific supervisor that they might be behind and should take timely measures in order to defend their dissertation in time.

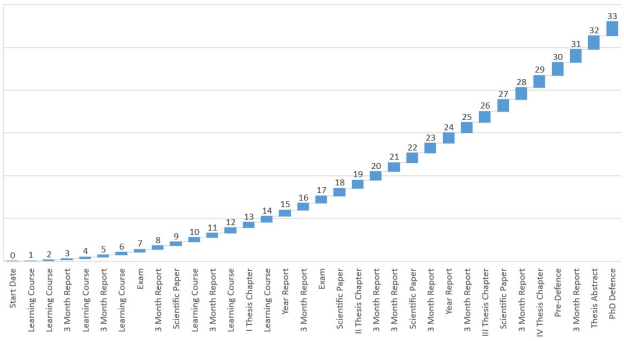

Figure 7. A trend diagram of a doctoral student

In order for the process to be compliant with the law, each procedure needs to be presented as a logically ordered aggregation of documents (e.g. orders, reports, certificates, etc.), which describe and elaborate the implementation of all activities in the individual plan. This documentation is stored in the doctoral student's electronic portfolio; every document is signed, stamped, scanned and stored alongside a description, date of issue and various other pieces of metadata, so that the document can be analyzed if needed.

The Web based system maintains a database to help track all stages of the doctoral degree, their sequence and timeline and offers doctoral students and their supervisors the ability to track the up to date schedule using a Gantt chart, which takes into account all important steps of the process – both the ones initiated by the educational institution and the ones initiated by the student or supervisor. A sample chart is presented on Fig. 8.

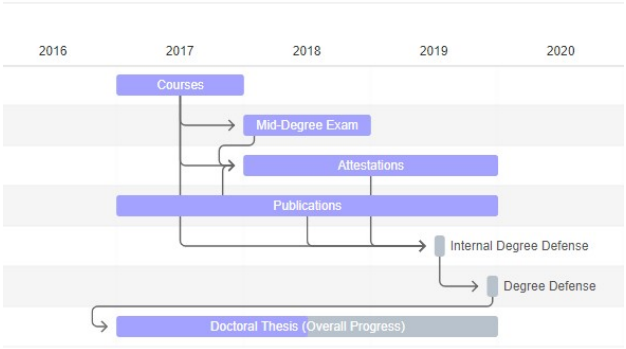

Figure 8. A visual representation of the Personal Learning Path and progress

The tracking of doctoral students' learning path is essential for the effective and timely evaluation of their progress. The proposed graphics aim to better visualize doctoral students' progress, and will help doctoral students better monitor their development process and evaluate the required effort needed to achieve their final target – defending their dissertation. This functionality is also useful to scientific supervisors, who can better control and adjust the process in case it gets behind the planned timeline or pace of development.

D. Administrative staff control panel. Reporting and statistics.

While scientific supervisors are responsible for the education of their assigned doctoral students, the whole process is usually also controlled by a centralized administrative department. At the University of Ruse, this is the Department for doctoral students. The process of management, control and decision making in the preparation of doctoral degree students requires timely access to up to date information for each student. This is achieved using the Web based system's administrative module. Of particular note is the recently developed reporting package, which allows easy status monitoring by means of different types of graphs, charts and reports, which can be customized by specifying various criteria. On Fig. 9, a view of the module is presented, with a few of the dynamic charts plotting various data points related to data for doctoral students in the past 5 years.



Figure 9. The administrative module's home page, part of the reporting package

Data about the personal path of each doctoral student at the University of Ruse is stored in the common database, and, when needed, generalized reports can be generated from the learning path data. For the purpose, a module for quick, dynamic reports on doctoral students based on various criteria has been developed; this module makes statistical analysis and processing significantly easier, as users can select only the data points and criteria they need for the particular report. This is especially useful for reporting on a university and national level, which are periodically required by various university entities and the Ministry of Education and Science.

A screen from the dynamic reporting module is presented on Fig. 10.

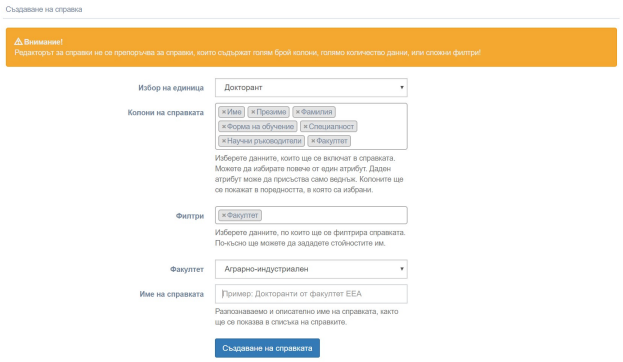

Figure 10. The dynamic reporting module; a report creation screen

The reporting section allows generating report tables for every doctoral student in the university by applying different criteria and filtering by: faculty, by scientific specialty, full-time/part-time, etc. Some of the reports are regularly used in the process, so they have been prepared in advance using static database queries; however, to extend the system's flexibility, dynamic reports can be created by making use of the dynamic report editor.

The report editor allows the administrators to create reports with user-defined columns and filters. This enables an effortless report creation and execution; most of the reports would otherwise require writing additional code or changes to entire modules of the system. As well as the columns, the filters are also user-selectable. Each report is saved as a template in the database and can be executed at any given time. Being saved as a template means that when the report is recalled at a later point of time, it will always be based on the most up to date data.

The report management module is shown on Fig. 11. It is used to manage and run the reports created via the dynamic report editor. Each report can be displayed as a HTML file or exported to Microsoft Excel for further processing or analysis.

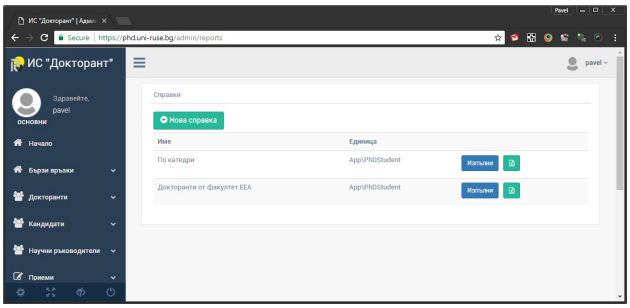

Figure 11. The dynamic report execution screen

It is notable that the system has been developed using the Laravel framework, and so the reporting module takes full advantage of the framework's features. The module is flexible and can be applied to any Laravel model; it is not limited to just the specific kinds of reports required by this system. This guarantees module reusability – both further in the development path of the system and in other projects. The code is based on Eloquent models (the object-relation mapping module of the Laravel framework), which makes it completely independent of the database management system that is used.

IV. CONCLUSION

The web based system for doctoral students is being tested and validated in real conditions and has been deployed for use at the "Angel Kanchev" University of Ruse. Its use helps the university's administration, the scientific supervisors and the doctoral students in many routine operations and facilitates the work related any procedures accompanying the doctoral degree's progress tracking. It ensures access to a verified, operative information set related to doctoral students and their educational and academic development. The automated deadline, timeline and stage tracking allows for monitoring of the quality of education of doctoral students.

The training of doctoral students is a complex process, which requires an innovative, contemporary toolset for management and reporting of the different educational activities; inherently, this allows for a higher quality tracking of each stage in accordance with the legislative requirements for doctoral degrees. The creation and refinement of a Web based information system for doctoral students ensures automation of the processes related to tracking and documenting the student's progress throughout their degree; this assures the credibility of the information of the current status of the training of all doctoral students throughout the university.

ACKNOWLEDGMENT

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for research and innovation at the University of Ruse "Angel Kanchev". The project is funded with support from the Operational Program "Science and Education for Smart Growth 2014 – 2020" financed by the European Social Fund of the European Union."

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Open Educational Resources as a Trend of Modern Education

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***Abstract* - The article presents the results of the study of open educational resources in mathematical disciplines. The purpose of the article is to summarize the experience of teaching mathematical courses based on quantitative analysis of the corresponding open educational resources and determination of ways of using such resources in the conditions of Ukrainian universities. The definition of open educational resources and their specific features are specified, in particular, support of different formats for presentation of materials, their publication under conditions of an open license, provision of free access, the possibility of modification of materials by other users. The analysis of the number of open educational resources Coursera, Edx, Udemy, and INTUIT has revealed that the bulk of mathematical courses in relation to others is not large, which suggests a reduction in young people's interest in purely mathematical disciplines. At the same time, it was noted that the presence of such resources on the site of the university contributes to the formation of its positive image within the country and the world. The own experience of studying mathematical online courses on Analytical Geometry, Linear Algebra, Geometry and Mathematical Philosophy is described.**

Keywords - open education, educational resources, open educational resources, open educational resources in mathematics, mathematics courses

I. INTRODUCTION

Nowadays, the information technology (IT) in the learning process is no longer news. In addition to specialized technical equipment and professional support, the Internet has been used in recent years. It brought in a large amount of information in various fields.

This causes the "consumption", but not the use of information content by the youth [1]. It currently leads to a deliberate reduction of areas of interest and reduce the motivation to learn and get a modern professional assistance in acquiring professional competences.

The educators are aware of these trends. They conduct searches of learning strategies that would not only attract IT, but also help in learning different courses, regardless of the age of the educatees, course duration, and the location of the learning process and so on. We distinguish the emergence of open educational resources among these innovations.

The term "open educational resources» (OER) was first introduced at the World Educational Resources Congress for developing countries, organized by UNESCO in July 2002. According to the adopted definition - open educational resources mean the educational and scientific resources that exist in the public domain or released under a license that allows their free use and modification by third parties [2].

According to the definition, the characteristics of open educational resources can be identified: methodical, educational or scientific orientation of materials, support for different formats of materials presentation, publication of educational and scientific material that is in the public domain on an open license, free access, recycling and redistribution of material by others, minimal restrictions (or lack thereof) when working with open educational resources.

We were impressed by arguments that speak in favor of open educational resources [2].

- Educational institutions that receive public funding are required to provide free access and use of created materials because they are partially developed by the taxes of citizens and thereby society already paid for it.
- Limited access to educational materials could lead to duplication of efforts, which also entails additional costs for the society.
- Placement of open educational resources creates a positive image of the university and the country as a whole, helping to attract more students and funding of the institution from private funds.

According to UNESCO [2] in the last decade, the number of open educational resources that provide university repository sites and projects increased significantly. The most famous of them are Coursera [3], Edx [4], Udemy [5], MIT OpenCourseWare [6], OpenLearn [7], and INTUIT [8].

The emergence of these resources, on the one hand, led to the development of ubiquitous learning technologies, on the other hand, made it possible to develop the educational sector under pressure of social needs to deepen knowledge in any desired direction.

In addition, the emergence of open educational resources has led to the globalization of the educational sector, which is why we can talk about blurring boundaries of "scientific schools" and the disappearance of the "closed methods" of learning. This is especially true for established classical disciplines, including Mathematics as one of the sciences that not only actively developed and has a broad scope of application, but characterized by certain ancient traditions in studying the classical mathematical training.

Today we can observe trends in university exchange of scientists, the emergence of specialized courses related to modern problems of Mathematics, developing specialized software designed to solve a wide range of mathematical problems by visualizing numerical and symbolic transformations or the dynamic modelling of processes in formalized systems.

Familiarity with such trends is made possible by the open educational resources created in the leading universities of the world to demonstrate, for example, the latest trends in the field of Mathematics. A detailed study of such resources (not only content, but also presentation technology of learning material, organizing its study, methods of knowledge control, etc.) help educators to understand their own scientific level and trends in educational requirements for professional training in modern Mathematics.

II. MATH COURSES ON OPEN EDUCATIONAL RESOURCES

A. Quantitative Analysis of Math courses on OER

As part of activity of the Laboratory of information technology in education (Makarenko Sumy State Pedagogical University, Ukraine) open educational resources have been analysed [3-8] to determine the presence of the courses in mathematics. We were interested in the quantity, authors, technology of certificates, etc. Graphical visualization of quantitative analysis shown in charts in percentage form (Fig. 1-6).

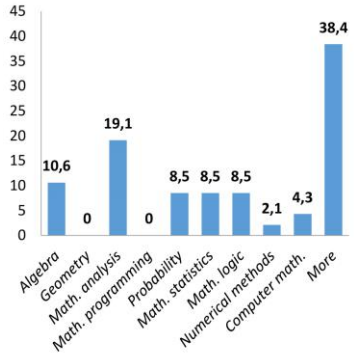

Figure 1. Coursera

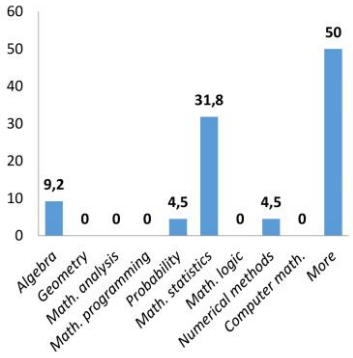

Figure 2. Edx

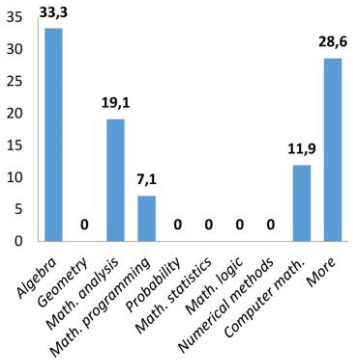

Figure 3. Udemy

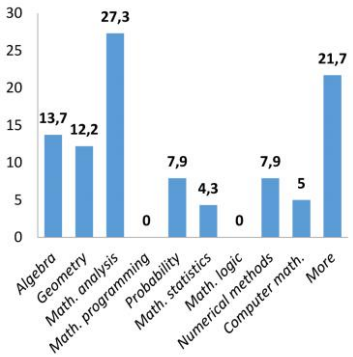

Figure 4. MIT OpenCourseWare

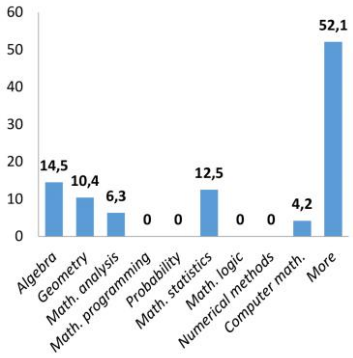

Figure 5. OpenLearn

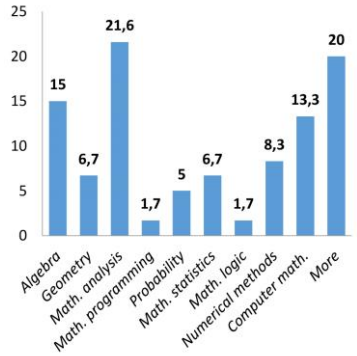

Figure 6. INTUIT

B. Comparative Analysis of Math courses on OER

Quantitative analysis of these resources suggests that in addition to the classical mathematical disciplines much attention is paid to courses that connect Mathematics and other fields of knowledge. Among them there are "Introduction to Mathematical Philosophy", "Mathematical Methods in Quantitative Finance" (OER Coursera); "Effective Thinking through Mathematics", "Relativity and Astrophysics" (OER Edx); "Mathematical Way of Thinking about Biology", "Sinking Fund" (OER Udemy); «Nonlinear Dynamics", "Mathematical Methods in Nanofotonics" (OER MIT OpenCourseWare); "Modelling of Displacement and Speed", "Mathematics Everywhere" (OER OpenLearnresurs) and others.

One of the tasks of our study was to investigate the characteristics of technology of on-line courses. We gained experience learning different professional disciplines, including the course "Fundamentals of Analytic Geometry" (INTUIT), «Introduction to Mathematical Philosophy» (Coursera), «Linear Algebra» (Edx), "Geometry" (Udemy). Brief information about these online courses is given in Table 1.

TABLE I. ANALYSIS OF MATH COURSES ON EOR

Course Name	**Fundamentals of Analytic Geometry**	**Introduction to Mathematical Philosophy**	**Linear Algebra**	**Geometry**
Source	Intuit.ru	Coursera.org	Edx.org	Udemy.com
Course Description	The aim of the study is the introduction and application of analytical geometry and linear algebra	The course is linked to mathematical philosophy and demonstrates how to analyze philosophical questions based on basic mathematical concepts and methods	The course is designed to study the course of linear algebra. It also researches practical implementation of the theory of algorithms	This course is an introduction to the study of geometry and is designed for students who have not studied geometry before, or have a need to recall the geometric material
Lecturer	Assoc.Prof., Ph.D., B. Boyarshinov	Prof. H. Leitgeb, Prof. S. Hartmann	Prof. R. van de Geijn	Prof. M. Fortress
Language	Russian	English	English	English
Course volume	48 hours (lectures), 24 hours (tests)	10 weeks	12 weeks	7 hours
Accounting	Tests (24 topics), each not less than 60% of correct answers. The exam (30 test questions)	The exam(tests), not less than 70% of correct answers	Homework, tests and exam	Enough to listen to all the lectures
The presentation of electronic materials	Lectures in the form of video fragments. Online test (8 questions) after each lecture.	Lectures in the form of video fragments that contain questions	Lectures in the form of video fragments. Homework (tests).	Lectures in the form of video fragments.
Result	In case of successful completion of the course (at least 60% of the maximum possible points) student receives an online-certificate	In case of successful completion of the course (at least 70% lectures attended) student receives an online-certificate	In case of successful completion of the course (at least 60% of the maximum possible points) student receives an online-certificate	When viewing all lectures online student receives a certificate.

Comparing the curricula of mathematicians and mathematics teachers training at Ukrainian universities and online courses mentioned, we note the following.

"Fundamentals of Analytic Geometry" course in a Ukrainian university and on OER INTUIT is identical. We believe that this is because this course is offered by the Russian public resource, and methodological features of studies in Ukraine and Russia are similar. It should be noted that the training of analytical geometry on OER is very similar to the usual lectures. The tasks of the course are also similar.

Analogue to the course "Introduction to Mathematical Philosophy" (OER Coursera) in the curriculum of mathematicians' preparation in Ukrainian universities is the special course of studying philosophical problems of mathematics (normative discipline). The difference in the study lies in the methods of control: enrollment in online courses require fixing the review at least 70% of lectures, in Ukrainian universities it is not usually enough to attend 70% of lectures and require personal communication or writing some control paper.

The essential difference between an online course in linear algebra (OER Edx) and the one studied in Ukrainian universities is allotted number of hours of training and its content (in Ukrainian universities course contains more topics in algebra and more hours of learning). In addition,

there are differences in the tasks proposed in the study and during the course control.

Ukrainian universities do not have analogues to online course "Geometry" (OER Udemy). The material rather designed for Ukrainian school students who are acquainted with the notation of basic geometric objects.

III. CONLUSION

The use of e-learning courses allows receiving education at a distance without direct contact between teacher and educatees. The choice of course not least depends on its short description and possibly a video announcement with details about the course and what skills it teaches and the quality of educational material presentation. It is especially important that e-course is interesting for the educatee, contains various forms of presentation of learning material, reduces dependence on the teacher and allows learning at any convenient time and in any place where there is Internet access.

Analysis of the world's leading open educational resources suggests their active development and implementation in the USA and the EU. This explains that most of the projects are in English.

The part of Math courses on OER comparing to others offered is small. That indicates, in particular, the fact that Mathematics is less popular on these resources in relation to other sciences.

Experience of attending the courses allows talking about similarities and differences between traditional math courses on open educational resources and in Ukrainian universities. Thus, similar to Ukrainian are courses offered by Russian educational resources. It can be explained by established traditions of Soviet (but common) scientific and methodological school. Differences between foreign online courses and Ukrainian courses in technology study due, in our opinion, the various scientific and methodological approaches, and are found in the content of courses, number of hours for their study, practical tasks to form skills and control technologies. We believe that an important role in the development of these resources plays an imperious policy and funding (unfortunately, in Ukraine such projects are not funded and not encouraged because of bureaucratic obstacles in educational sector).

According to the experience obtained in the study of mathematical disciplines on open educational resources it can be determined what should be looked for when it comes to developing own electronic materials for teaching mathematics of the open model. In particular, it is necessary to create online lectures, video or multimedia presentations, taking into account the possible listener fatigue of the teacher, automated control, visualization of the results and communication on-line or off-line.

Assessing labor costs to create an online course, one should remember about not only the content, but also the form and the request. The foundation of classical course can be an educational standard. The content of the special course, usually the variable part of the curriculum, is developed at the discretion of the author or lecturer.

The ideas extend to create not just online video lectures and test control, but also such electronic educational products that provide interactive and multimedia support. This requires the involvement of programmers and psychologists, which increases the cost of quality educational content.

Online Mathematics courses in might be useful to teachers and Ukrainian students:

- While getting acquainted with such courses teachers can not only learn the experience of colleagues and learn specifics of teaching classical and new courses abroad, but also to increase their qualification, having an additional certificate of professional (or non-professional) disciplines.
- The practice of students studying certain subjects may include parallel attending of online course for which additional points can be accrued.
- The use of online courses can be productive in the organization of independent work of students, which is at least a third of all course hours and is not always evaluated by a teacher.
- These courses can be introduced in universities as a variable part of the curriculum of training in their preliminary review of the leading teachers of universities.
- Additional practice of English.
- Substantial support for one’s image and promotion of the careers of everyone who dares to do so.

In Ukraine, the development of open educational resources is just beginning. Much of Ukrainian universities that are experienced in distance learning technologies are unwilling to share their own best practices and teach courses in open form. However, there are trends in the development of open content together with changes in the Ukrainian educational sector, that is why we believe that the expectations of the Ukrainian youth of the opportunity to use quality national open educational resources is not wasted.

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Benefits of Experimental Supported Teaching

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***Abstract* – As physics is an essential part of natural sciences, it is always included in the curriculum of study fields in engineering. In conventional physics lectures, a typical approach consists of a theoretical part presented in class and additional exercises in lab performed by the students themselves. Here, the question arises whether this didactic approach is sufficient for students to comprehend the complex contents and to develop a better understanding of physics. In order to answer this question, a project at the Carinthia University of Applied Sciences dealt with the question if and how the implementation of experimentally supported teaching can improve the learning outcomes and how computers and modern technologies can be used for this approach.**

In our case, basic experiments in the field of mechanics have been defined and prepared, taking into account the inhomogeneous knowledge of the beginners. An important question to be answered was the contribution of the experiments on the overall learning progress in Systems Engineering. A feedback directly after the lecture and one month later shows that this method receives strong approval, leads to an improved understanding and supports to reach educational objectives.

Keywords - physics, physics didactics, physics teaching, experiment, mechanics

I. INTRODUCTION

In the first semester of a study program, lecturers frequently have to face the challenge that the beginners have various educational backgrounds, which leads to different stages of knowledge within one group. Often, this is especially noticeable in natural sciences like physics. In order to ensure that every student is able to follow the lesson and reach the same educational objectives, a thorough preparation of the curriculum is necessary. Here, it is especially important not only to think about the content that shall be taught, but also to define which methods and materials shall be used to communicate the content in a clear and comprehensible way.

Thinking about these challenges, it was decided that in course of the introduction of a new curriculum for the study program Systems Engineering at the Carinthia University of Applied Sciences in 2018, a new teaching methodology for the physics lecture shall be implemented and evaluated. It was the intention that in parallel to the theoretical contents, the utilization of experiments shall be intensified to make the physics lecture more practice-oriented. However, the implementation of new experiments requires careful planning to ensure that the students truly benefit from it.

A. Task definition

In the course of a project at the Carinthia University of Applied Sciences, it was the goal to define necessary preparations to integrate experiments in the physics lecture. As a first approach, a lot of research on physics didactics and on the significance of experiments for physics teaching had to be done. Afterwards, the focus was on the definition of experiments in the field of mechanics, including a description that contains the necessary knowledge, used material, structure, execution and knowledge acquisition. Here, special attention had to be paid to the fact that the experiments are suitable for the auditorium environment, constructible with little costs, executable with little effort, and repeatable at home. As a result, the experiments had to be demonstrated in the classroom followed by live feedback from the students. Thus, the impact of the experiments on the physics lecture and the benefits for the students have been evaluated.

II. EXPERIMENTAL PHYSICS IN TEACHING

Physics accompanies pupils in Austria from the fifth grade onwards. Depending on the focus of education, physics can be learnt and taught up to the graduation level and beyond. To achieve that the complex contents of physics can be understood by the learners, an effective teaching methodology is required. Therefore, the application of various didactic procedures and methods is advisable.

A. 3.1. What does "(physics)didactics" mean?

According to [1], didactics in the broader sense deals with the science of school learning and teaching as well as with the theory of educational content. Figure 1 shows that this also includes pedagogical practices as well as teaching research. Here, the educational research sector focuses on the development of new methods and concepts for school learning. As social and technical factors have a strong influence on education, this is a continuous procedure.

In simplified terms, didactics, especially didactics in the narrower sense, is the "what", i.e. the goals and contents of a curriculum. The methodology, on the other hand, deals with the "how", i.e. the tools, media and methods used to convey content. As can be seen in the diagram, didactics and methodology are directly linked.

Physics didactics, in particular, is didactics with a technical reference to physics and therefore deals with the theory of the educational task, pedagogical methods and teaching and learning research in the field of physics.

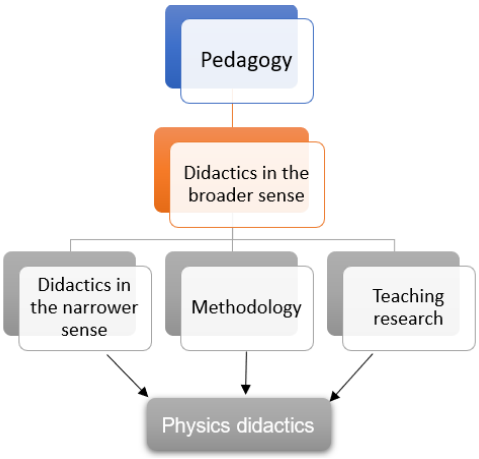

Figure 1: Interrelationship between physics didactics and pedagogy

B. *The Experiment*

In general, the experiment is a methodical, repeatable procedure under controllable conditions which aims to confirm or refute a central hypothesis. However, caution is required. As can be read in [5], an unambiguous confirmation of a hypothesis is not possible, because the requirement would be to know the sum of all possible results. At best, the outcome of an experiment can clearly refute a theory or substantiate its correctness. Since there are many methods and media to present teaching content in an understandable way, the question arises why exactly the experiment is a teaching method that should definitely be part of a physics lecture.

The possibility to illustrate and comprehend physical phenomena is the main reason why experiments are an important part of physics didactics. They can be seen as the connection between theory and practice. In physical research, comprehensive planning and control, as well as the complex acquisition of measured values and their interpretation are important components of every experiment [1]. When carrying out an experiment for the purpose of research, it must be ensured that the results are measurable, that the procedure can be repeated by third parties and that all data can be verified. In order to guarantee this, the entire test setup, all measuring equipment and methods, as well as environmental conditions and parameters must be accurately recorded and documented. Just as essential is the documentation of all results, including negative results or the absence of results [3] [4]. In contrast, experiments in the context of physics teaching primarily have an informative function and should concretize physical knowledge. Here, a detailed explanation and a thorough preparation and post-preparation are especially important to intensify understanding.

Overall, it can be said that experiments are essential for the acquisition of physical knowledge (see Figure 2). In [2] a four-stage process of obtaining physical knowledge is described.

a) Experiment: In the course of an experiment, physical parameters are observed, measured and compared in order to recognize and record correlations.
b) Induction: If experiments confirm certain connections repeatedly, it can be concluded that there is some kind of law. Only if existing physical constants are not changed, such generalizations may be made.
c) Physical Law: The generalization made by the induction conclusion goes hand in hand with the (mathematical) formulation of a physical law. If several laws form a contradiction-free system with each other it is called physical theory.
d) Deduction: Laws and theories are used to predict the outcome of further experiments or problems.

Thus, the significance of experiments, not only for physical teaching but for physics as a natural science in general cannot be denied.

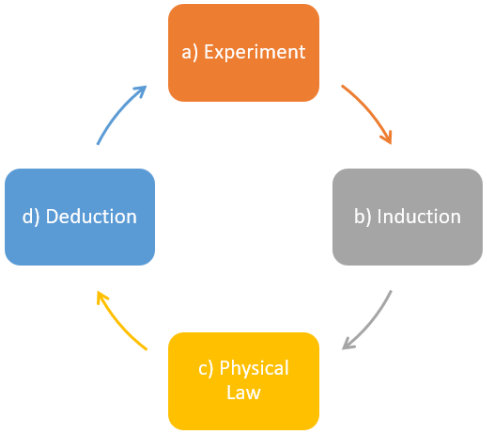

Figure 2: Circle of physical knowledge acquisition

III. Experiments in Mechanics

As can be read above, a thorough preparation and post-preparation are especially important to ensure that students benefit from experiments in physics lectures. As an example, the following section describes different experiments in the field of mechanics, to visualize how such a preparation can look like. Mechanics was chosen as the first field of physics where experiments shall be implemented for two reasons. First, it is a major part of the physics curriculum of the first semester. Second, mechanics deals with phenomena which are easy to recreate experimentally. In many cases, only little time and effort are needed to demonstrate a mechanical principle effectively.

In course of the project, it was defined that all experiments shall be prepared in a similar pattern. First, necessary physical knowledge for the respective topic shall be explained with the aid of figures and formulas. Next, for each experiment a list of needed material and an explanation for the basic design and construction shall be provided. As it was mentioned in the introduction, the focus should be on low-cost experiments which are easy to construct. Furthermore, the execution needs to be described in detail. A short statement concerning the essential findings and gained knowledge from this experiment ensures that every student will come to the same conclusions and cannot misinterpret the results. Finally, it is described how new technologies

can be used for documentation and evaluation of the experiment.

A. Free fall experiment

The aim of this experiment is to demonstrate in a simple and fast way how time and height of a free fall depend on each other.

1) Basic knowledge and goals

If a body changes its position within a coordinate system over a certain period of time, the ratio of distance travelled to elapsed time is called the average speed *Δv*. It can be positive or negative and is the slope of the curve in the path-time diagram (1). If the speed changes over time, the body accelerates and therefore performs an accelerated movement (2) [6].

$$\Delta v = \bar{v} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} \rightarrow \Delta x = \bar{v} \cdot \Delta t \quad (1)$$

$$\Delta a = \bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t} \quad (2)$$

If a = const. it follows:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_{(t)} - v_{(0)}}{t - t_0} = \frac{v - v_0}{t - 0} \quad (3)$$

$$v = v_0 + at \quad (4)$$

Since the velocity changes linearly with time at constant acceleration, the instantaneous velocity can be calculated as an average of the initial and final velocities:

$$\bar{v} = \frac{v_0 + v}{2} \quad (5)$$

From the equations above, the dependence of the travelled distance on the time can be derived at constant acceleration.

$$x(t) = x_0 + v_0 \cdot t + \frac{1}{2} \cdot a \cdot t^2 \quad (6)$$

It can be seen that, in accelerated motion, the dependence of the path on time is quadratic.

2) Material

- Thin, solid strings (e.g. fishing line)
- Several masses which can be dropped, e.g. several identical coins, knobs or screw nuts
- A sheet metal underlay

3) Construction

- At the end of a string, one of the masses, e.g. a screw nut is attached.
- The remaining nuts are attached to the string so that their distance to the first nut is equal to 1:4:9:16, resp. $1^2:2^2:3^2:4^2$.

4) Execution

- The string hangs loose to the ground in a way that the first nut just touches the sheet metal. If necessary, a ladder can be used or the test can be carried out in a staircase.
- It is dropped and the noise of the impact of the nuts is recorded for further analysis.

5) Findings

The noises of the impact occur in equal distances to each other. If the starting height is defined as zero and *a* is replaced by the constant acceleration of gravity *g*, an abbreviated variation for free fall is obtained from (6):

$$x(t) = \frac{1}{2} \cdot g \cdot t^2 \quad (7)$$

All nuts on the string are released at the same time and experience the same acceleration. If the nuts are to reach the bottom at the same time intervals, the following ratio must exist between the fall times:

$$t_2 = t_1 + t_1 = 2 \cdot t_1$$

$$t_3 = t_2 + t_1 = 3 \cdot t_1$$

$$t_4 = t_3 + t_1 = 4 \cdot t_1$$

Thus, it follows that $t_1:t_2:t_3:t_4 = 1:2:3:4$. As the relationship between fall time and -height is quadratic, the required ratio of fall times is obtained if the heights equal to $x_1:x_2:x_3:x_4 = 1:4:9:16 = 1:2^2:3^2:4^2$. If the nuts are attached to the string at equal distances, i.e. $x_1:x_2:x_3:x_4 = 1:2:3:4$, the corresponding fall times have the following relationship to each other: $t_1:t_2:t_3:t_4 = 1:\sqrt{2}:\sqrt{3}:\sqrt{4}$ $t_1:t_2:t_3:\ldots = 1:\sqrt{2}:\sqrt{3}:\ldots$. This means that the time interval between two successive impacts becomes smaller and smaller.

6) Research approach by using new technologies

In order to illustrate these findings, a video recording of the fall of the string was made with a smartphone, where the impacts on the sheet metal where clearly audible. Afterwards, the audio track of the video was extracted and analysed on the computer by using the software *Audacity*. Consequently, the time intervals between two impacts could be measured. Together with the known height differences between the screw nuts, these data were handed to the students for further analysis with MATLAB. The goal was to proof the quadratic relationship between fall time and -height. By this approach, the students not only learnt the physical principles, but they also developed a computer-assisted measurement data evaluation. The results and setup are further illustrated in Figure 3, Figure 4, Figure 5 and Table 1.

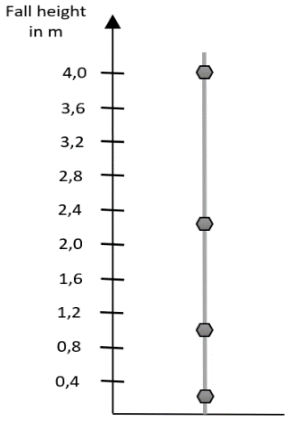

Figure 3: Free fall experiment setup

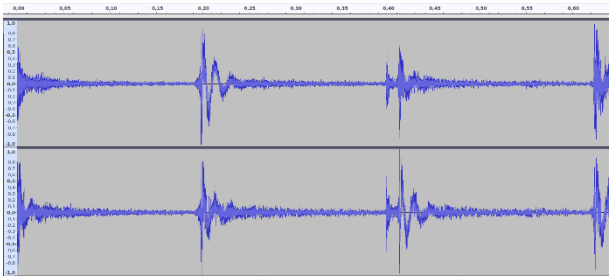

Figure 4: Free fall experiment, audio file

Table 1: Free fall experiment results

Fall time in s	Fall height in m
0	0
0,226	0,25
0,428	1
0,613	2,25
0,853	4

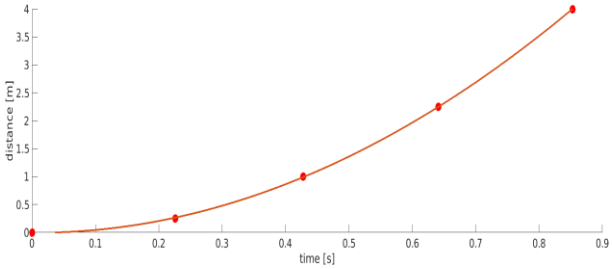

Figure 5: Free fall experiment figure

B. *Experiment on the orbit of a rotating mass*

1) *Basic knowledge*

This experiment aims to explain the relationship between angular velocity, radius and centripetal force on a circular path. If a mass point moves on a circular path, the number of revolutions per time is called the frequency *f*. The reciprocal of the frequency is the duration required for one orbit. It is called period duration *T*. Here, too, the correlation applies to uniform movements as in (1). However, since the travelled distance describes a circular path, the orbital velocity is described as follows:

$$v = \frac{2 \cdot \pi \cdot r}{T} = 2 \cdot \pi \cdot r \cdot f \qquad (8)$$

The angular velocity describes the relationship between the covered angle and time:

$$\omega = \lim_{\Delta t \to 0} \frac{\Delta \varphi}{\Delta t} = \frac{d\varphi}{dt} \rightarrow \varphi = \omega \cdot t \qquad (9)$$

For the duration of one rotation $\varphi = 2\pi$ and $t = T$, the angular velocity is:

$$\omega = \frac{2\pi}{T} = 2 \cdot \pi \cdot f \qquad (10)$$

From the (8) and (10) results the relation between orbital velocity, angular velocity and radius:

$$v = r \cdot \omega \qquad (11)$$

In order for a body to be able to move on a circular path, there must be a force that keeps it on the path curve. This force is always directed to the centre and is called centripetal force F_z [7].

$$F_Z = m \cdot r \cdot \omega^2 \qquad (12)$$

$$F_Z = m \cdot \frac{v^2}{r} \qquad (13)$$

2) *Material*

- Two masses of different weights
- A smooth, strong string (e.g. fishing line)
- A sturdy tube made of plastic or metal

3) *Construction*

- The string is pulled through the tube
- One of the masses is attached to each string end

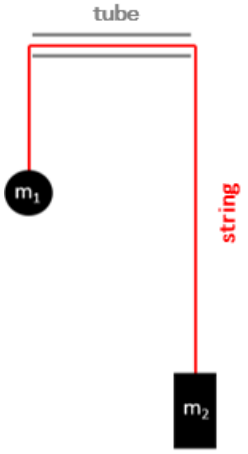

Figure 6: Construction for the experiment "orbit of a rotating mass"

4) *Execution*

- The tube is held in such a way that the small mass m_1 is further away from the body.
- The small mass is rotated.
- The orbital velocity needs to be verified slowly.

5) *Findings*

The effective centripetal force is determined by the mass m_2. In order for the rotating mass m_1 to remain on the circular path when the orbital velocity increases, the rotation radius must become larger. This can also be seen from the fact that the mass m_2 is pulled upwards.

6) *Research approach by using new technologies*

This experiment was recorded with a smartphone, as well. However, here the approach of video analysis was further chosen. The video of the experiment was shown in the lecture several times in order to allow the students to start an in-depth discussion about the physical phenomena and their learnings.

IV. RESULTS

The results are based on feedbacks and evaluations conducted by students. After an experiment had been executed, the students were asked to do an online evaluation by using the platform Mentimeter. This is an easy-to-use software which offers the possibility to present content more interactive and innovative by the usage of computers, tablets or smartphones. The students are integrated into the learning process, as they can give anonymous live feedback on pre-

designed questions. The access to the evaluation does neither require complex computer skills nor the installation of a special application. It is sufficient to visit *menti.com* and enter the six-digit code to participate. Exemplary, Figure 7 shows the Mentimeter interface on a smartphone. The results are displayed in real time.

To start with, overall feedback concerning the concept of experimentally supported physics teaching was given. As Figure 8 shows, students approve the concept of experimentally supported teaching contents. The majority rates the experiments to be helpful for the general understanding of the lecture´s contents. Furthermore, it can be taken from Figure 9 that graphs, pictures, and videos are the most important media for the preparation and post-preparation. This indicates, that students benefit the most from visual media when learning physical concepts.

Additionally, both, the free fall experiment and the experiment on the orbit of a rotating mass, have been evaluated individually in order to obtain corresponding feedback. As it is illustrated in Figure 10, most of the students claim to benefit from these experiments. After watching the experiments and receiving all explanations, the overall opinion is that they well-illustrate the theoretical contents and that the preparations were sufficient. Partially, students would even dare to explain the contexts of these experiments to someone else. This feedback implies that learning objectives can be reached easier and contents can be understood better when practical experiments are taught in parallel to theoretical contents.

This statement can be supported by the results of further evaluations. Hereby, the students had to answer repetitive questions concerning the core hypothesis of both shown experiments. Between the lecture where the experiments have been executed and the repetitions, over four weeks of time passed. Moreover, the students have not been informed in advance that they will have to answer these questions. Nevertheless, the majority could answer correctly, which can be seen in Figure 11 and Figure 12. Hence, it is demonstrated that experiments not only support general understanding but also improve the long-term retention of information.

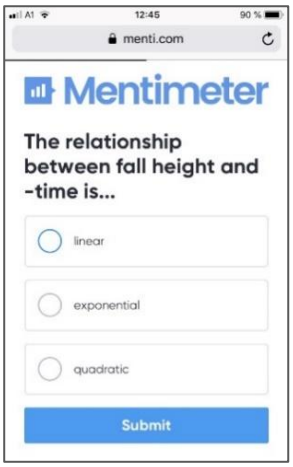

Figure 7: Mentimeter online evaluation interface on a smartphone

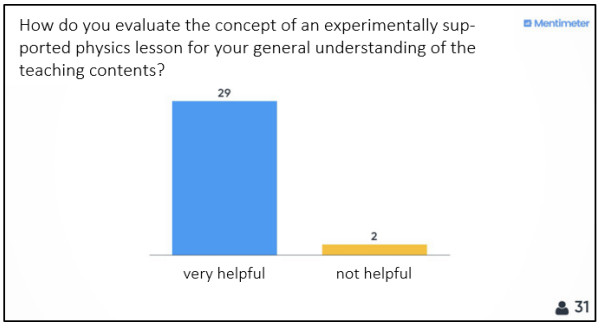

Figure 8: Overall feedback 1

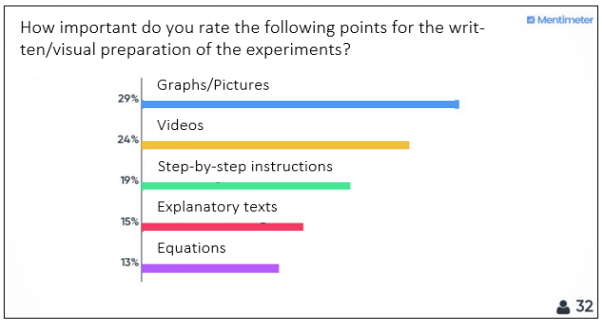

Figure 9: Overall feedback 2

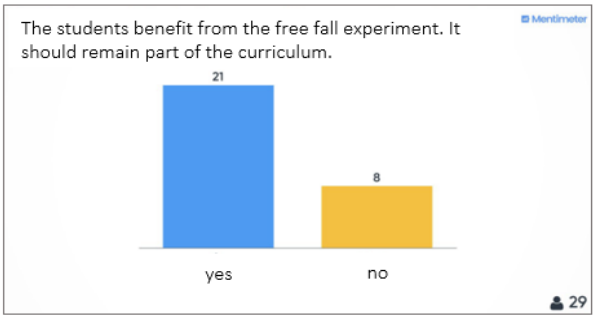

Figure 10: Feedback on free fall experiment

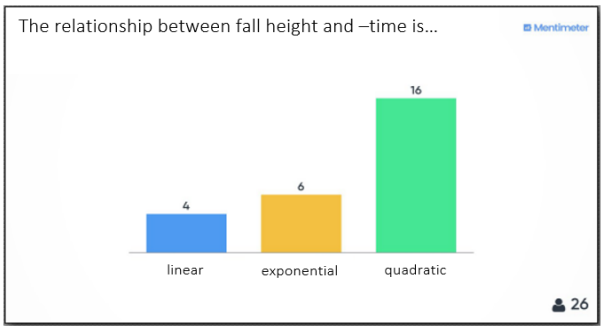

Figure 11: Result of the repetitive question on the free fall experiment

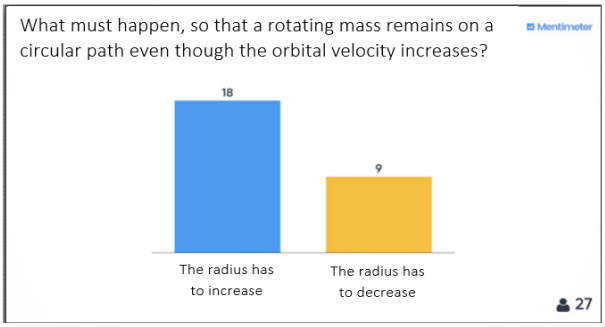

Figure 12: Result of the repetitive question on the experiment "orbit of a rotating mass"

V. Discussion and Conclusion

This study set out with the aim of assessing the importance of experiments in physics teaching and defining methods of how experiments can become a permanent part of a physics lecture.

Theoretical research showed that experiments are essential for both, physical research and teaching. One important outcome was that experiments are a necessary approach to gain physical knowledge. By repeatedly observing the same processes and results, generalizations can be made which, with the aid of mathematical formulas, can be chamfered together to form laws. For the purpose of teaching, the physical experiment is first and foremost a method to connect theory and practice.

The main goal of this work was to gain insights into the best possible implementation and effectiveness of experiments in the physics lecture. For this purpose, three experiments have been prepared and executed in class. In the previous chapters, two of them are described in detail, however, a third experiment concerning the inclined plane was prepared and executed in the same way. The reason why these three topics had been chosen to be the first which were explained theoretically and experimentally, is that they demonstrate the corresponding physical phenomena in a very descriptive way. It was anticipated that this would result in a significant learning success and would therefore lead to positive impressions with the students. Moreover, especially the experiment for the inclined plane can be used to demonstrate not only one, but various physical phenomena. In addition, many more experiments have been prepared theoretically, already. They shall be constructed and executed in the future, as it is the goal that at least one or two fitting experiments exist for each chapter in the curriculum.

The importance of the usage of new technologies for the purpose of demonstrating and evaluating an experiment in the classrooms can be seen in the results of the two described examples. Here, smartphones and computers have been used to record and extract the essential data and present them to the students. Especially for topics which cannot be demonstrated by live experiments in the classroom, videos but also simulations might be used for visualization instead. Furthermore, no matter which new technology is used for demonstration or evaluation, it is also essential that the students have the chance to interact with the provided material afterwards. Therefore, a Moodle course has been set-up where the material to each experiment is uploaded.

To gain feedback from the students, live evaluations have been done after executing experiments in class by the usage of the online platform *Mentimeter*. The results of this study indicate that students benefit immensely from the experiments and that they approve of the concept of experimentally supported teaching contents. Overall, theoretically explained contents have been understood easier and memorized longer if they have been supported by an experiment. A possible explanation for this might be that information which is processed by the support of different media and interaction (visual, auditive, or haptic) is stored easier in the long-term memory than information which is only explained once without the utilization of additional media or interaction.

To support this study, further research should be done by preparing more experiments and executing them in different ways and with different methods. A reasonable approach could be integrating the students more in the process of execution. This could be achieved by setting preparatory tasks and discussing them with the students before carrying out the experiment. By conducting additional evaluations and testing the students on their learning progress, more information could be gathered. In future investigation, it might also be possible to prepare the experiments with more complex measuring methods, in order to gain data with which calculations can be done.

Summarizing, this paper has argued that experiments are an essential part of physics and physics teaching. Furthermore, it was shown that improved understanding and memory can even be achieved by using little material, time and effort to prepare the experiment. The complexity of an experiment does not influence the learning effect. However, it is even more important that an unambiguous connection between theory and practice can be made.

Acknowledgment

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Regional Computer Graphics Competition As A Tool Of Influence On The Profession Choice: Experience Of Sumy Region Of Ukraine

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***Abstract* - Recently, the IT-industry has become increasingly popular in Ukraine. Young people are aware of the prospects of their own realisation as programmers, system administrators, web designers, etc. At the same time, the prestige of teachers' work decreases. Pedagogical universities face the problem of small recruitment for pedagogical specialties, where the specialty of a computer science teacher is not an exception. The article describes the experience of the regional computer graphics competition "Colour Your Life" as one of the solutions to the problem of professional orientation of young people in the computer science teaching profession in Sumy region of Ukraine. The authors studied the following problems: 1) confirmation of the competition status as a regional level competition by determining the geography of the participants; 2) determining the most popular graphic editors among youth; 3) determining the preferences of the competition participants for the future profession choice; 4) confirmation of the relationship between the number of participants and the number of applications for the specialty "014 Secondary Education. Computer science" (results are illustrated with infographics). Based on correlation analysis, a direct relationship between the total number of participants and the number of applicants to Makarenko Sumy State Pedagogical University was confirmed.**

***Keywords - computer graphics competition; computer science teacher; professional orientation; future profession*.**

I. INTRODUCTION

Recently, the IT-industry has become increasingly popular in Ukraine. Young people are aware of the prospects of their own realisation as programmers, system administrators, web designers, etc. At the same time, the prestige of teachers' work decreased. Pedagogical universities face the problem of small recruitment for pedagogical specialties, where the specialty of a computer science teacher is not an exception [2].

The findings of M. I. Zhaldak, N. V. Morze, O. H. Kuzminska concerning spesialized education in computer science [8], N. O. Ponomarova on the theory and practice of professional orientation work at secondary schools [3], N. V. Zhyteniova concerning the formation of cognitive interests of adolescents based on IT [9] suggest solving the problem. At the same time, the analysis of scientists' findings indicates a point-based solution to the issue of professional orientation in the direction of computer science teachers' training.

Among the ways of solving the problem, we consider the involvement of young people in activities conducted based on the pedagogical university and popularized the teacher's profession, in particular in the field of computer science.

The purpose of the article is to describe the conducting of the regional competition on computer graphics "Colour Your Life" as one of the options for solving the problem of professional orientation of youth for the computer science teacher's profession in Sumy region (Ukraine).

II. DESCRIPTION OF THE TECHNOLOGY FOR CONDUCTING "COLOUR YOUR LIFE" COMPETITION FOR PROFESSIONAL ORIENTATION WORK

Due to the fruitful cooperation of the Computer Science Department of the Makarenko Sumy State Pedagogical University, Laboratory of the use of information technologies in education and Sumy Regional Institute of Postgraduate Pedagogical Education, a regional competition on computer graphics "Colour Your Life" (further the Competition) has been held since 2015 among students of secondary schools of Sumy region (Ukraine).

The Competition statute [4] states that its purpose is to promote the teaching profession and to develop the information and digital competence of young people by promoting among young people computer graphics software; stimulating the creation of high-quality information resources; distribution the best youth projects on the Internet; questionnaires and interviews for entering university.

Pupils from different secondary schools are allowed to compete in two age categories: 1) from 8 to 13 years old; 2) from 14 to 17 years old.

The participant may submit several works, but each work can be attributed only to one of the nominations.

Each year, participants are offered a subject, according to which pupils should submit a work for consideration.

The Competition is held in two rounds. The first (distance) is the verification of the work to match the subject of the Competition and technical requirements. At this stage, the organizing committee informs the participant about the acceptance of the work to the Competition or the rejection with explaining the reasons.

The second round is held based on the Computer Science Department of Makarenko Sumy State Pedagogical University. Its goal is not only to define winners in computer graphics, but also to promote the computer science teacher's profession, which can be mastered in the University. Participants must complete qualifying work, which involves communicating with the university teacher, and then using computer with the software installed.

All the author's works of the second round are evaluated by a highly qualified commission (jury), which consists of IT specialists, designers, computer graphics teachers and computer science teachers, whose pupils proceeded to the second round of the Competition.

The assessment is carried out in accordance with the criteria established and known in advance for each nomination of the competition. The highest rating points (the sum of all ratings of all jury members) determine the winners of the competition in each of the nominations.

Below we will describe the nominations and criteria for their assessment.

Nomination "The Best 2D Raster Graphics". This nomination includes works, representing any raster images, collages created in raster graphic editors.

Nomination "The Best 2D Vector Graphics". This nomination includes works, representing various vector-format images, which are described by mathematical formulas and created using geometric primitives.

Nomination "The Best GIF-Animation". This nomination includes works that represent computer gif-animation (both raster and vector).

Nomination "The Best Flash-Animation". This nomination includes works representing interactive animations, applications, cartoons that contain control buttons, accompanied by audio track and programmed elements, etc. These are computer animations developed with Adobe Flash or Adobe Animate.

Nominations "The Best 2D Raster Graphics" and "The Best 2D Vector Graphics" are rated by the following criteria:

– *originality* – the peculiarity, originality, identity to other similar works, originality of the idea (up to 10 points) is assessed;

– *completeness* – it is determined how much the idea is implemented in the work (up to 10 points);

– *artistry, mood* – artistic expressiveness and aesthetics of work, brightness and level of emotions that cause work (up to 10 points) are assessed;

– *compositionality* – the unity, integrity and subordination of all elements of work are assessed, the general correspondence of the light-shadow elements, the harmony of colour and font decisions, etc. (up to 10 points);

– *technicality* – the level of proficiency of the computer tools of the software, in which the work was performed (up to 5 points), the correspondence of the file size and the resolution to the functional purpose of the work (up to 5 points), as well as the quality (up to 5 points) and the complexity of the work (up to 5 points).

The criteria for rating works in the nominations "The Best GIF-animation" and "The Best Flash-animation" are defined:

– *the idea of animation work* – the level of figurative reproduction of a plot on the basis of animation means, its logically-linked sequence (up to 10 points) are assessed;

– *compliance with the principles of animation* – the adherence to the basic principles of creating animation is assessed [1]: squash and stretch, anticipation, staging, straight ahead action and pose to pose, follow through and overlapping action, slow in and slow out, arc, secondary action, timing, solid drawing, appeal (up to 10 points);

– *naturalism (realism) of animation* – the degree of correspondence of graphic objects to natural analogues (up to 10 points) is assessed;

– *aesthetic design* – the general impression of the animation, its general design and relevance to the subject (up to 10 points) are assessed;

– *complexity* – the amount of work on the creation of animated images (up to 10 points) is assessed.

The assessment of works involves filling out a Google form (Fig. 1), access to which only members of the jury have and the data from which are entered into a specially created general database for automating the calculation of the total score (Fig. 2).



Figure 1. Created Google-form for works assessing

№	Вікова група	ПІБ	Номінація	Місто	Загальна кількість балів	Місце у віковій групі	Загальне місце у номінації
1	8-13рр	Рубан Іван Олегович	Краща 2D растрова	Охтирка	420	1	1
2	14-17рр	Хекало Альона Іванівна	Краща 2D векторна	Ромни	418	1	1
3	8-13рр	Волков Сергій Павлович	Краща 2D растрова	Липова Долина	410	2	2
4	8-13рр	Гарцунова Анастасія	Краща 2D векторна	Суми	390	3	2
5	14-17рр	Гончаров Роман Артемович	Краща GIF-анімація	Охтирка	350	2	1
6	8-13рр	Гундар Кіріл Андрійович	Краща 2D векторна	Охтирка	344	4	3
7	14-17рр	Калемі Марія Дмитрівна	Краща GIF-анімація	Суми	330	3	2
8	8-13рр	Калмикова Юлія Юріївна	Краща GIF-анімація	Ромни	321	5	3
9	8-13рр	Клюєва Катерина Олексіївна	Краща Flash-	Суми	319	6	1
#	8-13рр	Корюк Маргарита Олександрівна	Краща 2D векторна	Суми	307	7	4
...	...	...	...	...	...	...	...

Figure 2. Screenshot of a general framework for automating score counting

Within the framework of the Competition, there are excursions to the classrooms and laboratories of the Computer science Department. The talks with potential entrants about the courses taught at the department, about the research activity of the Laboratory of using IT in education [7], about specialized software in various fields of knowledge, which is used in prepare future computer science and mathematics teachers' preparation are held [5].

III. RESULTS

During the four years of the Competition (2015-2018), more than a thousand works were presented. They were made in various artistic techniques in the field of visualization and design.

The subject of the Competition changed from year to year: 2015 – "I See the World in such a Way!"; 2016 – "My Digital World"; 2017 – "The Future in the Hands of the Teacher"; 2018 – "Education is a Treasure, and Labour is the Key to It".

The winners' works of the Competition (2018) in different nominations of two age groups are in Fig. 3.



Figure 3. Winners' works (2018)

IV. STATISTICAL ANALYSIS OF THE RESULTS

The authors investigated the following positions:

1) confirmation of the Competition status as a Regional Level Competition by defining the geography of the participants;

2) identifying the most popular graphic editors among youth by questioning participants about their preferences;

3) determining the preferences of the Competition participants for choosing a future profession by questionnaire;

4) confirmation of the connection between the number of Competition participants and the number of applications for entering submitted to the specialty "014 Secondary education. Computer science".

Let us describe the results for each position.

1. Confirmation of the Competition status as a Regional Level Competition

We have created the infographics (2015-2018), which confirms the distribution of the competition within the region: the green points mark the participants, and the red points marks the Competition winners (Fig. 4-7). The number of sent works in the regions is proportional to the diameter of these points. Infographics confirms that the Competition is a truly regional competition with equal opportunities for all its participants.

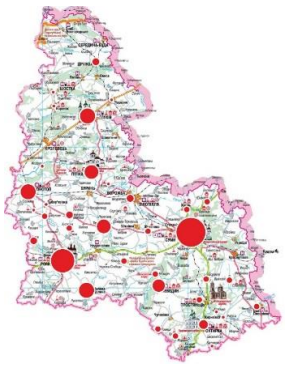

Figure 4. Distribution of works in the nomination "The Best 2D Graphics"



Figure 5. Distribution of works in the nomination "The Best 2D vector graphics"



Figure 6. Distribution of works in the nomination "The Best GIF-animation"

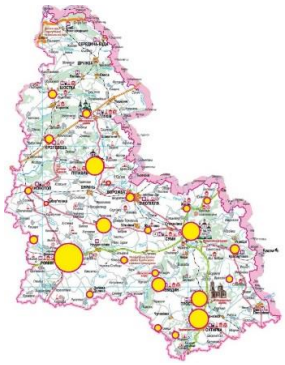

Figure 7. Distribution of works in the nomination "The Best Flash-animation"

The developed infographics demonstrate additional trends in the study of types of computer graphics in Sumy region. In particular, from the south of the region, more works are presented in the nomination "The Best GIF-animation" and "The Best Flash animation". The works in the nomination "The Best 2D vector graphics" represent the eastern part of the region. At the same time, the analysis of works from Sumy did not identify priority directions in the nominations. We explain this with the preference of computer science teachers in the region

regarding the choice of software and their own preferences in computer graphics.

2. Identifying the most popular graphic editors among youth

To identify the most popular graphic editors among youth, we used data for 2015-2018 to select the software in which the participants want to create their works in the second round. We should note that such an analysis was carried out by the Laboratory of the use of IT in education to determine the preferences of students, future teachers, and secondary school teachers for the use of dynamic mathematics software in their professional activities [6].

The analysis showed that:

– Adobe Photoshop, Microsoft Paint and Krita are the most popular (the nomination "The Best 2D Graphic");

– CorelDraw is the most popular, Adobe Illustrator and PaintTool SAI are less popular, but demanded (for the nomination "The Best 2D Vector Graphics");

– Adobe Photoshop, Microsoft GIF Animator, Autodesk Animator are the most popular (the nomination "The Best GIF-animation");

– Adobe Flash or its updated version Adobe Animate are the most popular (the nomination "The Best Flash-animation") (Fig. 8-10).

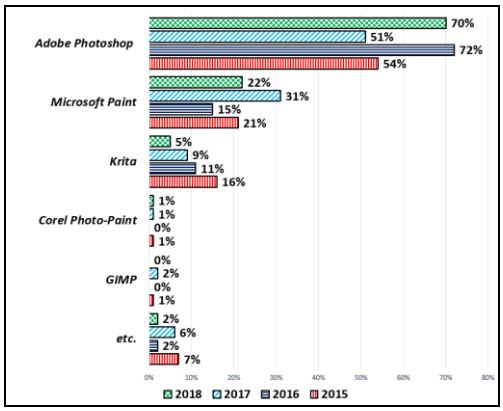

Figure 8. Required raster graphic editors

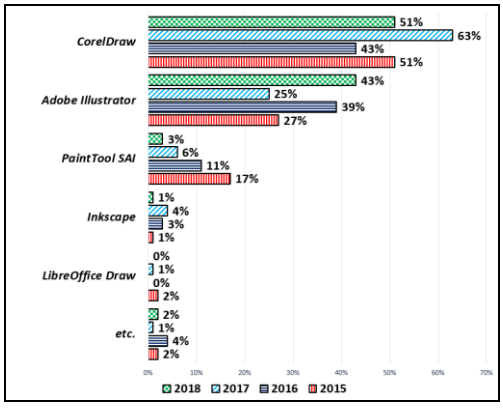

Figure 9. Required vector graphic editors

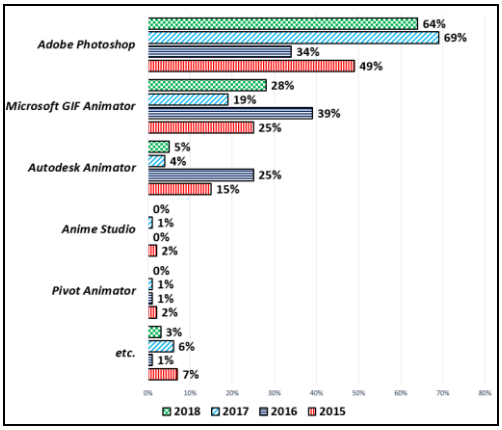

Figure 10. Required editors to create gif-animations

3. Determining the preferences of the Competition participants for choosing a future profession

We conducted a questionnaire to determine the Competition impact on the preferences of its participants in choosing a future profession. Respondents had to answer the questionnaire (Table 1), which was also offered to competition participants in the Google form.

TABLE 1. QUESTIONNAIRE OF THE COMPETITION PARTICIPANT (SELECTION OF SEVERAL FROM PLENTY)

№	*Question*	*Answer variants*	*Commentary*
1	How did you get know about the competition?	A) from teacher; B) from social networks; C) from the University resource; D) from friends; E) other _____	With the help of this question, we found what the source of information about the Competition was.
2	Why do you take part in the Competition?	A) my friends take part in it; B) I want to master my skills in the field of graphic design; C) I want to get more about pedagogical university; D) I want to feel myself a winner; E) other _____	Motives of competition participation were revealed.
3	Computer science teacher is for you:	A) authority; B) older friend; C) mentor in IT questions; D) stranger; E) other _____	We determined how computer science teacher is perceived by each participant.
4	How does the work of a computer science teacher affect your future profession?	A) I want to be like him; B) he knows a lot in IT; C) he is a modern person, because he works with youth ; D) doesn't affect at all; E) other _____	We determined the reasons for choosing computer science teacher's profession.
5	Do you see yourself in the future as a computer science teacher? If so, what influenced your choice?	A) parents; B) the university itself and organised events on its basis, in particular the competition; C) job prospective; D) no; E) other _____	We determined the subjective factor of influence the choice of computer science teacher's profession.

The analysis of the answers of the questionnaire made it possible to draw the following conclusions:

1) the official website of the University and social networks are a source of information for potential entrants, along with information from teachers (33% and 37% respectively), and therefore it is worthwhile to inform about activities of professional orientation topics in various Internet sources;

2) the desire to learn more about the pedagogical university and the specialties that it offers is partially satisfied with activities carried out at its base (23% of respondents);

3) a computer science teacher for the participants of the Competition in most cases is a mentor (89%), and therefore we consider the cooperation with the computer science teachers important for work in the direction of professional orientation of entrants to the pedagogical specialty (in particular, the computer science teacher);

4) for the participants of the Competition, who see themselves as teachers of computer science in the future, it is important to communicate with young people (35%), to satisfy parents' desires (34%), and to have opportunities to get a job (23%).

5) the Competition impacts on the positive perception of the University as a base for professional training (54%), the computer science teacher's profession as a demanded profession of the future (45%).

4. Confirmation of the connection between the number of Competition participants and the number of applications for entering submitted to the specialty "014 Secondary education. Computer Science"

We conducted a quantitative analysis of data (Table 2), which were accumulated during the Competition.

TABLE 2. QUANTITATIVE ANALYSIS OF DATA

Year	*Number of participants*	*Number of participants, who are school-leavers (11-th grade)*	*Number of those entering the specialty "014 Secondary education. Computer Science"*	*Number of those entering, who took part in the Competition*
	Data Set A	*Data Set B*	*Data Set C*	*Data Set D*
2015	68	27	94	2
2016	109	29	89	15
2017	160	26	77	21
2018	176	29	69	25
Coefficient of correlation between A and B.		0,11383688 (there is no connection)		
Coefficient of correlation between A and D.				0,97695291 (there is a connection)
Coefficient of correlation between B and D.				0,25992252 (there is no connection)

We can claim that the number of Competition participants increases each year (Data set A, Table 2), while the number of participants, school-leavers (grade 11) is approximately the same – 26-29 people (Data set B, Table 2). The number of those entering the University (Data set D, Table 2) is constantly increasing. The number of those entering the specialty "014 Secondary education. Computer Science" is constantly falling (Data set C, Table 2).

Correlation analysis of data demonstrated:

- the direct connection between the total number of Competition participants and the number of those entering, who took part in the Competition ($r = 0.97$);
- the absence of connection between the number of participants, who are school-leavers, and the number of those entering, who took part in the Competition ($r = 0.26$).

The analysis of the obtained results are statistically confirm according to Student's test (at the level of significance 0.05, number of freedom degrees of 2) with hypotheses: "H_0: $r = 0$" and "H_a: $r \neq 0$".

Calculations using the formula $t = r * \left((n-2)/(1-r^2)\right) * 0.5$ confirmed that the increase in the number of those entering, who took part in the Competition, is not random. The critical value of the test $t = 2.1$ is smaller according to the statistical $t = 6.47$. Therefore, an alternative hypothesis about a direct connection is taken. We conclude that the Competition really influence the number of those entering the specialty "014 Secondary education. Computer Science".

V. CONCLUSIONS

1. The prestige of a computer science teacher's profession in Ukraine is small; therefore, work on the professional orientation of young people should be strengthened.

2. Among the ways to strengthen the professional orientation of young people into the teacher's profession and effective tools of influence on the choice of profession for secondary schools graduates, we have chosen to hold popular competitions in the field of computer science based on pedagogical university.

During 2015-2018 at Makarenko Sumy State Pedagogical University, the computer graphics competition "Colour Your Life" was held. For the competition works, topics related to the teaching profession are offered.

3. The statistical analysis of the accumulated results confirmed the positive impact of the Competition on the number of applications from the entrants.

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Use of the Software BIOMECHANICS in Physical Culture and Sports Specialists' Preparation

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Abstract - **The use of computer technologies allows to form the theoretical knowledge and practical skills of future physical culture and sports' specialists qualitatively. Software Biomechanics was developed in order to improve the assimilation of biomechanical knowledge and to increase the level of kinesiological competence of students of Kharkiv State Academy of Physical Culture and the Institute of Physical Culture of Makarenko Sumy State Pedagogical University (Ukraine). It includes educational and methodological information that enables the student to acquire practical skills and abilities for the independent use of the theory and methods of biomechanical measurements, biomechanical analysis and didactics of motor activity in physical education and sports training. The software contains different parts (theoretical, practical, references control). The practical part provides the execution of calculation and graphic works aimed at determining the geometry of human body mass, measuring the kinematic characteristics of motor actions, finding the center of masses by analytical and graphical methods etc. The software enables physical education and sports' professionals to train with the use of basic biomechanical positions, to improve motor programs, and to promote health and safety in the process of physical education at school as well as in the performance of sports coaching and physical rehabilitation of patients and athletes.**

Keywords - computer technologies, internet resource, biomechanics, kinesiological competence, physical culture and sports specialists.

I. INTRODUCTION

The state policy of implementation the information technologies in the field of physical culture and sports is governed by relevant regulations and state programs. We should mention the Law of Ukraine "On the Basic Principles for the Development of an Information-Oriented Society in Ukraine" [5] and "Strategy for the Development of the Information Society in Ukraine" [6] approved by the order of the Cabinet of Ministers of Ukraine (May 15, 2013). Also we can mention the order of the Cabinet of Ministers of Ukraine "On the Approval of the Concept of the Development of the Digital Economy and Society of Ukraine for 2018-2020 years and the Action Plan for Its Implementation" (January 17, 2018) [7]. According to the Annual Global Outsourcing Industry Analysis "Global Service 100" Ukraine ranked the 11th place in the top of 20 the largest global centers for the number of people employed in the field of information technology.

In the modernizing process of the Ukrainian model of physical culture and sport development, the computerization of this field plays a significant role. It is shown by findings devoted to the use of information and computer technologies in the process of physical education and sport [1; 4; 8; 10; 11]. Also it is shown by the computer analysis of athletes' movement technique in accordance with biomechanical parameters, adaptive models of athletes' capabilities and their reactions to physical activity in different intensity zones, software for analyzing a large number of individual parameters of the athlete, computer multimedia systems which manage various aspects of physical education process and sports training etc. independently.

In modern education, the process of professional training of future specialists in physical culture and sports is also inextricably linked with the implementation of the modern information technologies achievements. However, the list of such electronic means, that would allow the qualitative formation of theoretical knowledge and practical skills of future specialists in physical culture and sports, is described deficiently in literary sources. Therefore, this issue is relevant today.

A. An overview of recent research

The analysis of scientific and methodological literature has allowed identifying several groups of possibilities for using IT in the theory and practice of physical education and sports.

The usage of IT in conducting sports events as a tool of sports management. It includes the solutions for logistic tasks of regulating the flow of athletes and spectators, planning financial and demographic aspects, advertising and information support for sports events, financial and legal affairs. The use of IT in sport management is explained not only by the fact that these investments have high rates of return and they lower the estimated cost of the event, but because IT development is an investment in local infrastructure. An example is the "Automated System for Holding of Sports Competitions" [3] and Heracles (www.unitedworldwrestling.org).

Training complexes using information technology provide*:*

– the possibility of objective analysis and tracking of such complex phenomena as trajectory of movement or maintaining equilibrium in the formation of motor skills and abilities (video analysis of movements);

– the possibility of modeling rare and atypical situations, as well as solving problems of forecasting by using virtual reality systems;

– the possibility of registering athletes' indices for the analysis of the objective assessment of the technical and tactical actions of each and the results achievement on-line;

– biological feedback systems (biofeedback) allow to create conditions for registration, amplification and "return" of physiological information to the patient.

The "BioVideo" software [8] is considered to be one of the most comprehensive application software, because it allows to perform biomechanical video analysis based on videograms (video footage) and to obtain quantitative biomechanical characteristics and a graphical model of movements scheme of the object being studied.

Research work or medical and biological support. IT plays the important role in research work, because it allows scientists to perform complex mathematical calculations and to handle significant arrays of numerical data in a short time that assesses physical fitness and athlete's health. An example of the successful use of IT to monitor an athlete can be found in the following software: an international system for collecting and processing information "Athlete Biological Passport" developed by the World Anti-Doping Agency (www.wadaama.org/en), ergometers and exercise devices, the software "Organization of athletes' nutrition" [10], "Coach's journal" and "Health analyzer" [9]; the "Check" device to stimulate a specific neuromuscular reaction of the brain; new generation of FuelBanS bracelets; the Goji Play system, which allows you to combine training with a video game on the simulator.

IT as a means of fixing sports results ensures the rapid collection, transmission, storage and processing of a large amount of information. Specialized tacheometers, based on Global Positioning System (GPS), sports timing technologies, integrated with the system of electronic scoreboard are widely used. An example of more accessible video analysis software is Kinovea [2], which is designed to view and analyze the sports video and video analysis of movements.

IT is actively used *in the training of future professionals*, that allows you to create a comfortable environment both during the theoretical studies and in the process of training by means of the visualization of educational materials, what contributes to the development of practical skills of the correct technique of motor activity. Examples of such software will be discussed later.

II BIOMECHANICS SOFTWARE

A. Biomechanics as a subject of study

Biomechanics as a subject in higher education institution of physical education and sport belongs to the disciplines of the natural sciences and the methodological kind of professional knowledge. Biomechanical knowledge is an important component in the structure of the modern system of European pedagogical education in the field of physical culture, and the biomechanics as a discipline is taught in 73% of European universities.

The subject of study of the discipline is the biomechanical characteristics of the body and motor activity of a person performing physical exercises in different conditions. The biomechanical aspects of motor activity and biomechanical rationale of physical exercises as the main means of physical education, rehabilitation, recreation and sports training are also studied. The subject of the study is also biomechanical analysis of motor activity, pedagogical process of teaching motor actions and their correction, biomechanical modeling of human motor activity in different conditions with the aim of substantiating the individualization of the pedagogical process in physical education, sports and physical rehabilitation as the main way to increase their effectiveness.

To understand the essence of human motor activity and the complexity of managing them it is not enough to know the basic laws of mechanics and ways to describe the external image of the movement. It is necessary to consider the laws of physiological phenomena, the biological nature of the interaction of the organism with the environment. This is why the study of this course is closely related to such disciplines as anatomy, biochemistry, physiology, psychophysiology, functional systems theory and many other sciences.

The discipline has close interdisciplinary connections, because it takes into account the previous knowledge of students in such disciplines as "Human Anatomy", "Human Physiology" and suggests the possibility of using the obtained knowledge in the course of studying the following disciplines: "Theory and Methods Physical Education", "Metrological Control" and "Physical Rehabilitation".

Firstly, it is necessary to be guided by the principle of "do no harm" when applying software to train students in biomechanics, because the computer cannot become a means of solving all problems of education. V. M. Bogdanov, V. S. Ponomarev, A. V. Solovyov, T. V. Utkin focus on the expediency and effectiveness of the use of electronic teaching materials in the preparation of future specialists in physical education and sports. P. K. Petrov, O. B. Dmitriev, E. R. Akhmedzyanov consider the use of diagnostic system of knowledge level in biomechanics on the basis of modern information technologies. V. S. Ashanin, L. V. Filenko, O. V. Basenko, S. S. Pyatisotskaya, S. V. Garkusha,

N. P. Bateev studied the development of an innovative teaching methods based on the integrated using of computer means and biomechanical methods.

Using of the software will help future physical culture and sports professionals to study the biomechanical foundations of human activity, pedagogical means and methods of its optimization aimed to improve motor activity in order to achieve planned results in physical education, sports, as well as in physical rehabilitation and recreation.

B. Biomechanics software

In order to improve the mastering of the biomechanical knowledge and to increase the kinesiological competence level of students of Kharkiv State Academy of Physical Culture, an educational and methodical software for the discipline “Biomechanics” has been developed (http://biomehanika.pp.ua/). The main window is shown in Fig.1.



Fig. 1. The main window of the educational and methodical software Biomechanics

This software was being created by using the WordPress platform. This platform is used as a management system for educational content and an educational process for conducting on-line courses and interactive education.

The content was formed in accordance with the curriculum in this discipline. The form of representing the information allows the user to choose the training material necessary for study.

The information resource contains the following sections:

- educational-methodical literature (including lecture material, as well as laboratory workshop with the implementation, drawings, tables and control questions at the end of each work) (Fig. 2);
- themes of independent work;
- themes of individual tasks;
- requirements for formalizing the individual tasks;
- an example of calculating and graphic work;
- tests for extramural students;
- exam questions;
- examples of sports tasks;
- recommended literature;
- articles on the subject of biomechanical research.

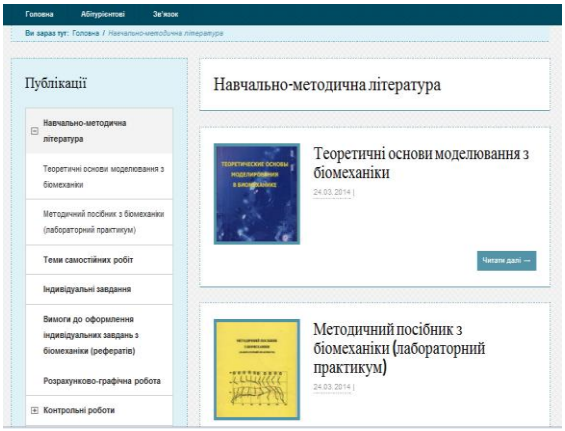

Fig. 2. The window with educational methodological literature on the discipline “Biomechanics”

The content of the developed resource includes educational and methodological information that will allow the student to master practical skills and abilities, to use the theory and methods of biomechanical measurement, biomechanical analysis and didactics of motor activity in physical education and sports training.

The e-mail addresses of the Department of Informatics and Biomechanics lecturers, which teach this subject on the course (for additional consultations, verification of the correctness of the design abstracts and the resolution of organizational issues) are indicated. This form of communication has become relevant, as students may not always consult with lecturers directly for a number of reasons (departure for sports events, frequent trainings, weekends, illness etc.).

Practical learning of the discipline “Biomechanics” by students with using a computer laboratory workshop suggests that the acquired knowledge will provide the opportunity to teach movements with the using of basic biomechanical positions, to improve motor programs, to promote health and safety in the process of physical culture activity in school, when performing sports coaching and physical rehabilitation of patients and athletes.

C. Computer Workshop on Biomechanics

In order to increase the mastering level of kinesiological competence of future specialists in physical culture and sports at the Department of Informatics and Biomechanics of Kharkiv State Academy of Physical Culture a computer workshop on the discipline "Biomechanics" has been created.

The technical side of the problem implies the specification of the type of activity that should be modeled. It can be a competitive activity of the best athletes (a natural model), a description of the simulated process in the form of mathematical formulas etc. In addition, it is necessary to determine the components of the model and the parameters and variables with corresponding functional relations; evaluation of the adequacy of the selected analogue and modeled type of motor activity; development of a computer simulation model of the motor activity type. The collection of output data can be performed through physical, functional and technical tests, the results of pedagogical observations of competitive activities, etc.; directly computer simulation of the motor activity type; adjusting the type of activity by the results of computer simulation.

This workshop was developed in Borland Delphi 7 using Pascal programming language. The main menu contains the user registration form and the list of laboratory works (Fig. 3).

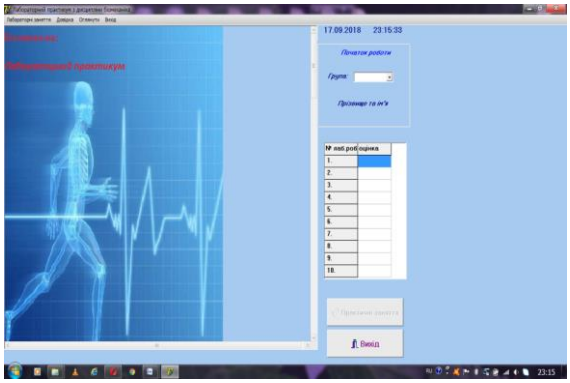

Fig. 3. The main window of the computer workshop on Biomechanics

Theoretical information concerning the selected work appears in the main window after selecting the laboratory work. The "registration" field should be filled before the beginning of work (Fig. 4).

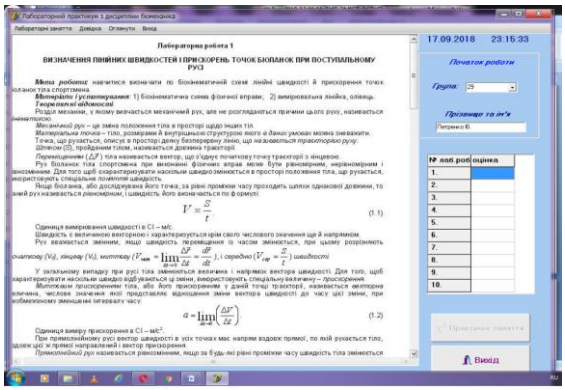

Fig. 4. A window with theoretical knowledge concerning selected laboratory work

Moreover, by clicking the button "Practical classes" the window with electronic tables and graphic elements related to the selected work is displayed (Fig. 5). When processing these data, the user calculates and inserts the data in the table.



Fig. 5. Worksheet windows

A measuring complex of movements' parameters, based on the use of a stroboscopic effect allows you to measure the distance to the object in the range of 3-110 m and instantaneous speed of movements; to display information on the monitor and print it; to form a database of results of motor activity analysis.

Besides, after clicking the "Save Data" button, the computer processes the information being entered and it builds a graphic that visually reproduces the results of calculations made by the user in the table. To implement the graphic part, Pascal methods, classes and procedures, such as Canvas and StringGrid, were used.

Since the calculation of all entered data in the software is done automatically, the user needs only to enter the required data and to go to the window with a table on the tab "Graph", where the software builds the coordinate system and graphs of studied values, depending on the indicators in the table. As a result of the performed laboratory work, the software analyzes the performed calculations and evaluates the user's work.

After entering data and processing, the user saves the performed laboratory work using the "Save Data" button. When you click on it, the software will offer to select the path for storage on the hard disk or portable storage. The saved file stores the following data: the calculations entered into the table, the functions graph, the user name and group number.

The presence of tests, which are distributed on the main themes of the discipline "Biomechanics", is important for monitoring of self-training (Fig. 6), Students can examine questions and prepare for the exam independently.

It can be said that the computer laboratory workshop on Biomechanics contains elements of the expert system, because it is partially capable to replace a specialist in the field of biomechanics. Each laboratory has its own graphical interface and a complex internal system of programming formulas for data computation and their graphical representation.

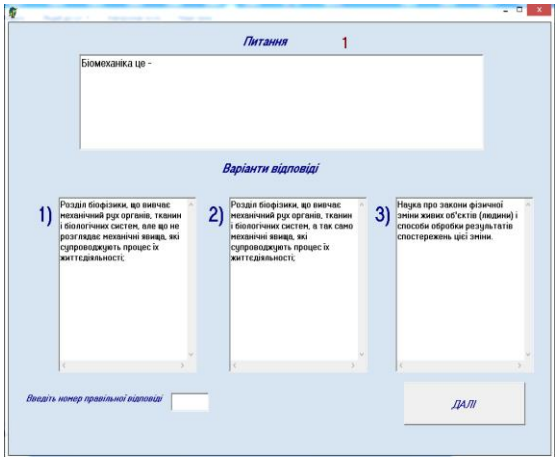

Fig. 6. Window with the control part of the workshop on Biomechanics

The theoretical block is the main section of the resource. It includes theoretical educational information. The practical block envisages the performing of calculation and graphic works aimed at determining the geometry of human body mass, measuring the kinematic characteristics of motor actions, finding the center of masses by using analytical and graphic methods, and others. Each practical work is evaluated on a 5-point scale, taking into account the state of work, which helps the lecturer to objectively evaluate each student. The results of the performed work with the marks are automatically recorded to the database, where the lecturer can check the results at any time, indicating the student's name, surname and group.

The control block includes a special testing program, which consists of a set of 4 test tasks, distributed by topics, by which the student and lecturer can check the quality of knowledge and the level of skills in this discipline.

The reference block includes a dictionary of key terms and formulas used in Biomechanics, and a list of basic teaching and supplementary literature. There is also a list of themes for individual tasks, tests and questions for preparing for the exam.

This software can be used for independent training of students, for extramural students and for the further training of specialists in the field of physical culture and sports.

III. Conclusion

IT has been of great importance in the theory and practice of training future professionals in physical education and sports. The implementation of IT, on the one hand, expands the capabilities of an athlete and coach, however, on the other hand, it sets new tasks.

The software developed by us forms the general competence of students: to understand the problem, to be able to determine main ways for its solution; to be able to work with the literature on the problem; to be able to combine theory with practice.

The software Biomechanics forms students' kinesiological competence that makes it possible to analyze kinematics and dynamics of motor actions based on data of objective registration of physical exercises; to quantify the biomechanical characteristics of the human body and its motor activity; to quantify the level of development of basic motor qualities; to model biomechanical characteristics of individual rational technique and tactics of motor activity; to use modern biomechanical technologies for quantitative control, evaluation and training (correction) of motor actions.

The developed complex can also be effectively used for studying new motor actions (movement techniques) and improving motor actions mastered during practical training of future specialists in physical education and sports. It can also be used in the process of training activities in the sport of higher achievements.

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Information Literacy and Critical Thinking Freshman Course Experience

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***Abstract* - The aim of the research is to prove author's intention of designing a successful high school freshmen course that can improve students' generic skills and competences needed to empower them on a journey to become valuable contributors of modern society. Literature review of similar successful courses was used for general course design technique with some learning outcomes modified from information literacy and critical thinking international standards. All main design principles of "Information literacy and Critical thinking" course syllabus is elaborated. Discussion part concerning students' satisfaction and skills improvement is followed after the analysis of two types of surveys conducted over the first two generations of students.**

This particular course is very rare, if not unique, as an approach for freshmen generic skills improvement in Croatian High Education society. This elaborated experience is excellent opportunity to provoke wider society discussion in order to establish formal ways to improve employability skills of Croatian students.

Keywords - information literacy, critical thinking, generic skills, fake news, freshman course

I. INTRODUCTION

Global phenomena of industry shift to "Industry 4.0", or business in the digital age[1], is one of leading topics on World Economic Forum agenda, today's world leading International Forum for Public-Private Cooperation. "Concurrent to the technological revolution are a set of broader socio-economic, geopolitical and demographic drivers of change, each interacting in multiple directions and intensifying one another. As entire industries adjust, most occupations are undergoing a fundamental transformation. While some jobs are threatened by redundancy and others grow rapidly, existing jobs are also going through a change in the skill sets required to do them" [1]. Parallel and fully related to cited report from series Future of Jobs, even more important dialog on education started.

In 2015, WEF published a report that focused on the widening skills gap and ways to address it through emerging and ubiquitous technology [2]. In that report, a set of 16 crucial proficiencies for education in the 21st century is laid out. Those skills include six 'foundational literacies', and ten skills that are labelled either as 'competencies' or 'as character qualities'.

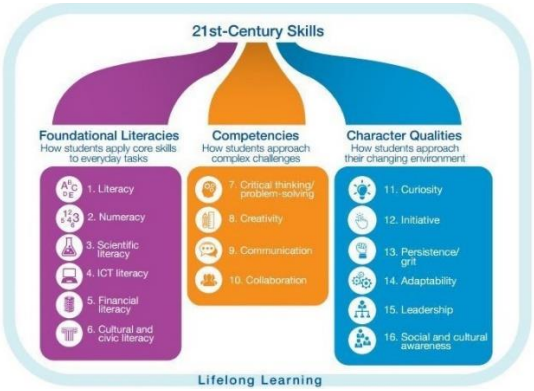

Figure 1. 21st Century skills [2]

In about same time another global phenomenon aroused – fake news. Although it dates back to 1938, when the broadcast of a radio adaptation of H. G. Well's drama "The War of the Worlds*"* frightened an estimated one million residents [3]. It was present in modern society as a way to amuse by mocking the established order, on daily bases by John Stewart, host of Comedy Central "The Daily show" and The Onion News Network, a satirical daily web video broadcast that had been in production since mid-2006. All that changed with the 2016 USA presidential election and its aftermath. Fake news, once delivered by cable channel hosts and comedy writers, became more ominous as the electorate slowly realized how altered facts had been created and manipulated to influence a nomination and election. A recent study by the Pew Research Center found that only 11% of those surveyed were not confused by current events news stories, with the vast majority experiencing some or a great deal of difficulty discerning a story's legitimacy [4].

II. COURSE

In about the same time the author offered full freshmen course named "Information literacy and Critical thinking" developed for the students of IT design, an orientation of Undergraduate study of Information Technology at Zagreb University of Applied Sciences. The general idea was to empower new students to better develop skills and competences needed for new learning environment –

[1] Industry 4.0 | World Economic Forum, May 12, 2016, https://www.weforum.org/agenda/2016/05/industry-4-0/ (accessed on 4.2.2019)

university study. Two basic topics of Information literacy and Critical thinking are used as front skills that should be both understood and practiced during the course, followed by myriad of valuable skills and character qualities introduced, developed or enhanced through the course.

A. Previous experience

Looking for similar courses through literature research and worldwide practice showed mixed results. Not much course examples were found, especially ones having both topics connected. It seems like Information literacy, mainly advocated by Librarian communities through its models and standards seems very loosely connected with topics of Critical thinking. Similar situation is in Croatia, where only one documented example of such courses was found. As expected, topics is on Information literacy, and the course is conducted at School of Medicine, University of Zagreb. Together with Central Medical Library, they are delivering compulsory course "Introduction to Research in Medicine" since 2011 [5].

However, American Association of School Librarians (AASL), in the release in 2007 of the "Standards for the 21st Century Learner", provided a very effective description how Information literacy is intrinsically connected to critical thinking. Standard identifies following four classes of skills: (1) Inquire, think critically, and gain knowledge, (2) Draw conclusions, make informed decisions, apply knowledge to new situations, and create new knowledge, (3) Share knowledge and participate ethically and productively as members of our democratic society and (4) Pursue personal and aesthetic growth [6]. This popular AASL standard is for instance fully incorporated into USA nonprofit organization Partnership for 21st Century Learning (P21) initiatives, which together with its members and partners have been pioneers of 21st century learning since 2002.

So, the skills to develop indicators from the first group of strategic skills "Inquire, think critically, and gain knowledge", de facto became learning outcomes for the Course:

1.	Follow an inquiry- based process in seeking knowledge in curricular subjects, and make the real-world connection for using this process in own life.
2.	Use prior and background knowledge as context for new learning.
3.	Develop and refine a range of questions to frame the search for new understanding.
4.	Find, evaluate, and select appropriate sources to answer questions.
5.	Evaluate information found in selected sources on the basis of accuracy, validity, appropriateness for needs, importance, and social and cultural context.
6.	Read, view, and listen for information presented in any format (e.g., textual, visual, media, digital) in order to make inferences and gather meaning.
7.	Make sense of information gathered from diverse sources by identifying misconceptions, main and supporting ideas, conflicting information, and point of view or bias.
8.	Demonstrate mastery of technology tools for accessing information and pursuing inquiry.
9.	Collaborate with others to broaden and deepen understanding.

Figure 2. Class 1 skills indicators - Standards for the 21st Century Learner, AASL, 2007

The further search for examples of Information literacy and Critical thinking skills courses also gave poor results mostly because of the fact that in most developed countries such learning outcomes are incorporated in learning outcomes of a whole study, not just a single class.

For instance, each of the University of Kansas Core's six educational goals has one or more distinct learning outcomes, which can be met by a variety of courses and educational experiences[2]. For example, they defined Goal 1 as "Integrate information literacy, research skills and information resources into the curriculum to enhance critical thinking, academic success and lifelong learning". This goal has two specific learning outcomes, with related metrics. On a list of University of Kansas Critical Thinking and Quantitative Literacy approved courses, there are 204 courses within Goal 1 and learning outcomes 1 or 2, student can pick in order to gain desirable skill.

In 2016, in project Polytechnics 2025, Zagreb University of Applied Sciences designed its own educational standards and started the harmonization of study programs in order to meet the needs of existing and future Croatian labor market. Project team developed 13 new occupational standards proposals, improvement proposals for nine existing study programs and made four completely new study programs. In order to develop all study programs, a complex and detailed model with competences as a pivotal entity was deployed. Usual entities from education point of view like Education institution, Department, Study, Study program, Course, Learning Outcomes, etc. are related to employers' side entities like Occupation, Working place, Key job, etc. Down through the Skills and Competences, which are the central entities enabling mutual understanding of student's wishes and employer's needs [7].

Unfortunately, existing study programs, like Undergraduate study of Information Technology, did not have a chance to re-model current study programs accordingly. That is the main reason for decision to build one Course from the scratch.

Advanced search for best practice found few usable examples of elective, student orientation courses like ones in San Diego State University [8], or as block of two "thought and expression" courses "Advancing critical thinking and information literacy skills in first year college students" delivered at Gonzaga University, Spokane, WA [9].

B. Course Design

As Zagreb University of Applied Sciences is known of very practical approach, much more emphasis should be on delivery part than on theoretical knowledge. That is why the Course have only one knowledge test, delivered in early stage, right after explaining the theory through main principles.

[2] The University of Kansas, KU Core, General Education Goal 1, http://kucore.ku.edu/goal1 (accessed on 4.2.2019)

In order to get the knowledge, students should gain experience through practical work, applying Dale's Cone of Experience[3].

A delivery should be both in on stage presentation (developing rhetorical and visual skills) and in a form of a seminar, teaching them to stand up for their idea and be able to elaborate it in more than one form. Delivery should involve teamwork and foster open and constructive communication, which are top two generic skills Croatian IT employers are looking for [11].

All the teaching and exercises should be done in front of the all class, letting them to learn not primary from lecturer, but much more from each other, either through good or bad examples. Moreover, it should foster changing mind philosophy, encouraging and valuating intention more than a result [12]. Students should be free to make mistakes, learn out form them and eventually later on produce acceptable result. Atmosphere should be encouraging, not strict with only one truth.

An ERR teaching method should be used whenever possible. ERR stands for Evocation (E), Realization of meaning (R) and Reflection (R), and is adopted from both Reading, Writing, and Critical Thinking for the 21st Century [13] and Croatian Reading and Writing for Critical Thinking Project teaching materials [14].

Exercises are primarily used for discussions and head start of given tasks in order to check out weather all students understood what they have to deliver. Since their task could be categorized as Group-Based/Open-Ended Problem Solving, Flipped Classroom learning method in a broader sense is used [15]. Most of their actual work should be done outside the class organized by themselves, with very rigor milestones.

Lecturer should be easy, friendly, authority based on knowledge, attitude and professionalism. Offering interesting, new or twisted facts and situations, asking questions, provoking dialogue, letting students express themselves freely. At the same time, he/she should keep the pace of three long hour sessions, continuously showing progress, often with recapitulation of learned topics. Fully active and helpful during exercises, and especially breaks, discussing good practice results or approach as much as possible. Available offline, approachable by mail and phone when needed.

C. Course Delivery

According to the Course design, both lectures and exercises are conducted in one large classroom, in 3-hour sessions. At the beginning of a Class, there are more lectures than exercises and later on, there are practically only preparations and exercises, delivered in teams.

First session is very important is, when introductory (set the scene) lecture about the importance of the actual fake news scene is presented, followed by the story of Trumps elections and a group of Macedonian students, who made a small fortune out of the fake news production used in his campaign [16]. After that, the whole course with exact calendar is presented up front, followed with a session on their understanding of what information literacy and critical thinking actually is. For them, in their own terms.

Several next sessions are more lecturing, followed by knowledge test of understanding the basic concepts. After that, all students are assigned to teams, each with specific role, according to the Bloom's Six Thinking/Learning Levels [17]. Adopted roles are (1) Team leader, (2) Analyst, (3) Evaluator, (4) Synthesist, (5) Visualizer and (6) Creator. Team lead is supporting role, joker in a way, responsible for all team delivery. Analyst would gather appropriate information (mostly from the internet), and evaluator would evaluate it using CRAPP methodology developed at California State University [18]. After discussing their idea, Synthetist would make a mind map, and Visualizer would make presentation together with creator who would write a 7-10 pg. seminar. There is maximum of nine teams, so if there are more than 54 students, later role would be given to additional students.

What are the topics they are taking their stance, presenting and writing about? It is another information literacy/critical thinking exercise. They are given very generic, big themes like satisfaction, money, success, user, beauty, emotions, experience, change… etc. In first exercise, they learn how to narrow the scope. Exercise was adopted from Esther S. Grassian Teach Information Literacy & Critical Thinking site [19]. After that, they discuss and mutually agree upon their hypothesis/stance, and start working on content according to the schedule. Each week they are trained into the next role and after a week, they present each role's progress. Therefore, within 10 weeks, they are ready for the presentation and couple of weeks later they need to deliver a paper work in a form of a seminar. Both presentations and seminars are open for discussion, from all students and lecturer, pointing out both strengths and weaknesses.

Basic literature for the course is of course in Croatian language - "Informacijska pismenost - Teorijski okviri i polazišta" [20] and "Kritičko mišljenje - priručnik kritičkog mišljenja, slušanja, čitanja i pisanja" [21].

III. RESEARCH

The aim of the research is to prove author's intention of designing a successful high school freshmen course that can improve students' generic skills and competences needed to empower them on a journey to become valuable contributors of a modern society.

A. Methodology

Literature review of similar successful courses was used for general course design technique with most of learning outcomes adopted from "Standards for the 21st Century Learner" AASL standard. Two type of surveys were conducted over the first two generations of students.

[3] According to Dale's Cone of Experience (1946) the base of the cone is characterized by more concrete experiences, such as direct experiences (real-life experiences), contrived experiences (interactive models), and dramatic participation (role plays). Direct purposeful experiences represents reality or the closet things to real, everyday life and are the best way for learners to remember. They remember 90% of what they do [10].

First is official institutional survey of student satisfaction performed for all classes and the recent one is constructed by the author looking for students' personal improvement and their recommendation of most important skills and competences acquired during this Course.

B. Students satisfaction survey

Students satisfaction survey is official institutional survey that is performed at the beginning and at the end of each class, so all classes and lecturers can be compared. It has two group of questions: about topics of a course and about lecturer performance. At the beginning of each class 14 questions are asked - 10 about the class and four about lecturer, and at the end of each class 27 - 18 about a class and nine about lecturer. Scale is classical school grading (1 – 5). The survey is mandatory, but students can fill in the blanks, so there is usual low return rate. For this survey, return rate of first year (2016-17) was 63.04 % (29 out of 46 students) and for 2017-18 was 93.85 % (61 out of 65).

From this survey, 13 questions are used to analyze students' satisfaction and comparison with other classes during their study – eight about the class and five about the lecturer.

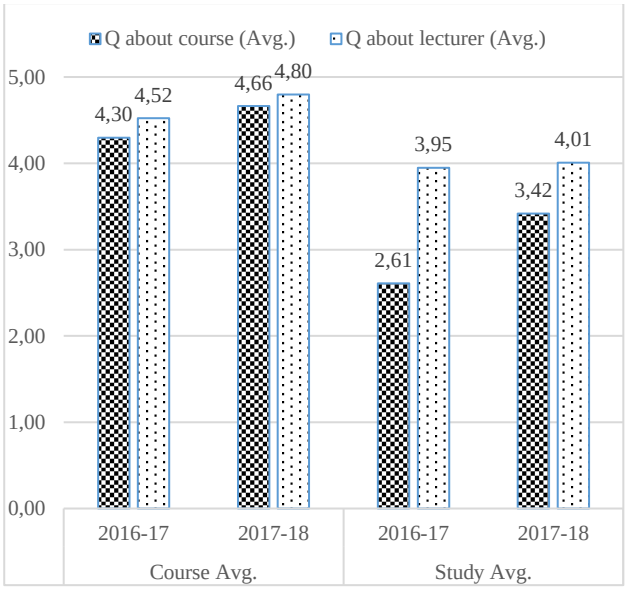

Figure 3. Official students satisfaction survey average performance and comparison

It is obvious that for both years, students are highly satisfied with the course as well as the lecturer, and their satisfaction is much higher than the satisfaction with the whole study. During the second year, the satisfaction is even higher. It is probably because of teachers' performance, because the content was unchanged. Questionnaire scale is standard school grading from 1 to 5, as in official one.

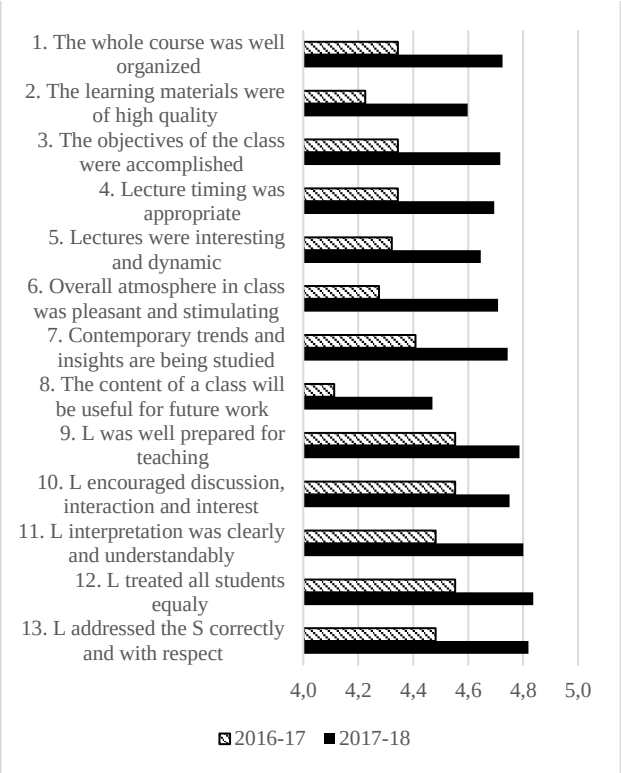

Figure 4. Selected 13 questions, comparison for two year period

All the grades are above 4 (very good), most of them inclining to excellent, which is not common for students' grade (as seen from study average in Fig 2.). It is obvious that the students received class very well, especially the way lecturer approached them – lot of interaction, open communication and discussion.

C. Students improvements survey

As students satisfaction study intention is not to go into the actual topics of each class, in order to understand their attitude towards the class, author decided to conduct much more detail questionnaire looking for their personal improvement of most important skills and competences acquired during the course.

Survey was unannounced, and conducted from 21st to 29th of January 2018, for both generations. As it is more than half year, or year and a half in other case, students were not biased by anything from the class; they were truly recollecting their thoughts about the things they have learned.

It was prepared and executed via Limesurvey survey system from Croatian University Computing Centre (SRCE). It addressed 109 students out of 111 who competed the Course (two of them left the University) and got exceptional return rate of 38.53 % answers (42 out of 109). Six of them were uncompleted, so there is more than qualified representation of almost one third of total population – 33.03 % (36 out of 109).

As in the class, majority of students were male (72.22 %), with little more (19:17) students with general (gymnasium) than vocational background. Majority of them (88.88 %) are 20 – 25 year old. Half of them (52.77

%) are very good (4) graded students, ten of them good (3) and six excellent (5). Only one is just sufficient (2). Most of them, 22 out of 36 (61.11 %) are regular students and the rest are studying and working. As study of Information sciences produce very much needed industry experts, even though they are still undergraduate students, most of them have working experience as follows: six never had any working experience, eight of them are full time employees, and majority, 22 out of 36 (61.11 %), are working on temporary bases. That means that even they are very young undergraduate students, most of them are in contact with labor market already.

The survey structure is simple: after asking them one simple open question "Have you learned something useful during the course?" with only one negative answer, they were encouraged to elaborate it in their own words. Response is remarkable – 91.66% left their opinion. Most of the answers will be presented during discussion part, right after the structured part of the survey.

In the structured part of the survey, they were offered a list of 20 skills and competences to grade them on Lickert seven point scale according to criteria "Evaluate how much you have developed and improved your skills and competencies during the course:"

Scale was described from (I) not at all, (II) very little, (III) little, (IV) average, (V) above average, (VI) very much and (VII) extremely, and the results are given in Table 1.

Table 1. Improvement of skills and competences after the Class

Skills and competences	I	II	III	IV	V	VI	VII
Taking the stance/attitude	1		1	8	7	9	10
Awareness of information need		2		10	7	12	5
Critical evaluation of stance (own incl.)			3	4	17	8	4
Self-criticism		2	1	9	10	5	9
Communication	2	1	2	5	11	5	10
Information presentation (ppt & seminar)	1	1	4	6	6	14	4
Responsibility	3	2	2	4	9	8	8
Openness	2	3	1	7	9	5	9
Adaptability	1	2	2	6	13	8	4
Learning by participation	1	2	3	8	9	6	7
Information evaluation (CRAPP method)		1	3	8	14	9	1
Teamwork	1	3	3	8	6	9	6
Result orientation	2	1	2	8	12	7	4
Persistence	3	2	1	7	11	7	5
ERR learning method	2	1	3	11	7	8	4
Idea and formulation	1	2	2	9	13	8	1
Argumentation		2	3	13	8	9	1
The influence of emotion on attitude		2	6	10	8	7	3
Logical component of argumentation	2	1	4	10	13	5	1
Tools (Mind mapping)	1	3	6	12	10	3	1

The results are sorted out according to most developed or improved skills, and clearly showed progress in all 20 skills covered in this questionnaire. Even the last rated skill – using the mind-mapping tool have more (V) above average indicators (10) than (III) little ones (6). Two of them standing out are the primary skills of Critical thinking (taking the stance) and Information literacy (awareness of information need).

After this, a simple check box criterion is offered to them: "Out of all the above mentioned features, select a few (5-10) of the ones that you personally consider being the most valuable and which you believe are important for the next generation of students". Before the list, a comment has to be made, that in average they pointed out almost nine skills each (8.72), proving a point that most of learned skills are considered very valuable to them. A list of top 10 acquired skills, all mentioned from more than a half of students, is given in Table 2. The percentage is calculated as percentage of students nominated particular skill in an arbitrary group they believe are most valuable.

Table 2. Most valuable acquired skills according to students recommendation

#	**Top skills**	%
1	Teamwork	75,00
2	Taking the stance/attitude	61,11
3	Critical evaluation of stance (own incl.)	61,11
4	Idea and formulation	58,33
5	Argumentation	55,56
6	Responsibility	55,56
7	Communication	55,56
8	Self-criticism	52,78
9	Awareness of information need	50,00
10	Persistence	50,00

First of all valuable skills list is Teamwork. This means that 27 students out of 36 of them selected Teamwork. Even they were not taught this skill during the class (no special teamwork instructions during the class, they were rather forced to work in teams), they all realized how important is not to work alone in order to solve given task. As this also on the top on employers list of competences [11], intention of an author of a course is fully accomplished. Apart of already mentioned basic Critical thinking and Information literacy skills (taking a stance, argumentation, and information need awareness) there is remarkable list of valuable personal skills / character qualities like responsibility, self-criticism and persistence. The other ones standing out is realizing the value of improved communication (No2 on employers list [11]), and definitely generating the idea and how to appropriate formulate it. This particular one in not high on their list of improvements (16), but after the Course they got the idea of its importance right (4).

D. Discussion

From both surveys, it is obvious that students had very positive experience with the Class. From immediate comments during official survey there were much more positive than negative comments. The only real negative

was two comments under category "Unclear purpose and benefit of the Course", which suggests that early in the beginning of a course author should check out are all the students on the same page, realizing what is the intention of the Class. The rest of the comments (10) were very positive, encouraging, including the remark "Dynamic atmosphere, encouraging discussion and interactivity", really describing the working atmosphere. Even if considering one student complained of "*very long schedule (Thursdays, from 18:15 – 21:00)*", and one complaining, "*that the workload of roles were not equally distributed, so some students made benefit of others work*". However, this was done by design to emulate situations from the real life, where some obstacles like late working hours are often necessarily, including unjust division of tasks.

Comments made during their second survey (what did they learn) are even more positive, considering the fact that only one student chose option "I did not learn anything". Out of 33 received comments, four of them were not really connected to any Class benefit, and several of them were simple and obvious answers like (critical thinking, value of information, recognizing fake news, team work, value of communication, …); but there are more than dozen, shoving real breakthroughs in their everyday life as: "*I learned how to learn. I have developed the ability to understand the learned and how to get reliable information.*", "*Observe things from a different angle*.", "*Good ground for further learning of certain things*", "*Improved way of thinking and approaching a problem with open mind, teamwork*". Even small essay: "*In a way, I got a new glimpse of the world and began to think differently, from everyday things to some more complicated ones. That is why I am judging even more before making a decision (though it sometimes happens to be a mistake). I would like to add that through the subject I have even more mentally matured and strengthened myself*." Most of them could be summarized with "*I have adopted my way in a new way to think. As explained in the answer below, I have somehow made a progress in personal development*".

After this free form comments of what they have learned, they were just asked final question to choose area of their life they improved the most: faculty, family, friends, work, personal development, all of above or none. Most of them (41.66%) attributed it to the area of personal development.

IV. CONCLUSION

This Course is very rare, if not unique, as an approach for freshmen generic skills improvement in Croatian High Education society. Results and discussion of students evaluation of the Course presented in this research clearly confirms that "Information Literacy and Critical thinking" course is successful high school freshmen tool to their generic skills and competences development and improvement in order to empower them on a journey to become valuable contributors of modern society. Not only Croatian society, because the students' list of most valuable acquired skills is very much corresponding to 21st Century Skill Set promoted by World Economic Forum.

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Developing Leadership in a Simulation-Games Environment

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***Abstract* - Leadership is a process of inspiring people in pursuit of various goals and various activities. Leadership is often discussed in the context of project management, and leaders referred to as being able to organize and motivate a group of people to successfully finish a given project. In order to inspire, organize and motivate others, leaders need to have advanced social skills. Successful leaders are constantly trying to improve their social skills and knowledge. Life-long learning is important for leaders, especially learning by experience and in a real-time environment. Simulation games enable participants to learn by doing which gives them the opportunity to understand real everyday situations and possible consequences better. During simulation games, users train, analyze and predict possible actions which help them in the decision making process. The goal of this paper is twofold. The first goal is to present and analyze the usage of simulation games in leadership, their desirable characteristics, advantages, and disadvantages in the area of leadership. The second goal is to present relevant platforms for using simulation games for leadership activities and to discuss them in the context of students learning.**

Keywords – leadership, simulation games, life-long learning, social skills

I. INTRODUCTION

Definition of leadership has been changed over the years. Scientists argued that leaders were born with special characteristics that help them to influence others, however various research indicated that other elements are important for successful leadership process. Some of them are situational context, the readiness of colleagues to accept and follow the leader's ideas [1]. According to situational context, leaders should aim to adjust their leadership styles according to the motivation of their employees, readiness, and competency of the colleagues, as well as specific characteristics, e.g., type and nature of a specific project or organization who differ for each particular situation. Leadership is a complex process that depends upon situation, project, organization, team members, social, cultural and economic factors [2]. Constant changes and complexities of knowledge society implicit new challenges and tasks for leaders, and require continuous learning and. Therefore, leaders should constantly educate themselves and improve their knowledge and skills through theoretical and experiential learning in a real-time environment [3]. In addition, organizations depend upon successful leaders who create a motivated and positive environment for all employees and encourage them to be efficient regarding business activities and to foster a social environment with good communication. Therefore, investigate in further education and development of leaders is cost-effective for organizations.

Simulation games are based on experiential models and offer users learning by doing which help them to understand real everyday situations better [4]. Participation in the simulation game enables users to make decisions and plans, interact with others and evaluate their results [1]. Therefore, simulation games have great potential in leadership development. Based on that proposition, we develop two research goals. First, we present and analyze the usage of simulation games in leadership, in the context of previous research. Second, we present relevant platforms for using simulation games for leadership activities and focus on two case studies of simulation games designed for specific leadership challenges.

Paper consists of four parts. After the introduction, in the second part of the paper, characteristics of simulation games, their advantages, and disadvantages, as well as usage in the area of leadership are described. Selected simulation platforms that offer leadership development games are presented in the third part. Case studies of presented simulation games are discussed in the fourth part. The fifth part concludes the paper.

II. BUSINESS SIMULATION GAMES FOR LEADERSHIP

Simulation games present a useful tool for facilitating learning using information and communication technology and enabling students to understand the situational context, to react properly, to expand possibility for action and to learn how to adapt to the new situation [5]. There are different objectives of simulation games, such as inciting learning in some specific business areas (e.g., trade, finance, supply chain management, production) and others for developing leadership skills and knowledge [2]. Learning through simulation games is experiential, enabling that participants learn-by-doing, while they practice how to make a decision in the real world in a safe environment. In addition, people learn and understand better if they are faced with real business situations and when they have the possibility to analyze their good or bad decisions [1]. However, it is important to emphasize that ex-cathedra presents a base for learning which should be supplement by simulation games.

Various modeling methods are used for developing simulation games, such as system dynamics, discrete simulation, and agent-based simulation. System dynamics is a simulation method used for modeling the long-term behavior of complex systems [6]. It provides a better understanding of real situations while presenting a model of the behavior of social, economic or political systems in a controlled environment and with feedback over time [7].

System dynamics is used to investigate characteristics of system behavior in order to suggest improvements and to evaluate the long-term impact of particular decisions to the system behavior [8]. There are many unpredicted factors in real life which unable qualitative prediction of our decisions [9]. Therefore, using system dynamics models, we can get much easier to forecast the consequences of decisions we have made, identify factors which influence the system's growth and stability and analyze given results [10]. System dynamics models are often used to design and develop simulation games while they provide a very good overview of the structure and behavior of the system and elements of the system and relationship among them. Therefore, simulation models developed using system dynamics can be very simple or very complex depending on variables and relationship among them [11].

Simulation games are also useful in the development of various skills, such as active learning and collaboration [12]. Experiential learning which is based on simulation games has a strong impact on improving leadership expertise and knowledge [1], enabling leaders to improve their knowledge and skills learning through practice and observation [13]. Business simulations provide the participants with a safe and controlled business environment where mistakes have no negative effects in real life. The main advantage is that participant in the simulation experience situation and makes decisions using their leadership skills and knowledge [14]. Simulation games accelerate leadership learning, by encouraging employees to be proactive and to take on new challenges [15, 16]. Simulation games transform learning activity into a business environment where participants can achieve desirable leadership skills and technical expertise essential in today's business processes [17]. Various software is available for developing system dynamics models and later transferred to simulation games, such as Vensim, iThink, and STELLA.

Capobianco Lopes with his colleagues [1] conducted a systematic literature review aims to identify business games used in leadership development and how they contribute to effective leadership. Firstly, they suggest that there is still an insufficient number of research using simulation games to foster leadership skills and knowledge. Secondly, they notice that the relationship between the theory of leadership and business simulation games is not clearly presented in the context of learning. They also noticed that participants are not eager to change their behavior or skills, even after finishing the simulation business game. In other words, using simulation business games as an active learning method does not automatically ensure effective education for leaders. It is likely that more qualitative business models and realistic business games will attract leaders and managers and improve leadership development using an active learning environment.

However, the results of their study provide insight into organizations that are creating simulations games. In order to provide a better picture of possibilities that simulation games offer and their importance it would be interesting and useful to do in-depth interviews with leaders after finishing simulation game. Their experience and later practicing what they have learned during simulation game, provide the role and advantages that simulation games offer to users.

Simulation games can also help participants to improve their specific leadership style which can help them in real business situations. People differ regarding personality traits, cognitive ability, motivation, and self-efficacy and simulation games have the potential to improve their knowledge and skills and to prepare them for real business situations [18].

III. SIMULATION GAMES PLATFORMS IN THE AREA OF LEADERSHIP

Simulation games are developed by various organizations, such as universities as well as companies that sell them to interested parties. Simulation games are usually offered using various platforms. Several specialized organizations are selling custom made simulation games for multinational companies and universities, aiming to help them in finding well-trained employees. They also offer free demo versions of their simulation games. Simulation games platforms offer various types of simulation games, focusing on learning in a specific industry (e.g., hospitality or telecommunications), or to development of specific skills, such as leadership.

For the purpose of this paper, we shall present the following platforms: Cesim, Forio, and Isee. In addition, there are platforms that offer only leadership development games, such as Simulearn and LeadPro. Among them, Isee and Forio develop business simulation games based on system dynamics modeling approach [11]. Some of these companies cooperate, such as Isee and Forio, as is elaborated in the fourth part of the paper.

A. SimuLearn

SimuLearn offers products that enable better leadership skills through simulation training program [19]. At platform SimuLearn clients can choose among three main products: Blended learning products & bundles; Easily integrated self-paced modules and Custom development. Their games can be used by corporations and university classes and have already made programs and custom development which can be prepared according to clients' wishes. Using the game, clients will work in a controlled environment through several weeks of practice real business simulations. At SimuLearn platform clients can also find games based mainly on leadership activities: vLeader Professional, vLeader Professional Supplemental Text, The Leadership Experience Instructors Compendium, vLeader Advantage and vLeader Essentials Supplemental Text. Those who are interested in their programmes can apply to a free webinar to find which simulation is the best for them.

B. Cesim

Cesim is also one of the organizations which offer different simulation games that can easily present business processes in a risk-free environment through an online platform [20]. Their simulation solutions start with Introduction, practice round, strategy and objectives, decision making, conclusion and analysis and are prepared for four business areas: Business, Management & Strategy Simulations, Marketing, Hospitality, and Industry specific.

Figure 1 presents the dashboard of one of the Cesim simulation games. Players make the decision using the dashboard, and see the consequences of their decision in virtual settings. Cesim offers to their client's demo version which enables them to have better insight into simulation games and to choose the right one according to their needs. All simulations are a competitive and present market with 3-12 teams including 2-8 members. All teams begin with the same start position and with similar market shares, profits and market conditions. According to their decisions, they will have positive or negative results at the end of the simulation.



Figure 1. Cesim dashboard
Source: www.cesim.com [accessed February 22nd, 2019]

One of Cesim products dealing with leadership is a Project management simulation game focused on teamwork and leadership collaboration and communication. The simulation game is prepared in five languages: English, Finish, French, Spanish and Chinese. The main task for team members is to manage a project and to complete it with the highest quality, least cost, and on time. Through simulation game, participants will learn how to lead a project and how to organize given task and needs of team members; how to communicate with each other and how to collaborate with different team members according to unexpected situations. The success of the team depends upon the leader's skills to manage task and team members.

C. LeadPro

LeadPro is offering virtual experience through simulations regarding different leadership styles [22]. Through their simulations, they offer the experience of practicing leader skills in a virtual environment about decision making. Participants get a chance to practice their decision-making process in a controlled environment. After finishing the simulation game, users get instant feedback and data analysis regarding their decision process. The dashboard is presented in Figure 2. They also offer a demo version to interested clients in order to try a simulation and decide whether it is suitable for their needs.

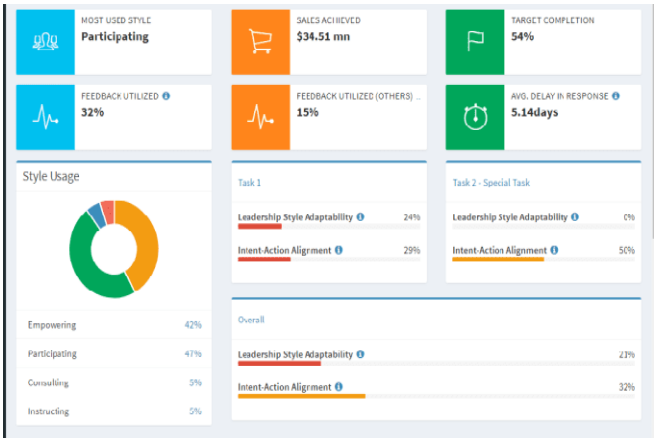

Figure 2. LeadPro dashboard
Source: http://www.leadprosim.com [accessed February 22nd, 2019]

D. Isee Systems

Isee systems were founded in 1985 by Barry Richmond one of many experts in system thinking [23]. In 1989 they invented model building and simulation tool, STELLA. Software iThink was developed in 1990 for business activities and strategies and in 1991 Isee systems created the first Management Flight Simulator. They successfully continued they work in the area of simulation modeling and in 1995 introduced the first Learning Environment and in 1999 provided the first conversational systems thinking workshop in 1999. In 2015 they delivered software Stella Professional, which allows real-time analytics with Stella Live.

Isee systems offer different modeling and simulation software which enable a better understanding of the world. By using Isee systems' Dynamic Modeling software, participants develop system diagrams that can be simulated over time which enable them to understand the behavior of the system and recognize possibilities for progress. Isee systems offer not only software but also online courses, workshops, one-on-one modeling support, free webinars, and tutorials. They offer simulation solutions in different areas: development, economics, environment, health care, human resources, policy, social, urban dynamics. At the Isee Directory, clients can find more than 200 simulations published by their customers which

they can search by specifying Title, Description, Keywords or Author. One of the simulations in the area of leadership is SysQ where they highlight the importance of systems thinking and systemic intelligence for successful leaders. Participants can get insight into the simulation model, how feedback loops are developed and what are relationships in the model. In their games, system dynamics models are also presented in order to increase learning. Figure 3 presents the example of elaboration of the system dynamics model in the simulation game SysQ.

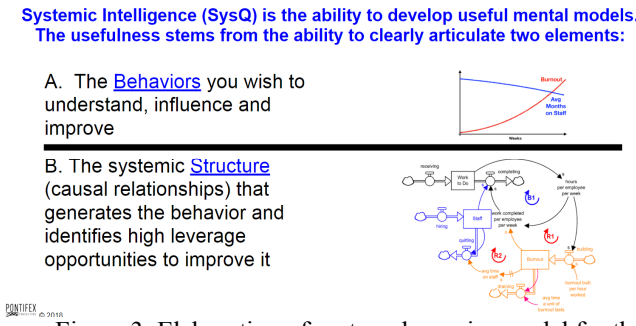

Figure 3. Elaboration of system dynamics model for the game SysQ
Source: https://exchange.iseesystems.com/
[accessed February 22nd, 2019]

E. Forio

Forio has been founded in 2001 and creates software products that enable simulations, data explorations, and predictive analytics [21]. They have three main categories of products: Epicenter-platform to create & share powerful web-based simulations; Performer-offer soft skills through online role-playing and Ready-to-Run Simulations-simulations for higher education or corporate training. Forio presents games developed with system dynamics modeling. It is possible to upload the game using Vensim, ithink, or STELLA software. Various organizations are using Forio platform.

Several simulation games are free to run, and Figure 4 presents examples of such games.

In the area Ready-to-Run Simulation they have several categories, such as Capacity & Supply Chain, Entrepreneurship, Finance & Accounting, Group Communication, Innovation, Leadership & Management, Market Growth, and others.

There are several simulations in the category Leadership & Management that are suitable for corporate training or higher education: (i) Leadership and Teamwork: Everest, (ii) Cybersecurity: Cyber Attack!; (iii) Organizational Behavior: Judgment in a Crisis; (iv) Global Collaboration: Tip of the Iceberg; (v) Change Management: Power and Influence; (vi) Renewable Resource Management: Fishbanks; (vii) Project Management: Scope, Resources, Schedule; (viii) Startups and Entrepreneurship: CleanStart; and (ix) Network Externalities: Video Game Platforms. Forio is also interesting for university studies while offering many demo simulation games in different areas.

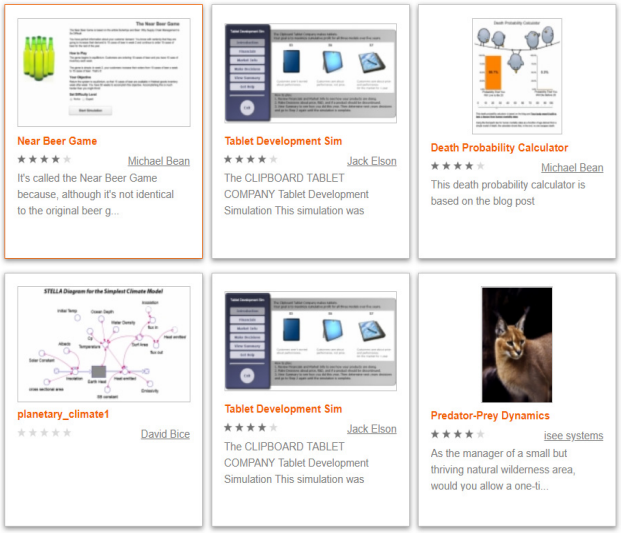

Figure 4. Forio games showcases
Source: https://forio.com/simulate/showcase [accessed February 22nd, 2019]

Figure 5 presents the dashboard of the Leadership and Team Simulation: Everest Demo, which is hosted on Harvard Business School platform.



Figure 5. Leadership and Team Simulation: Everest Demo
Source: http://academic.hbsp.harvard.edu/everestv3
[accessed February 22nd, 2019]

The simulation is about climbing to Mount Everest and all unexpected situations that could happen during climbing. Team members have to work together and make decisions about climbing to the next camps, hiking speed, distribution of supplies and oxygen bottles, weather and health conditions.

Team members and team leader have to work together, communicate, share information and collaborate in order to get on the top of the mountain without any negative consequences on team performance.

IV. CASE STUDIES OF SIMULATION GAMES FOR LEADERSHIP DEVELOPMENT

In order to better elaborate usage of simulation games for leadership development, we present two examples of simulation games, available as free games over Forio platform.

A. Headcount strategy game

The Headcount strategy game was developed using software iThink. The software provides to users to test their decisions, to apply different strategies and to see results of their own actions and possible consequences in a safe environment. The program is user-friendly and enables to players visualization of each step and a better understanding of decisions they made. The game is available through Forio platform.

Figure 6 presents the model structure of the game. The game was uploaded by Isee company to the Forio platform and is available for free usage.

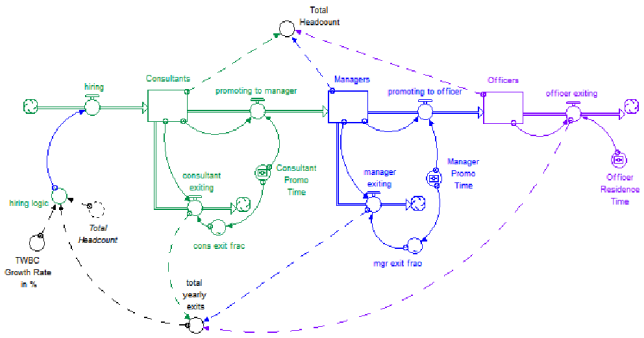

Figure 6. Elaboration of the system dynamics model for the Headcount strategy game
Source: https://forio.com/simulate/netsim/simple-headcount-dynamics/run/ [accessed February 22nd, 2019]

Players define the firm's strategic goals. However, they have to be careful in defining strategic goals which should not be in conflict with one another and which all together should contribute to efficient business strategy. Players have a wide range of different scenarios regarding business strategies which are based on real business situations prepared in co-work with example consulting company called TWBC.

Description of the model is as follows: (i) Company employes juniors while their intention is to increase mid and upper management; (ii) Consultants can be promoted to managers, or they can resign; (iii) Managers can be promoted to officers or they can resign; and (iv) The top managers are officers and each year few of them leave the organization. In presented model, if employees tend to prosper quickly through junior and consultants and spent a long time as top managers, the system will distribute a larger portion of the total headcount to the Senior's stock. In a situation when growth slows, headcount will distribute itself in proportion to the relative size of each stock's residence times which enable employees to become top managers. One of the possible solutions is to prolong consultant and managers promo times.

Figure 7 presents the dashboard for the Headcount strategy game. Players make the following decisions by moving the sliders at the dashboard: (i) consultant promo time, (ii) manager promo time, and (iii) officer residence time. Based on these times, the consultant to manager ration and managers to officer ratio has been calculated. Scenarios can be further complicated with different levels of market growth rate, depending on the general economics situations. The goal is to establish a balanced growth with the minimum costs. Different consequences of bad decisions can occur, i.e.., if the ratio of managers to officers is too high, the clients can be dissatisfied, since they are not served by the most experienced experts.

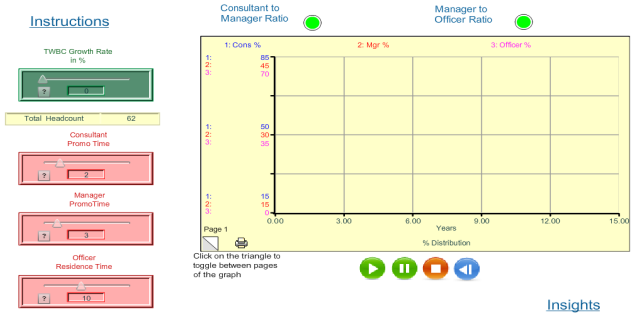

Figure 6. Dashboard for the Headcount strategy game
Source: https://forio.com/simulate/netsim/simple-headcount-dynamics/run/ [accessed February 22nd, 2019]

B. Business Cycle Dynamics game

Business cycles and the process can be studied in different industries while market demand peaks one year only to drop a year or two later and after a negative business period, the industry demand peaks again. Figure 7 presents the dashboard of the game, where players define the value of two variables defining the supply chain behavior: (i) normal capacity utilization, and (ii) capacity acquisition delay. As well as the Headcount strategy game, the game was uploaded by Isee company to the Forio platform and is available for free usage.

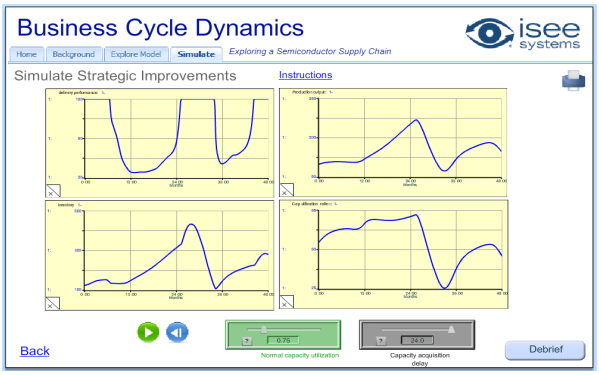

Figure 7. Dashboard for the Business Cycle Dynamics game
https://forio.com/simulate/netsim/business-cycle-dynamics/run/ [accessed February 22nd, 2019]

Business Cycle Dynamics game was developed by Henk Akkermans, Professor of Supply Network Dynamics at Tilburg University, who noticed that capacity investment in new factories would typically start at the peak of the market which during several years leads to an excess of production capacity. Reducing utilization of existing capacity has delays and leads to an excess of inventories for up to two years.

In the Business Cycle Dynamics game, the players investigate the behavior of delays in supply chain and late responding to market demands. In this simulation, the supply network is based on four interrelated processes: Order Handling, Production Process, Capacity Management Process, and Production Planning.

V. CONCLUSION

In leadership simulation games, participants compete with others, communicate, make decisions and strategic plans, and analyze their actions in a safe environment. Participants can see the consequences of their own decisions immediately within the setting of the simulation games, while in the real world it would take months and years until the real effects of their decisions would become visible.

In this paper, we discuss leadership simulation games. Based on the results of our analysis, business simulation games play an important role in improving leadership skills and knowledge while enabling leaders to manage team members in a controlled environment without any consequences and with detailed data analysis at the end of the simulation. We present various platforms offering business simulation games, among which several are aiming at developing leadership skills. Presented platforms are Cesim, Forio, Isee, Simulaern, and LeadPro. Cesim, Forio and Isee systems provide simulations in many business areas not only for leadership development, while Simulearn and LeadPro provide only simulations for developing leadership skills. The disadvantage of all presented platforms is their price, which is all high-priced and is in most of the cases affordable for companies with sufficient budget, which use them for training their leaders or selecting new employees. However, Cesim and Forio demo simulations are suitable for playing with students during the class. They do not offer all features of full simulation, but demo versions are suitable for playing them among students during the class. At the end of the game, students can see their final results according to decisions made during the game. In addition, we present two case studies of leadership simulation games. One game supports the players in learning the dynamics of human resources management in a consulting firm, while the other support the players in learning the dynamics of business cycle dynamics.

The presented overview of leadership simulation games is situational since we presented only selected platforms distributing business simulation games, while we did not conduct the systematic search for such games. However, the results of our analysis can be useful to higher educational institutions teaching leadership in their curriculum, as well as corporations seeking to utilize simulation games in attracting and detecting new talents in their organizations.

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Learning analytics and academic libraries in Croatia - are we ready for it?

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***Abstract* - It is not unusual for academic libraries to modify their services around (library-created) data. Data is information, one of the critical inputs among other variables that we can measure in the libraries. Librarians are familiar with the statistical methods and their full potential in library analytics for creating data-informed or data-driven decisions regarding collection management, library catalogue searches, logs to online resources, etc. Learning analytics, on the other hand, is focused on the data about learners and their context for purposes of understanding and optimizing learning and the environment in which it occurs. Academic library as a part of the higher education ecosystem is a natural partner with data sources that can combine with other institutional systems and generate new information about our learners, learning and instruction. Although it is a novelty for libraries, some of them are using learning analytics to evaluate the impact of libraries services, collections and student learning. The literature states that librarian investment in learning assessment to involvement in learning analytics is a natural one - but are we ready for it?**

Keywords - Academic library; Learning analytics; Higher education; Assessment; Data-informed decisions

I. INTRODUCTION

In the past few years usage of analytics has been getting considerable interest as one of the principal instruments in the academic libraries. Librarians are becoming more research-based guided and involved in assessment culture. They are aware of the implementation of the evidence-based approach into management for improving library and teaching services. The research-based approach is responsible for the changes that are (on)going in the academic libraries to include more and more different data sources to track changes and needs of their users.

Learning analytics

Learning analytics (LA) is increasingly recognized as a new component in the higher education system worldwide. Learning analytics is the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding, and optimizing learning and the environments in which it occurs. It is primarily concerned with improving learner success [1]. The other widely used definition of LA is from EDUCASE [2]: collection and analysis of usage data associated with student learning. Its purpose is to observe and understand learning behaviors in order to enable appropriate interventions – such as tracking and predicting learners' performance as well as identifying potential problematic issues and students at risk.

LA is also defined by an attribute of the level or object of analysis, where LA is directed toward providing educators, learners, and decision makers with actionable insights to classroom and course level activities. Academic analytics (AA) target higher-level analysis and the needs of senior administrators, policymakers, government officials, and prospective funders [1]. Although it seems that the future is data-based oriented, we must focus on data as one of the key variables in the assessing activities or behavior among students.

Learning analytics and the academic libraries

If we are discussing the isolated view of data and its analysis in the library, then we are talking about library analytics. Collected data in the library can build a more in-depth understanding of the impact of library services and resources. Traditionally, library analytics data is used to drive data-informed decisions in the library.

Some library associations [3], [4] and researchers have reported that learning analytics is currently the top trend in the academic librarianship. It is stated in the "Library Integration in Institutional Learning Analytics (LIILA)" white paper: library involvement with learning analytics represents a natural evolution of library efforts to assess student learning. Librarians have always sought to determine the impact of library services and resources on student learning. (…) The Inclusion of library data in institutional analytics initiatives offers renewed hope that librarians will discover new connections – and perhaps uncover missing links that can inform, enable, and empower libraries to support and generate student learning success [5]. In another paper authors [6] state that faced with different realities, librarians will no doubt select different approaches regarding information literacy assessment. Showers [7] described in the 2014 the LAMP project: "the prototype will deliver a data dashboard enabling libraries to capitalize on the many types of data they capture in day-to-day activities and will support the improvement and development of new services and demonstrate value and impact in new ways across an

institution, in line with the three strategic drivers highlighted above".

With that enthusiastic view that the libraries can capitalize on many types of data they capture in day-to-day activities we will demonstrate current situation and display the current state of data collection, and the connections of LA and academic libraries in Croatia. So, in that context, the key research question of this study is whether the academic librarians in Croatia are ready for involvement, and implementation of learning analytics?

II. METHODOLOGY

This study was based on an online survey (via GoogleForm) consisted of thirty-nine questions. The survey was inspired by a Spec Kit 360: Learning analytics [8] survey. In our case, the survey was carried out only in the segment regarding the introductory part of learning analytics. The survey was divided into four parts:

(a) The first section was introductory with questions about the institution of the library - consisted of two multiple-choice questions about types of the institution and field of study of the institution. (Q1-Q2)

(b) The second section examined library and user data activities through 14 questions: five multiple-choice, six open and three closed questions. (Q3-Q16)

(c) The third section analyzed the educational activities of the libraries and the engagement of librarians in formal an informal education through 10 questions: two multiple-choice questions, three open and five closed questions. (Q17-Q26)

(d) Finally, the fourth section was focused on learning analytics and consisted of thirteen questions: seven closed and six open questions. (Q27-Q39)

In order to be more open and cooperative with librarians only the two questions in the first section and one regarding the inclusion of library data in learning analytics system (fourth section) were mandatory.

The survey was distributed on February 12, 2019, to the heads of the libraries in higher education institutions in Croatia via e-mail message which contained an invitation to participate in the survey. The survey was closed on February 22, 2019. The direct e-mail contact was selected because it was intended for heads of the library to respond in the name of the library and institution. The survey was anonymous, and fulfillment was optional.

As this study was based on an online survey author collected all contact information about academic libraries from the sources at Ministry of Culture [9], Library Statistic System (via National and University Library) [10], Croatian Bureau of Statistics [11] and libraries web pages. The total number of registered libraries at institutions in higher education in the Republic of Croatia is 118 [9]. Fifty-two librarians completed the survey.

Statistical analysis was performed using Microsoft Excel software.

III. RESULTS

A. *Introductory section*

The first section of the survey required from respondents to give information about their institution. The first two questions were mandatory for respondents to answer in this part of the survey. (Q1-Q2)

In the first question (Q1 "Your library is part of what type of institution in higher education?") the majority of those who responded (52) stated that library is a part of Faculty (31), University/University Department (7), Polytechnic (6), College (6), and from Academy of Arts (2).

The second question (Q2 "What field of study in higher education is your library part of?") accordingly to the type of institution, the type of field of study respondents stated that they are in Social Science (22), Technical sciences (11) Biomedicine and Health (7) and Biotechnical Science (7), Humanities (9), Natural sciences (4), and Arts (3).

B. *Data in the library (Library data and the library user activity data) section*

The second section of the survey required from the respondents to give information on collecting data in the library, with emphasis on personal and library user activity data in the library. (Q3-Q16)

Q3 "What personal information about users does your library collect?" Using multiple choice question respondents stated that they collect information about: name and surname (52), home address (43), e-mail (private) (30), date of birth (33), sex (30), e-mail address (official) (25), Personal Identification Number (19), Academic Citizen Unique ID Number (8), other minor responses were about phone/mobile number, Identification Card Number.

In the question Q4 "What user activity data does your library collect?" the respondents indicated what user data activity they collect, and whether they collect at the user or group level. The data that libraries collect at the user level is data about bibliometrics analysis (13), interlibrary loan (12), reference service usage (11) and specialized searches (11). At the group level, libraries collect data about library visits (physical visits) (33), circulation statistics (31) and interlibrary loan request (26). At the user and group level, librarians collect most data about scanning or copying on demand (15), circulations statistics (9) and bibliometrics analysis (7). (Table I.) Q5 was an open question about any other additional user activity data that the library collection. There were no additional responds to that question.

Q6 "How does your library collect and track data about user activity in the library?" Participants stated that they mostly track manually (13). They also stated that they do combination of manual tracking and system that is developed in the institution (11), through system that is developed in library and manual tracking (9), combination of commercial system and manual tracking (7) or through system that is developed within the library (7), and just through commercial system (6). With the dominant

approach of manual tracking, most of the libraries rely on the traditional system of tracking, collecting, and we can say managing the data in the libraries.

TABLE I. USER DATA ACTIVITY

Data collected at:	User level	Group Level	User and Group Level
Library visits (phisical visits)	8	**33**	4
Circulation statistics	8	31	9
Databases usage	3	22	0
E-resource usage	1	19	3
Single sign-in login portals (e.g., Proxy, Shibboleth)	2	12	0
Interlibrary loan requests	12	26	4
Bibliometrics analysis	**13**	14	7
Scanning or copying on demand	9	1	**15**
Reference service usage	11	19	2
Specialised searches	11	11	1
Workshop attendance	9	21	3
Library space usage	8	23	3
Attendance at other events (e.g., tour, exhibits)	6	16	1
Library website usage	2	16	1
Social networks visitis	2	13	0
Library computers login	7	16	0
Security systems (e.g., security camera recording)	2	9	0

Q7 “Does your library provide parent institution information about library user data activity?” Participants stated that 27 of them deliver data to the institution, 13 of them stated that they sometimes do, and 12 stated that they do not provide any information about user activity.

Q8 “State the reasons why library provides user activity data to the parent institution.” Author identified four reasons from the participants' responses: library analytics (15), annual reports (15), reports/analysis to prove library value at the institution (5) and reports on demand (4).

Q9 “Specify how often the library shares data with parent institution.” In this question, only 37 responded. When they were asked to specify the period when they share their data with the institution: the majority responded (25) that they share it once per year, rest of them (11) vary from 1-4 times, and only at the demand (1).

Q10 “Does your library have access to user information from institution’s information system?” Of the 52 participants who responded to this question 27 stated that they do not, 23 stated that they do, and two stated that institution has access in a partial segment. In the follow-up question (Q11 “Name the system(s):”) 21 librarians stated that they use Higher Education Institutions Information System (ISVU) which is intended for informatization of the student’s services at higher education institutions.

Q12 “Does your library share any user data with the other departments of the institution?” This was a closed question where respondents stated that 37 of them do not share user data, 14 stated that they share and only one stated that they share it on demand. In the follow-up question (Q13) participants were asked to name the type of data they share. Only 15 participants indicated that they: share data about personal data (7), data about user activity (6), and a combination of personal and user data activity (2).

Q14 “Does your library share any collected data about user activity outside the institution?” When they were asked if the library share any data about user activity outside the institution 43 participants responded. Responses were: no (22), and yes with multiple combinations; a) Library Statistic System (via National and University Library) (5), b) Library Statistic System and Croatian Bureau of Statistics (4), c) Library Statistics System, Croatian Bureau of Statistics and University Statistics (3), d) General statistics reports (3). The rest of the answers were related only to one of the above segments: Croatian Bureau of Statistics (1), general statistics report at national level (1), University Statistics (1), Accreditation (1), and statistics for the National and University Library (2) (not for Library Statistic System).

Q15 “Name the purposes of use of library user activity data.” Participants were asked for what purpose library uses user activity data. They stated (48) that they use data for statistics (20), for improvement of services (19), work report (7), and have no answer (2). (Fig. 1.)

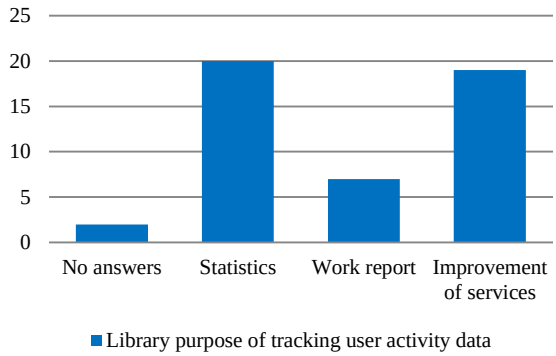

Figure1. Library purpose of tracking user activity data

Q16 “How are user activity data protected in your library?” Respondents were asked to indicate how user data activity is protected in the library. There were 34 responses to the question with the majority of those who responded (17) that the data is protected in the way by limiting access to data only to library staff. The next most efficient way to protect user activity data is regulated by the EU General Data Protection Regulation (GDPR) (7) or a password (4), or the most restrictive way: they do not share data (2). Other data protection measures are: deleting data, physical security protections, limit data retention, and isolated system. One participant stated that

they do not know how they protect user data, and one stated that they do not protect it at all.

C. *Education activity of library and librarians section*

In the third section regarding the educational activity with the emphasis on information literacy, participants were asked how librarians participate in teaching at their institution. (Q17-Q26)

Q17 "Are librarians from your library included in the formal education courses at the institution?" Of the 52 respondents who responded to this question, more than half (36) indicated that they are not included and only 16 stated that they are included in formal education at the institution.

Q18 "State the librarian participation in education activity." Librarians stated that they are involved in education activity in different roles as (answers from multiple-choice question): administrative help (1), lecturer as a part of the course (8), lecturer as a part of the course and administrative help (3), lecturer in the stand-alone course (3), lecturer in the stand-alone course, lecturer as a part of the course and administrative help (1).

Q19 "Do you use Learning Management System (LMS) in courses that librarians participate in?" Regarding the activities in formal educational courses and the question about the usage of LMS they responded that they do not use LMS (9), they do use (5), and 3 only stated that some of the courses are in LMS. The sub-question (Q20 "Name of Learning Management System that librarians use in courses that they participate in.") was formulated for positive responses. Participants needed to state which LMS they use, and the answers were: Moodle (3), Loomen (1) and Merlin (1).

Q21 "What data is collected about students and their activity in Learning Management System?" Participants reported only 4 answers. They collect necessary data (name surname, ID) and student course assignments activity.

Q22 "What data is of exceptional value to you for evaluation of your lecture?" When they needed to specify the importance of data value, participants (5) stated that they use it just for participants' lessons assessments - commented that they track overall student activity, the completion of course, course survey results, and evaluation of professors and students. There was no mention of any detail data segment that is important for the librarian to track student education activity in the LMS.

Q23 "Does your library offer informal education through library instruction(s)/workshop(s) of information literacy?" Besides formal education, the author also asked participants if they are offering informal education through library workshops. More than half (33) responded that they carry out workshops. The rest of them (19) stated that they do not hold workshops.

Q24 "Where does your library organize instruction(s)/workshop(s) of information literacy?" Of the 33 who responded positively, there was a sub-question regarding the location of the workshops. Physical space is dominantly represented in the workshop (14), of the workshops that are held in the library spaces, or combination in library spaces or institution spaces (10), only in institution space (7). Two participants stated that they cover both physical and virtual spaces, but only one participant stated that they hold workshop only in the virtual environment.

Q25 "Does your library collect information about instruction(s)/workshop(s)?" There were 25 participants who stated that they do, and 9 stated that they do not collect any data.

Q26 "What type of data librarians collect about instruction(s)/workshop(s) of information literacy?" In the sub-question regarding the type of data that they collect about workshops the librarians stated that they collect data about the number of attendees (13), information about attendees (Name Surname, study year, department) (8), Satisfaction survey (7), number of workshops (5), information about topic of workshop (2), pre and post testing of attendees (1).

D. *Learning analytics engagement and initiative participation section*

The last section of the survey required respondents to give information about learning analytics and the involvement of their institutions in it. In this section, there was an introductory text explaining what learning analytics is and what the difference between learning analytics and academic analytics is. The text intended to inform participants about differences between those analytics, and to remind those who were not sure the specific difference between those two. This section questions were about current participation/initiatives in LA within the library and institution, focusing on participation, and types of collected data. (Q27-Q39) Question Q31 was mandatory question to respond.

Q27 "Are you familiar with the concept of learning analytics?" Responded were asked to answer if they are familiar with the concept of learning analytics. More than half (37) stated that the concept of LA was not familiar to them, 14 of them stated that they are familiar with the concept, and only 1 stated that he/she is partially familiar with the concept. (Fig. 2.)

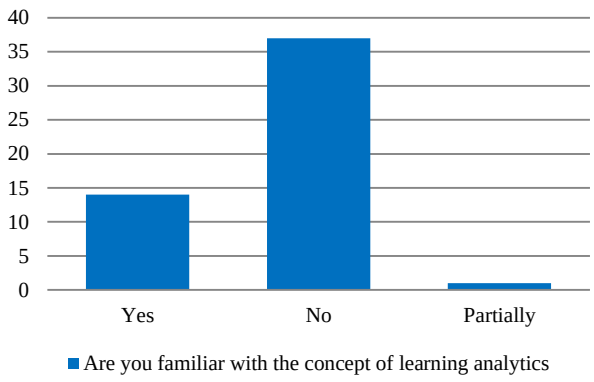

Figure 2. Librarians familiarity of the concept of learning analytics

Q28 “Where did you hear about learning analytics?” Those who were familiar stated that they heard about LA in literature and networking at conferences (9), from colleagues at the institution (3), in official documents and this survey (1).

Q29 “Does your institution have a learning analytics system?” There were 46 responses: 31 stated that they do not have, 8 stated that they have, 6 stated that they do not know, and 1 that they have it in a hybrid format (data sources are not connected in one single system). In the follow-up question (Q30) those who responded to previous question affirmative, they needed to name the system(s) that they use. They stated that the system they use is: a homemade system (7), some of them uses a commercial system (2), one stated that they use system developed outside of institution (it is not stated if it is a commercial or any other kind of system), and one respondent does not know.

Q31 “Are library data included in the LA system?” It is interesting that in additional question about library data inclusion in those systems 7 of them responded that they include library data and 4 that they do not include library data.

In the next question, Q32 “Specify how are library user activity data included in institutions learning analytics.” the respondents were asked to describe and specify how the user data activity is included in the intuitions learning analysis system. There were only 3 responses, stating that “the user activity data is included through a system of quality,” “through a program of information literacy in formal courses” and “data of library visits/circulation, literature usage for bachelor and master thesis.”

Also, at Q33 “What is the purpose of user activity data in LA system?” they needed to describe the purpose for which libraries are using user activity data in the LA system, and they stated: “to improve the quality of teaching and quality assurance of teaching programs”, “improving the educational role of the library”, “for statistical purposes”.

Q34 “Describe how does your library connect user activity data in learning analytics systems and information literacy education.” By connecting parts of librarians’ education activity with library user activity data, in this question participants needed to describe how they link user activity data in LA and information literacy education: (in only two response) they stated, “we send our data into the institutions quality system” and “through survey methods”.

Q35 “Is your institution engaged in learning analytics project(s)/initiative(s)?” More than half respondents (41) answered this question: 3 said that they are involved, 29 said that they are not, and 9 do not know if they are involved. For the definite answers, we added sub-question (Q36 “If yes, name the project(s)/initiative(s)?”) to give us the name of the initiative/project that they are involved in, and we received only one answer that stated: ERASMUS.

Q37 “Are there any indications that your institution is interested in learning analytics?” To get further in the institution willingness to include itself in LA we asked a question are there indications that their institution is interested in LA, overall of 38 participants answered: yes (17), no (13), and do not know (8).

Q38 “Does your institution have a program(s)/office(s) that is responsible for learning analytics projects/initiatives?” Of the 34 participants who responded to this question, most of them (26) do not have any program(s)/office(s) responsible for the LA project(s)/initiative(s), rest of them stated that they do not know (1) and only one (1) stated that they do.

Q39 “Name the program(s)/office(s) responsible for LA project(s)/initiative(s) at the institution.” only one stated that they have a program(s)/office(s) responsible for affirmative commenting and that it is the Quality Management Centre/Commission. Another participant stated that he/she does not presumes it is also the Quality management Centre/Commission that is responsible for it.

IV. DISCUSSION

This survey started from the general to common knowledge of usage of library user activity data to specific knowledge of learning analytics. A variety of perspectives about library data and user activity data were expressed with an overall look that most of the libraries still have a traditional way of examining data in the library.

Regarding the collection of user activity data, we can say that we are still in the traditional higher education library environment where the most critical data collected is about circulation, bibliometrics analysis, interlibrary loan requests, and copying or scanning on demand.

When asked about sending data for internal institutional use or for external sharing of data the majority of librarians stated they still uses statistics as a primary tool of proving their value. We can presume that the statistical reports were generated at the basic descriptive statistics level (keeping in mind the type of user activity data they collect, e.g., name and surname, e-mail). A possible explanation for these results may be the lack of visibility of libraries and librarians at the institutions (e.g., Q8 “to prove library value at the institution”). However, it is hard to prove academic library value (and visibility) to the institution, if the librarians still manually track data, if they are not familiar with the potential of the specific data sources or its segments, and if there is a lack of assessment culture in the library. It is visible that the librarians are confusing information about user data (personal data) with user data activity in the library. In question, Q11 it is visible that they do not recognize functionalities of the systems at the institutional or national level. The other potential reason problem could be in the lack of professional librarians in the libraries, or the lack of infrastructural support, and even financial support. Besides the above-stated problems in detecting and assessing data, only a small number of librarians are informed about data protection and the way we need to handle collected data.

Education activities of the librarians in the formal environment are almost at the bare minimum. The problem can be detected in the low inclusion of librarians into formal education (course or modules on information

literacy). With the inclusion of librarians in the educational activity, they will be aware of the potential of user activity data and even find new variables to correlate with other educational activities at the institutional level. Besides the formal education activity, the informal education activity was mentioned because the author wanted to know is there any interest among librarians to share user activity data from the educational activities, e.g., courses, workshops or instructions of information literacy. Similar to the data gathering, physical space is dominantly represented in the informal education environment of the workshops that are held by the librarians. The virtual environment, and respectively, data collecting of user activity in those kinds of informal environments are still not represented.

The previous sections of the survey support the relevance of the answers in the last fourth section. Lack of basic knowledge resulted in some misleading answers in the LA section. The answers from Q32-Q34 are the most apparent findings to emerge from this study. Only one response was consistent with the LA practice (the first answer in all questions). One of the misleading responses from the survey was when the respondents needed to describe and specify how the user data activity is included in the intuitional learning analysis system, they stated that (Q34): "we send our data into the institutions quality system" and "through survey methods", which means that they are talking about assessment segment, not analytics. In this part, we can see that there is a common misconception about terminology regarding assessment analytics. Library assessment can help libraries to see, improve, communicate and demonstrate data by facilitating the data to data-informed decision-making process, also to identify trends, recommend changes, and demonstrate the library value to the institutions, and beyond that. As Oakleaf [12] states: library assessment that does not lead to a decision, actions, and communications with stakeholders is not worth doing. Librarians must take ownership of the decision-making process concerning what library data is used to support student learning and success.

If we compare answers with the LA segment, then we can see that the librarians are not aware of the difference between learning and academic analytics.

V. CONLUSION

The practices and thoughts among the librarians in higher education institutions in Croatia about data in the library, educational practice and learning analytics have not been analyzed prior to this research. The survey focused on finding out the level of knowledge, preparedness and actual usage of LA in libraries and parent institutions. Currently, we are not ready for it, and our environment is not ready for it. For the better involvement of library, and data, librarians need to know the potential data and how we can channel them as the indicator(s) in the collaborating system such as learning analytics. There are still disputes whether we are talking about "library analytics" or "library assessment" and where is learning analytics situated among other assessment approaches – even in the literature. To be ready, as librarians, we need to be: more engaged in educational activities, to be the data-informed library community and to promote assessment culture not only to prove the library value but to use analytics as a supplement for constantly tracking and adapting to the new situations. We need to know the nature of user activity data, and only then we can be ready for the inclusion of library data in LA. As librarians, we do not need to stop when we find the "right compulsory" data. Library data and the library user activity data can help manage the activities, services, sources (whatever data we can gather) – but alone they cannot tell us anything about student learning. Local view and local data usage specific for the libraries will be most relevant and exceptional in higher education. As this topic is new, now is the moment for the librarians to explore what data can be useful, what activities can we include/correlate with library user activity data and LA. The crucial segment of being up to date with novelties in higher education librarianship is lifelong learning and positive and motivating examples from practice. However, for the future, we need to be careful that all collected and analyzed data do not become just another part of (l)earning analytics.

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Teaching for virtual work

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Abstract **– Universities are still mainly preparing students for the world, where 'do something useful', i.e. 'do something with your hands' was the main principle and work was done during strictly regulated time. But world has changed and traditional areas of human activity (what also are the main target in University courses) are rapidly diminishing. More important have become virtual products - computer programs, mobile apps, social networks, new types of digital currencies, IOT (voice in your bathroom suggesting to buy the next model of Alexa), video games, interactive TV, virtual reality etc. Most of these new areas are not present in current curricula and there are problems with involving them in curricula - (working) students know (some aspects of) these areas better than many of university teachers, since corresponding knowledge is not yet present in textbooks – it is present only on Internet. The Internet strongly influences both what we teach and how we teach.**

I. Introduction

Nicholas Negroponte, founder and Chairman Emeritus of the Massachusetts Institute of Technology's Media Lab noticed already in 1995 that humanity is 'moving from a world of atoms to the world of bits' and replacing 'manipulating atoms with manipulating bits' – virtual things [1]. Manipulating atoms, physical things is left for automata and robots, we only create programs which rule these automata and robots.

Our values, the GDP (Gross Domestic Product, the measure of new values) produced in the whole world use less and less input from our natural environment, raw sources of nature - agriculture is producing only 5%, construction – 10%, manufacturing 15% of all values of the GDP produced in the World [2] and all these numbers are decreasing. The remaining 70% of GDP are produced inside human society itself, using as input data, generated also in human society – 2.5 quintillion bytes per day in 2017 [3].

The technology of production of new values – work – has also substantially changed. Work is not any more an activity, what we perform on defined times ('work hours') on defined location – workplace. More and more peoples work (sometimes not even recognizing this) all around the clock using laptops, mobile phones, tablets. Results of this work – information - goes to Negriponte's 'word of bits' and constantly accumulates there; information grows [4].

The 'world of bits' and its gods - Google, Facebook, Microsoft, Alibaba, Amazon – have become an essential part of our lives and their role is constantly increasing.

The irreversible move/encoding all our human environment into 'world of bits' has made this virtual world a very mighty power. Google, Facebook, Amazon know about us more and more and we do not even know, what all they know about us – it takes some (new) Snowden revelations to get even a glimpse of richness of all information stored about us in Google, Facebook, Amazon, Microsoft. And this 'Almighty God in Internet Clouds' does not forget anything; quite the opposite – every data item about us gets constantly distributed/sold.

Many teachers still think: "We teach. We present courses. A course is an interaction of teacher with students" – there is no or very little place for Internet in their teaching activities. Very wrong.

Here are considered some aspects of Internet influence in university teaching of IT specialty students. In the next chapter are considered economic reasons which create for many students need to work and become active self-learners using sources from Internet; then – the current rather confusing state of Internet and reasons for this; after that – more specifically state of JavaScript – the most important tool for designing web-based commerce and content delivery services and finally some techniques in course design and delivery which have been used and have been useful in practice.

II. Work and income

We (teachers) are just a part (diminishing) of all interactions what students constantly get. Students who do have not (very) rich parents have to work, since ability of their parents to support their studies in university is increasing. The percentage of money returned from production process as wages is diminishing [5] and returns from capital are increasing, since the production is increasingly using more effective technologies.

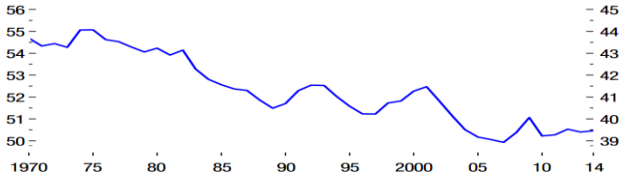

Figure 1. The labor share of income (wages) from production in economically advanced countries (% on left) and developing countries (on right) [5]

As a result the average income of working families have stayed flat or are falling [6]; the centuries-long dream 'our children will have better life' is not true anymore.

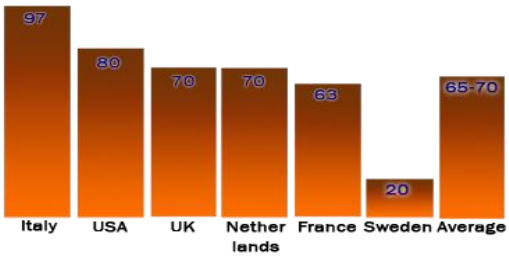

Figure 2. Percentage of population with flat or falling incomes in 25 advanced countries, 2005− 2014 [6]

Decrease of human labor share in production with increase of all kind of automata and robots is constantly eliminating professions. Universities with their slowly changing curricula develop skills, what are not corresponding to the skills needed by enterprises, thus their degrees do not a guarantee a getting a job or better salary. Constant pressure to increase the output (number of degrees/year) has gradually lowered the quality of those degrees [7]. At the same time number of alternative, free or low-cost learning opportunities is growing.

All this has decreased the value of higher education and researches claim, that our faith in the value of university education is not based on facts. Bryan Caplan, professor of economics at George Mason University (ranked as one of the highest research institutions in USA [8], the faculty have twice won the Nobel Memorial Prize in Economics) claims in his recent book "The Case against Education Why the Education System Is a Waste of Time and Money" [9], that education is grossly overrated, government should sharply cut education funding to curb this wasteful rat race and wasting public funds on education should be stopped. He is not alone, in USA percentage of confidents in higher education has dropped from 57% in 2015 to 48% in 2018 [10]. They may be right, e.g. when all your money-handling happens by clicking on screen or (diminishing) tapping your cards security codes, then why should you know how much is 2×2 ? If you really have to (diminishing probability), then take your mobile phone and ask the mighty source of all knowledge - Google. Information is constantly concentrating into greater and greater lumps [4] which all claim, that lower-level entities do not need to know all.

All these trends have supported increase of participation of students in work especially in specialties, which drive economy most - Science, Technology, Engineering and Mathematics (STEM), especially among students in Information-Communication Technology (ICT, IT) specialties [11]. From the survey made among EU students in 2018 [12] appears, that an average Estonian student works more than 30 hours per week; 48% explain this with economic reasons, but 72% claim that they need experience of work life (they want to learn); IT students (full) employment is over 80%.

Working IT-specialty students are active self-learners. From the Developer Survey [13] made at the end of 2018 by one of the most professional and popular IT sites 'StackOverflow' (over 80% of respondents rely on Stack Overflow Q&A when learning something) appears that three-fourths of professional developers have a bachelor's degree or higher, but almost 90% of developers stated, that they taught yourself a new language, framework or tool outside their formal education. New technologies/ideas in IT appear in much quicker temp than what it is in universities curricula.

A self-learning (working) student is not any more a 'tabula rasa' – a 'white paper' where teacher knows (or believes to know) what to teach. Working IT-specialty students have often deeply rooted habits and believes concerning IT technologies and their knowledge in some areas is superior to teachers. Adjusting university education with their previous knowledge is a problem [14] and with large part of their time devoted to work they have less time and interest for university. The professional knowledge they get from workplace and from Internet.

III. INTERNET

Learning has (the same way as work) become an all-time activity and with current Internet penetration and tools (mobile phones, tablets) this has become possible nearly everywhere (Internet is 'always on'), thus also more and more students are exercising learning nearly everywhere – at bus-stop, in bus, in a coffee-house, waiting for a girl/boy-friend etc.

Internet is not anymore the 'pure source of information' what it was intended when created. A growing part of Internet is driven by mighty force – "Make More MONEY!".

The first and simplest resource of money-making from www-page visitors is the Google AdWords – create account with Google, get some adds from Google, place them on your page/site and from every click on those you earn something – and (most important) Google as the broker earns also. Everyone wants to maximize the number of clicks and this has created a whole new 'Internet Science' – the Search Engine Optimization (SEO) [15] - how to move your page up in Google search results to have more potential clickers. From the first primitive technologies (add long list of keywords and build links to your site/pages in order to show it more significant) has emerged a new dark science employing multimedia (sound/video), entertainment (ea. images/videos, games on site) psychology (links to the social media, 'like'-s, 'Share', 'Follow') [16] have emerged businesses for selling clicks, from primitive click-farms [17] to modern services selling 'like'-s, followers and views [18]; e.g. for $35 you can buy for your site 25000 unique visitors from 60+ countries [19]. Every click has a value, it increases the rank of the site in Google search results – and this increases possibilities for more money. To achieve the ultimate target – make site visitor a paying customer – sites try to keep visitor's attention with content - distributing news items copied/steeled from other sites or simply creating 'fake news' using the latest AI (Artificial Intelligence), which can create stories which are undistinguishable from what humans can create (and not only in English) [20]; the open source program is already dangerous – it can be used e.g. for massive spam attacks, thus authors removed the most advanced version [21].

Current state of Internet resembles from history the era of conquerors - Genghis-Khan, Timur, Europeans establishing colonies etc, who rushed wherever they could

to conquer new lands and raw materials – gold, spices. Modern global companies are seeking modern raw material – data. The parallel with history creates question – will the current conquerors area in Internet end the same way – nations/countries rise to defend their territory, their data? Something along the way is already happening – the proposed EU Copyright Reform which may introduce upload filters and force new forms of copyright and data mining will substantially influence the use of internet. The already introduced rules (e.g. each cite asks for permission to store cookies) are only annoying and mostly nonsense – just answer 'No' or (if this answer is hidden in deep hierarchy of clicks) click in browser's menu 'Clear History' – all these cookies are also history, thus the current (mild) regulations do not work. Russia and some major internet providers are planning to test disconnecting the country from the internet [22]; China and several other countries have restricted Internet for years [23].

A site is interesting only if it has interesting content, thus many sites (Facebook, Google etc.) allow and expect users to add new content (blogs, comments), content is steeled (you may find from Google search the same text from several sites and often it is impossible to say, who was the original author). Internet dilutes information, it acts like the Second Law of thermodynamics.

We need constantly new information. On Internet stories are repeated and often slightly altered (to hide the original source), so that the 50th alteration may already look very different and be quite far from truth. But it is usually impossible to check, thus more and more people believe whatever. And even notice somewhere on www-page "Nothing On This Page Is Real" does not stop hundreds of people believe and create new, even more crazy stories [24]. President Trump stated in his book "The Art of the Deal" [25]: "People want to believe something is the biggest and the greatest and the most spectacular." Trump calls this kind of statements "little hyperbole" and "a very effective form of promotion" which "never hurts", but in Internet practices these "little hyperboles" are often total lies, but many people believe. Humans need new information, but Internet seems to destroy in many internet users the critical thinking ability what with profusion of content on Internet is extremely required. Humans have built-in need to get new information and for many the Internet has become the main source for satisfying this need. Neuroscientists claim that about 85% of humans are conformists, they 'go with flow' [26], [27]. The non-conformists become isolated, already Nikola Tesla noticed: "Anti-social behavior is a trait of intelligence in the world full of conformists".

Thus beliefs and opinions of growing number of people are driven by Pavlovian response to social media "like"-s. This concerns not only everyday stories, but also texts which are seemingly educational or (half) scientific [28], [29]. Because of openness of Internet many of those problems get corrected, e.g. problems with some articles in Wikipedia [30] have been afterwards several times and by several authors corrected [31], [32], but with many self-appointed specialists e.g. in programming technologies this is not so, the impact of diluted/fake information is quite strong also in sites concerned with science and technology, especially with programming technology, where new methods/protocols/tools are distributed just on WWW.

IV. Science on Internet

Every university teacher knows the universal pressure: 'publish or perish' university teachers are expected regularly publish articles in your specialty journals or (at least) conference papers. In most countries assessment of university teachers and researchers is based on Hirsch h-index [33], which should show your impact in humanity's development. But this is also a commercial product, thus - buyable [34].

Sometimes you do not have enough time for preparing an article or you simply do not have anything (new) to say – everything has been already said. But you still have to produce something, even if the quality of what you produce is not high. Thus there have appeared 'scientific publishers', who take your text to be published in an 'international web-journal' using 'rigid peer review' for a rather low fee from author (amount depends on author's country); the paper 'will be reviewed within 5-7 days' but publishing is promised already after 2 days; the published papers are mostly total garbage.

Number of 'scientific' conferences is growing in exponential rate. For instance, only one organizer announces for every month in 2019 that in Tallinn will be held 9—11 conferences, e.g. in March 2019 – nine conferences (but there are also many other organizers):

14th IASTEM - 569th International Conference on Social Science and Humanities (ICSSH) - Tallinn , Estonia

14th IASTEM - 569th International Conference on Medical, Biological and Pharmaceutical Sciences (ICMBPS) - Tallinn , Estonia

14th IASTEM- 570th International Conference on Environment and Natural Science (ICENS) - Tallinn , Estonia

14th IASTEM - 510th International Conference on Control, Automation, Robotics and Vision Engineering(ICCARVE) - Tallinn , Estonia

14th IASTEM - 569th International Conference on Science Technology and Management (ICSTM) - Tallinn , Estonia

14th IASTEM - 567th International Conference on Recent Advances in Engineering and Technology (ICRAET) - Tallinn , Estonia

14th IASTEM- 567th International Conference on Mechanical and Aerospace Engineering (ICMAE) - Tallinn , Estonia

14th IASTEM - 566th International Conference on Economics and Business Management (ICEBM) - Tallinn , Estonia

14th IASTEM - 567th International Conference on Civil and Architectural Engineering (ICCAE) - Tallinn , Estonia

Conference proceedings from the same organizer have extremely efficient publisher, e.g. the 5 papers in a conference held on Dec 28, 2018 have already all together 100 citations [35] – the h-index of authors grow rapidly.

Number of 'scientific on-line journals', 'wikis', blogs etc. is growing and it is very difficult for students (often also for teachers) to understand what is information, what just company advertisement and what – 'fake news', created with hope to get some traffic to web-site or, simply to satisfy authors need for self-importance.

The intellectual quality of many www-pages is (very) low. It is impossible to argue with claims: "is a self-

evidently poor choice", "is great" etc. [36], but most of assessments of programming technologies are made using such totally subjective claims which do not provide any supporting facts.

V. Jobs in Internet Era

Nowadays many students are not certain in their selected profession – old professions vanish constantly and sometimes very quickly. Even PhD diploma can not secure job; a PhD student confessed that job recruiter suggested to remove the notion of PhD diploma from his resume – this would make getting a job easier.

To have a glimpse – what is (currently) important, promising (good-playing) jobs, we checked some open work positions around the EU on Feb 2, 2019.

The IT-specific jobs in EU area [37] show several areas with growing demand:

security – 615326 offerings (e.g. for databases – only 572910); world's largest IT security organization The International Information System Security Certification Consortium (ISC)² states in their reacent study that worldwide need for cybersecurity professionals is close to 3 million [38];

entertainment: games – 526926, video – 518475, graphics – 515216, Virtual Reality - 510019 open positions;

AI - 508031; usually AI is considered for data analyses, but digital media specialists believe that the next big thing in interactive media is AI storytelling [39].

Students follow this kind of sites constantly, but advertisements for available jobs are for them only one source of interesting and important information what they follow to shape their live. The types of interesting and profitable jobs appear/disappear in IT rapidly.

An example: rapid changes in structure of Finnish economy is well seen from the last year's published personal income tax reports. The 'classical' powerhouses of Finnish economy are paper and metallurgy, but in the 2017 five from the top ten Finns with highest income tax were from the mobile game company Supercell, the company manager's personal income tax was 28 million € [40].

Games are the new literature of the 'Internet generation'. Authors of modern games use all the richness of book-era theoretical research up to Kant's theory of the sublime [41] in order to overwhelm players, create the full palette of human emotions from fear to ecstasy [42]. Arousing our emotions is the highest target of all arts what games are also approaching. The same target has been set by interactive streaming video, where users can decide in TV show, what happens next [43]. Augmented Reality (AR) and Virtual Reality (VR) market is expected to grow in five years 2017-2022 ten times [44] and number of users is doubling yearly. We all will get our emotions from virtual world.

The gaming (VR/AR/...) industry is huge, growing rapidly and together with constantly increasing bandwidth (bits/sec moving in your home Internet connection) provides many new ways for people to enjoy in home their favorite games.

Virtual world is already an essential part of younger generation and this shows not only from constant peeking of mobile phones. Many young people (students) make living playing computer games (in competitions), producing YouTube videos or publishing on social networks. Prize pools in video game tournaments exceeded 25 million USD in 2017 [45]. Best players have earned over $4,000,000 prize money; e.g. a 28 years old Estonian gamer has won from 106 tournaments total prize money $2,103,245.83 [46].

The International Olympic Committee (IOC) declared in 2017 that eSport (competitive video gaming) could be considered a sporting activity; in Singapore was launched eSport Academy; eSport market is growing 40% yearly, has multimillion-dollar prizes and international audiences, streaming game sites (Twitch [47]) have more viewers than CNN, Netflix and NBA finals.

Until the current Internet Era, skills and following incomes were part of one continuing person's development process – that's why we have schools and universities. These new possibilities 'to become rich quickly' clearly disrupt this tradition. Should these new skills be thought in universities and if, then who will teach them?

VI. Education in Internet Era

Connectedness and 'Information available at your fingertips' have changed the main premises of education. According to research, 35% of currently skills demanded for jobs across industries will change in 2-3 years and many of them will be obsolete in 5 years [48]. The average time in a single job is 4.2 years (in education, training, and library occupations - 5.1 years) [49], after that anyone should be ready for changes and re-learning, thus ability to learn constantly is the most important personal feature for success in our rapidly changing modern age.

It is difficult to give any receipt for developing learning ability – we usually assume, that this exists in everyone. However, there are some new approaches tried out for producing new IT professionals.

According to Douglas Adams, the "Answer to the Ultimate Question of Life, the Universe, and Everything", is the integer 42; the answer was calculated by an enormous supercomputer named Deep Thought over a period of 7.5 million years [50]. In the tuition-free computer programming school (Ecole) 42 which was opened in Paris in 2013 the main objective is not (only) in developing students technical competence, but developing students ability to solve and resolve problems, to collaborate, to learn and be able to inspect owns learning, self-teach, to be creative, to be critical thinkers [51] – the same targets which were stated in the EU framework for Education and Training [52].

The school 42 accepts students of any gender, religion, race, color and national or ethnic origin and provides to every student all the rights, privileges, programs and activities generally accorded or made available to

students. There are no regular classes, the learning room with networked computers is open 24/7. The school has campuses in Paris, in Silicon Valley and the model has been used also in Romania, South Africa, Ukraine, Bulgaria, Moldova, Belgium, Russia, Morocco, Netherlands and the Finnish game company Supercell announced that similar higher education level code school will start in 2019 also in Helsinki [53].

The school 42 is based on idea that the overwhelmingly important skill for future is programming (stressed everywhere) and the knowledge can no longer be transmitted in the classical teacher-student format, knowledge spreads in society and learning depends first of all from learner himself. Thus there are no teachers, students have to learn themselves, be resourceful and figure out how and what to learn. And since there are no teachers and traditional exams, grading is done by peer students and this is tougher than the traditional grading.

VII. PROBLEMS WITH SELF-LEARNING

The self-learning idea used in school 42 is quite similar to what working students (especially in new start-up enterprises) and also many other specialists (e.g. researchers and university teachers, who want to be aware of new developments in their field) use constantly. Since the school 42 is still rather new there aren't yet any solid data about the actual value of their method, but stressing in education only programming skills arouses suspicions on student's 'human' skills – communication, language – there are already many 'computer specialists' who can not express themselves in fluent written message (e.g. for asking pay-rise) in human languages.

The main difference of the school 42 method compared with self-learning working students seems to be in accenting the collaborative work –for all students there is one big classroom where students are supposed to interact and communicate.

But Internet has already changed the communication practices of 'digital natives' – many of them are not able to have a normal conversation or interacting with people in person [54], [55]. The first authors experience from his course on autumn term 2018 is similar – students do not communicate, they may sit hours next to each other and do not exchange a single word thus the advantages of this new form of education are not obvious. Experience got from teaching working students [14] show, that 'in wildness of Internet' appear 'fake news' also e.g. in propagating programming methods (just like in any other field) and without teacher's guidance this may cause not very good results and later re-learning, i.e. waste of learners time, as seen from the first author's experience in the course in browser game programming.

VIII. OUR EXPERIENCE

The main topic of the course are browser games using JavaScript together with advanced browser-programming technologies: 3D, sound and video in browsers, shaders and preparing games for mobile phones and tablets.

Browser is definitely the ultimate program in digital communication – if something visual appears on screen, then it is sent to you using the Internet communication protocol (IP) and rendered by a browser engine; most of the fixed-function apps in mobile phones also use browser rendering engines and Internet communication (in app the network side is striped – you can't switch to another site.) When Tim Berners-Lee created the World Wide Web (WWW) in 1989, the main idea was to enable scientists to exchange texts with their results. The WWW-documents were seen as pure ASCII text with minimal formatting based on the HTML format. Possibility to add images appeared only after several years, but even now the basis of a web-page and anything, what appears in browser, is HTML-formatted text which is denoted by its address, the URL (Unique Resource Locator). When user opens a web page (sends request with the pages URL), server responds with HTML-formatted text document – the web-page's text corresponding to URL. Server interprets this text and if the text contains links to images, videos, sounds etc. then browser sends new requests – a separate one for every image, video, sound. Browser can start page rendering – calculations where on screen should be displayed everything - only after he has received from server all page's components. On network it is impossible to say beforehand, when this happens. Thus to speed up page loading currently many www-documents consist of only one page (new information is displayed when you scroll downwards) and use one big image instead of many small ones – for every component is needed a new request.

The first HTML protocol did not have (except links) interactive elements. For interactivity was invented a new programming language – JavaScript, which was meant to be executed in users computer and therefore (for safety) very restricted, e.g. JavaScript did not have any access to user's hard disk (currently it has strongly limited access). The language was designed to be used also by no-programmers, thus it lacks many common features of typical programming languages (e.g. strong typing, modules, encapsulation etc.). But JavaScript is the only programming language for browsers and with human communication becoming more and more browser-based already in 2007 was stated a law: "any application that can be written in JavaScript, will eventually be written in JavaScript" [56].

Currently JavaScript is the main (only) front end, i.e. User Interface (UI) development tool. It is almost impossible to do something in modern web development without JavaScript – all interactivity is created with JavaScript.

The main activity on WWW comes from the 'big players' – Google, Facebook, Microsoft. Their web pages are quite complex with several frames, where user can enter data and connections with databases, where this data is stored. These 'big players' produce many web applications, but these pages are all repeating the same pattern, i.e. their programmers repeatedly produce many pages which are all similar, built from one model.

The 'big players' are also the biggest work providers in web programming, i.e. producing most www-pages/sites.

There are (on Jan 9, 2018) 218 Web browsers [57] – all with their differences/peculiarities. The major browsers

(Firefox, Google Chrome, Microsoft Edge – soon to be replaced with open-source Chromium) have their own JavaScript interpreters also with some differences; the JavaScript interpreters for browsers in mobile phones and tablets are also different.

In order to leverage JavaScript development for Microsoft browsers (Internet Explorer up to ver. 10), which did not follow web standards and were in many ways technologically outdated was introduced the jQuery library. Currently Microsoft browsers are already (somewhat) law-obedient thus jQuery is not any more needed [58] and its use is dropping rapidly:



Figure 3. Use of jQuery in recent years (%, Google trends)

But jQuery is still growing like a cancer – the current version is already > 266 KB (for comparison – there is a competition for browser games < 13 KB [59] – some even 3D).

In order to automate mass production of web pages having similar format have the main players – Facebook, Google, Microsoft - introduced their own JavaScript packages and frameworks, which should speed up mass-production of pages and create pages which would appear on higher positions in search engine's (Google) results - SEO [60], thus Google is already determining the Internet programming technology. These packages and frameworks - Angular, React, Vue, Node etc turn on its head the original intension of Javascript – to be used as a lightweight simple tool for adding interactivity to web pages. These packages allow to create a web server and also allow to create the whole page as a Javascript text on server – thus it is easier to read for Google's crawlers. But this kind of use contradicts with long-time practice of browsers not to display any mistakes in order to make user's interaction with the page smooth and fluid. Any serious programmer would not use a programming environment where mistakes simply disappear.

But UI (User Interface) programming is the base of all web sites, thus one of the most popular jobs and students learn this since without knowledge of this it is rather difficult to apply for a job. Thus many of self-thought students consider these libraries as the whole JavaScript.

These libraries were developed for mass production of WWW documents with similar structure, thus they all use 'top-down' development methodology – first load some (currently popular) libraries, then step-wise elaborate. Repeated use of this methodology becomes also a thinking pattern.

Most programming tasks are different, e.g. the task in the game-programming course – to program your own game, where the 'load libraries' thinking pattern does not work anymore. For students were several step-by step tutorials with ended with working code (the tutorials were 'pure' JavaScript, no libraries). As the main development guideline was repeatedly stressed need to use minimal number of requests to server (basically only for a spritesheet and soundclips), but it is difficult to break deeply rooted habits. Every year there have been some students who claim: ' in order to keep my mind I used all modern features...' – and fails to program a simple game. At their workplace they may be titled 'software specialist', but they cannot program – they can only load libraries. They have mastered tools, but not programming. Educational sources in Internet also teach tools rather than programming.

A browser game of one of participants using 'modern features' initiated 39 requests to server for loading modules – actually none were needed. His code contained total nonsense, definitions which were not used or objects, which were not defined, collision check of object with itself etc., there were described several levels with exactly the same functionality, difference was only in some object's shapes and colors, but author could (in second attempt) make only the first level working.

JavaScript seems to be the worst example of massively produced 'fake news' on WWW, and Node.js is the worst example of this. It is growing rapidly – every day are added 455 new modules [61], the total is now 800000 [62], but it seems that nobody checks the quality - you may upload 24252 useless lines of JavaScript [63] using for the same file two different names and get your name in the list of 2319 authors [64].

The Node.js is compared to mass psychosis [65]. It is (can be) highly inefficient – e.g. for three trivial functions `stripIndents`, `stripIndent`, `oneLine` (names are quite descriptive) are used 1826 files [66].

The Node.js library is created by developers free uploads, but it is practically impossible to restrict access or correct errors without paying - the website states "If you want to restrict access and visibility for a public package you own, you can make the package private", but before that "Making a package private requires a paid user account or Org" [67].

Its popularity is already declining, since many developers have (re-)discovered value of pure JavaScript [68]. :



Figure 4. Popularity of node.js (%, Google trends)

IX. CHANGING TEACHING METHODS

The game programming course has had very inhomogeneous audience. The course is intended for second year students of software science specialty, but in every year there have been participants with very different background and preliminary skills: some have already published their games (also commercially, for money), some come from other specialties (e.g. mechatronics) seeking a second profession or simply from curiosity. Because of very different preliminary knowledge of students the classical 'stand-and-deliver' model of teaching does not work and instead of 'direct teaching' students

were provided an opportunity to learn from specially prepared tutorials.

The 'lectures-practicums' format was changed into one continuous 195 min session in computer class, where every participant was working alone with his/her networked computer (many students used their own laptops). The whole course consisted of series of practical hand-on tasks – participants had to implement an example game using code explanations provided in tutorial; for more advanced students tutorials had also further tasks/exercises. At the start (and when needed) are given some oral guidance, most of the time students implement the task using presented www-tutorial and help from www (googling) – nowadays students prefer googling to asking from a neighbor student or teacher.

Universities are increasingly trying to align with economy inviting representatives from business enterprises to give talks before students telling their experiences and needs - what kind of skills do they expect from graduates – e.g. for the spring semester 2019 are planned for students more than ten talks from representatives of Estonian enterprises; the Estonia's biggest telecommunication company Telia has organized for the teaching staff and PhD students a 40-hours course to acquaintance them with company's current technological practice and future directions; in the first author's game-programming course have given talks several participants of this course from earlier years who now have become successful game designers/produces.

University teacher's possibilities to change some practices of commercial enterprises are not very essential. But methods used in commercial enterprises are often influenced by not-so-sapient factors, i.e. desire to flatter Google in order to improve SEO or blindly follow general trends – 'everyone is using THIS, we should also'. The best method to fight these tendencies is to use student's common sense and creativity.

Many researches point for need to focus more on student's creativity and imagination instead of trying to teach skills. Martha Nussbaum, philosopher and the Distinguished Service Professor of Law and Ethics at the University of Chicago states [69] that in an increasingly uncertain world, it has never been more important for universities to "educate the imagination" rather than impart specific skills.

Imagination and critical thinking can be developed in conversation. The best moments were when some questions ignite a general discussion in the class, where students freely express their opinions and improve their critical thinking skills – the prejudices ('everyone does so!') are often shown mistaken already by fellow students without the need for interruption from teacher. And they may even accept some trivial truths – e.g. that the thicker the layer of (unknown/strange) modules (e.g. Node) the more difficult it is to get helpful error messages and even the most 'hard-boiled' users of the 'request' (command to load a module) may (half-)accept that with growing number of outside modules grows also the danger that something goes wrong because of changes in these modules – as it happened when just one developer broke several popular JavaScript libraries (Node, Babel) and thousands of projects just with 11 lines of JavaScript [70].

X. Conclusions

The 'World of Bits' – Internet – has become an essential part of our lives. Especially noticeable is its influence on youth – our students. We all need information, students seek it actively and Internet is the greatest channel of information. But it differs from the classical distributors of news – it is focused on distribution and does not want to be responsible for the value of information what it distributes – it makes money on distribution, this allows to earn adding adverts to content. Mark Zuckerberg, creator of Facebook claimed before US Congress, that Facebook isn't a media company even though it hosts and produces content [71]. Traditional media companies - television, print and other media types have to follow strict regulations that make them responsible for the quality and truthfulness of their product. The textbooks what we use in teaching, their authors and publishers are also responsible for quality of their content. But it is nearly impossible to control quality and truthfulness of YouTube, where in every minute are uploaded 300 hours of video [72]; however, some students consider YouTube a useful source. Similar irresponsibility applies to many other Internet sources.

There are many very useful sources of knowledge on Internet, what we can and should use in teaching. But together with using this rich 'World of Bits' we also have to develop the critical thinking skills of our students so that they could themselves decide value of the 300 hours of new YouTube videos or 800000 Node.js packages.

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A ″Fingerbeeper″ School Monitoring Device

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***Abstract* – One of the European key competences is entrepreneurship. The focus of entrepreneurship education is on teaching practices that aim to create and enhance students' capacity to act responsibly, to be active, creative and able to seize opportunities, to assess and take controlled risks, and to plan and manage projects of suitable size. In the Slovenian national project, 'Po kreativni poti do znanja' (translated roughly 'Creative career leading to knowledge'), students deployed all elements of entrepreneurship. Even more, they combined (i) electrical engineering and (i)) digital competence with entrepreneurship, thereby enriching their competences. During the project, the students developed and manufactured a finger pulse plethysmograph measuring device called the 'Fingerbeeper' which can detect and display the heart rate. The main advantages of the device are as follows: its simplicity of use suits it for (lower) secondary school; output of the device is straightforward to interpret by users as well as teachers; and perhaps most importantly, it has low production and maintenance costs. These make the 'Fingerbeeper' device superior to other heart rate sensors on the market. The students were challenged by failures during development and production; however, with persistence and creativity, they reached their final goal of a working product suitable for several school levels. In this paper, the properties, advantages and disadvantages of the 'Fingerbeeper' device will be presented.**

Keywords - Computers, Digital Competence, Entrepreneurship, Heart Rate, Pulse Plethysmography

I. INTRODUCTION

The European Parliament and the Council published a Recommendation on Key Competences for Lifelong Learning as "a combination of knowledge, skills and attitudes appropriate to the context" [1]. In the recent decade, European societies and economies have experienced significant changes, digital and technological innovations as well as labour market and demographic changes. The EU Parliament found that competence needs are not static; they change throughout lives and across generations [2], although revision of the first framework of key competences, digital competence and entrepreneurship remains within the framework of key competences [3]. According to the latest revision of the EU key competences, the interest of education systems (different levels of education) should involve management to identify the numerous opportunities and gaps that exist in promoting entrepreneurship as a key competence.

Slovenia follows EU recommendations, so in the national project, 'Po kreativni poti do znanja' (translated roughly 'Creative career leading to knowledge'), students of several faculties within the University of Maribor employed several elements of entrepreneurship: students were active and creative; they were able to seize opportunities, to assess and take controlled risks, they planned and managed project of suitable size. Even more, they combined (i) electrical engineering and (ii) digital competence with entrepreneurship, thereby enriching their competences. In the project, the students developed and manufactured a finger pulse plethysmograph measuring device called the 'Fingerbeeper' which can detect and display the heart rate.

Through the project, they developed a range of key competences, such as entrepreneurship and digital competence combined with knowledge of electrical engineering and the physiology of the human body. With reference to section II, Project Background, we would like to highlight which digital competences, entrepreneurship, and knowledge of electrical engineering and physiology of the human body were developed and used by the students for developing a new electronic heart rate device.

II. PROJECT BACKGROUND

A. Defining Digital Competence

Recently, many terms have been connected with digital competence, as synonyms, as part of it or as a supplement, like digital competence, digital literacy, media literacy, ICT literacy, 21st-century skills, digital skills, computer skills, or Internet skills [4]. A digitally competent person is someone who has several attributes: theoretical knowledge, practical skills and attitudes appropriate for ICT usage.

Development of the device called the ″Fingerbeeper″ in the Slovenian national project 'Po kreativni poti do znanja' required mixture of digital skills, along with the social and emotional aspects of using and understanding digital devices. Digital competence is grounded in basic ICT skills, i.e. the use of computers to retrieve, assess, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet [5]. In creating the 'Fingerbeeper', students combined digital competence with electrical engineering and entrepreneurship. According to DigComp 2.1 [6], students in this project developed competences in all five areas, (1. Information and data literacy; 2. Communication and collaboration; 3. Digital content creation; 4. Safety and 5. Problem solving), at different proficiency and cognitive levels.

B. Defining Entrepreneurship

The European Commission promotes entrepreneurship as an individual's ability to turn ideas into action. It includes creativity, innovation, risk taking, and the ability to plan and manage projects to achieve objectives. Over the last decade, most people have understood the definition of entrepreneurship as commercial entrepreneurship [2], which is just part of it. Introducing entrepreneurship education into different levels of formal education involves a large number of actors at different levels [7]. In higher education, the emphasis on economy and employment possibilities has worked rather well as justification for the introduction of entrepreneurial education [8]. Ten years later, it is hard to change people's view of the same concept. Nevertheless, all citizens should understand entrepreneurship in a wider context.

According to the EU framework [9], students in this project developed all elements of entrepreneurship:

1. Intention (students were proactive and actively pursued the goals),
2. Opportunity for search and discovery (students made an innovation),
3. Decision to exploit opportunity (students flexibly responded to challenges),

Exploitation of opportunity (students acted independently on their own initiative; solved problems/conflicts creatively; persuaded others and committed to making things happen – they created the 'Fingerbeeper' device.

C. The project idea

The cardiovascular system offers numerous possibilities for attractive experiments in the fields of basic science, biology, physics, physiology, internal medicine and many other areas at all levels of education [10]. For educational, research and clinical purposes, several different devices are needed to provide a reliable quantitative assessment of the main parameters of the cardiovascular system, such as heart rate, heart rate variability, blood oxygenation and arterial pressure. It is possible to measure all these parameters with a single device, but such devices are expensive and thus inaccessible to the general population and learning environments. The motivation for the project was to develop cheap and reliable devices to measure at least some of the parameters of the cardiovascular system (developing entrepreneurship: intention, and opportunity to pursue search and discovery). A pulse plethysmograph provides a few important parameters and thus seemed an appropriate device, and the target users were the public, teachers, students and investigators in the field of cardiovascular physiology. With the help of students and mentors, we developed a single device that can perform on three levels of complexity (developing entrepreneurship: Decision to exploit opportunity and Exploitation of opportunity; developing digital competences: Information and data literacy; Communication and collaboration; Digital content creation; Safety and Problem solving):

- For the least demanding users: the device allows automatic interpretation and storage (for lay people and kindergarten and elementary school),
- for more demanding users (secondary schools and higher education): the device operates independently or complementary with other commercial interfaces, providing instructions for carrying out exercises (for high schools and university faculties),
- for the most demanding users (researchers and clinical purpose): the device allows assessment of plethysmographic parameters and is not limited to heart rate and its variability (for researchers and clinical purposes).

D. Plethysmography and the "Fingerbeeper"

Pulse plethysmography is a non-invasive method that enables single-step measurement of several different parameters: heart rate, heart rate variability and oxygenation of the blood, as well as an estimate of arterial pressure, and of the elasticity of the vascular system [11]. Pulse plethysmography or the 'Fingerbeeper' (Fig. 1) is a PPG (photoplethysmography) sensor system.

It usually consists of a light source with red (600-750 nm) or infrared (850-1000 nm) LED, and a detector that detects the change in light absorption of the skin [12]. Light travelling through biological tissue is absorbed by various substances, including pigments in skin, bones, and arterial and venous blood. Most probably, the continuous part of the signal that one records using PPG is attributed to light absorption and fixed blood volume [13]. The pulsatile part of the signal is attributed to changes in blood volume during the cardiac cycle and is therefore the main substrate for heart rate and heart rate variability determination by the Fingerbeeper. Yet another feature of PPG is pulse oximetry, based on the varying absorption properties of deoxygenated and oxygenated hemoglobin. The Fingerbeeper was not designed to be used as an oximeter.



Figure 1. Fingerbeeper device using a green photodiode as a light source.

E. Plethysmograph

The photoplethysmographic waveform has two components: a pulsed component (AC) and a non-pulse component (DC). The AC component is synchronized with cardiac function and is associated with arterial

pulsation, while the DC component is associated with the absorption of light in the tissues and veins, and with diastolic arterial blood volume (Fig 2).

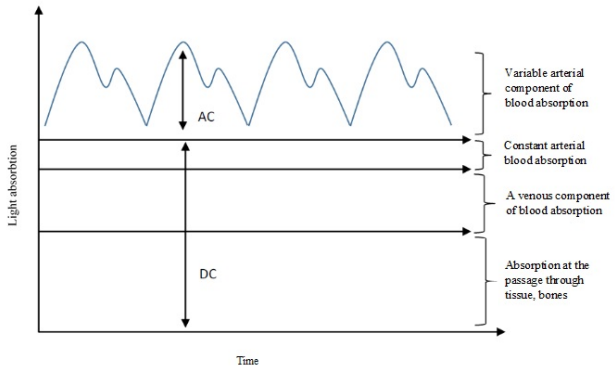

Figure 2. Absorption of light in various tissues. The AC component represents pulsation in the blood flow in arteries; the DC component represents thesignal when traveling through various tissues, including venous and arterial blood

The photoplethysmographic pulse component can be divided into two phases: the ascending phase of the pulse wave (anacrotic phase) and the descending phase of the pulse wave (catacrotic phase).

The first phase peak reflects primarily the systole, more specifically a forward-moving pressure wave transmitted from the heart to the finger [13] (Figure 3). The diastolic peak (Figure 3) is the consequence of a pressure wave transmitted from the heart to the lower body where it reflects, producing a reflected pressure wave from the lower body to the finger. The 'dicrotic node' or incision is seen on the diastolic part of the pulse wave in individuals with healthy, compliant arteries and may be lost in patients with a change in artery compliance such as arteriosclerosis [13] (Fig. 3).

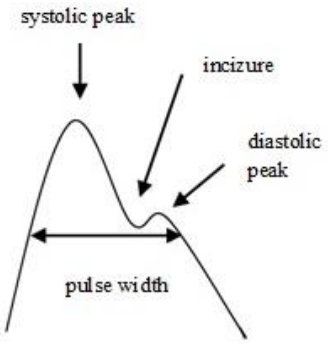

Figure 3. A typical form of a photoplethysmographic wave with characteristic incisura

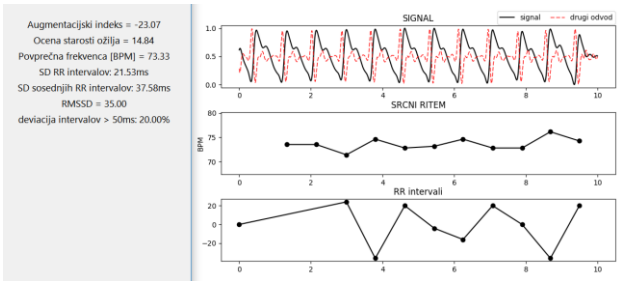

Figure 4. Fingerbeeper output for more demanding users

PPG offers more complex analysis, such as an augmentation index, which in included in the more complex version of the Fingerbeeper (Fig 4). The augmentation index is correlated with cardiovascular risk factors, e.g. arteriosclerosis [13].

Complex presentation results may not be appropriate for primary and lower secondary school; however, the Fingerbeeper does offer a simplified version that shows only the PPG waveform and heart rate (Fig. 5).

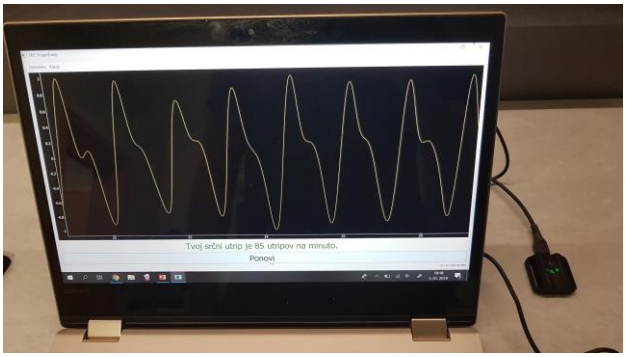

Figure 5. Fingerbeeper output for less-demanding users

III. CONLUSION

In the Slovenian project, 'Po kreativni poti do znanja' ('Creative career leading to knowledge'), eight students developed and manufactured this 'Fingerbeeper' device. The students came from different faculties and therefore had an excellent opportunity to combine distinct science areas (medicine, engineering, computing and education) on different cognitive levels. In order to achieve their final task, e.g. to create a low-cost device able to measure heart rate and heart rate variability, as well as some factors of arterial compliance, the students needed to cooperate with each other, teach their teammates their expertise, and apprehend different user needs. The 'Fingerbeeper' is a low-cost product with superior measurement features. It is suitable for wide use (education in primary, secondary school, higher education), and it does not exclude use beyond educational institutions (e.g. among athletes or patients). The measurement characteristics and accessibility to raw data ensure that the Fingerbeeper exceeds commercially available devices intended for educational use (e.g. Vernier, Biopac or mobile telephone applications).

In this project, students developed a range of key competences, including entrepreneurship and digital competence, combined with knowledge of electrical engineering and the physiology of the human body. This constitutes a good example of how to combine varied knowledge, to create a useful device and develop key competences. How different subgroups (pupils, teachers, students and researchers) appreciate the 'Fingerbeeper' and what are the opinions on the device's utility, can be left for future research. Whether students can develop yet another form of entrepreneurship in marketing the device commercially, will emerge in the future.

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Use of the system for authenticity verification at the Tourism and Communication Sciences of the University of Zadar

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Summary **- Development of information and communication technology and Internet gave education an additional incentive and opened new possibilities in education. Today the importance of education, improvement of the educational process and education as initial capital are increasingly highlighted, and the word combination "society of knowledge" is frequently mentioned. The Internet has made information more accessible, but it has also enabled unauthorized taking up and plagiarism of someone else's content, sometimes unintentionally, out of pure ignorance, and sometimes intentionally. It is therefore not surprising that today the discussion on academic integrity and safeguarding of academic integrity is increasing. In this endeavour, the academic world increasingly uses anti-plagiarism software, i.e. verification systems for authenticity of academic papers, as a means for dealing with non-academic actions. On the basis of a conducted survey the attitudes of students of undergraduate and graduate studies on the Tourism and Communication Sciences Section of the University of Zadar were analysed on the use of Turnitin system, the mode of approach, benefits and disadvantages of the system, self-evaluation of students on the contribution of Turnitin to the quality of academic papers, and thus education as a whole. The paper gives particular attention to understanding of the notion of academic integrity, quotation, paraphrasing and plagiarism. Method of descriptive statistics was used for presentation and interpretation of research results.**

Keywords: ***Turnitin, plagiarism, authenticity, verification***

I. INTRODUCTION

The development of the Internet and information and communication technology has influenced all segments of social development, including education, giving it additional incentive and opening up new opportunities in the educational process. At present time, education is, when viewed in a broader spectrum, a topic that is inexhaustible, so there is often talk about the importance of education, education as a core capital and the need to improve the education i.e. the educational process. Today, the highly used syntagma in the field of upbringing and education, the "knowledge society", according to the Oxford Dictionary, is defined as a society based on the acquisition, dissemination and use of information, especially by exploiting technological advances; a society with a knowledge economy [1]. In view of the changes that have occurred in the information and communication society, according to Miljković and Sitarica, education takes on new forms and new priorities emerge in the knowledge society: "the readiness of an individual to learn and improve himself throughout the whole life, choosing and acquiring of right information, applying acquired knowledge in new situations, developing curiosity, critical awareness, creativity, communication, independence, social skills and managing its own learning process"[2]. An individual realizes the mentioned priorities in the knowledge society today by using new information and communication technologies in the education process.

II. THEORETICAL BACKGROUND

The development of technology and the Internet, besides providing users with easier and faster access to information and the acquisition of new knowledge, opened up space and the possibility of unauthorized appropriation and use of the same. This problem is particularly relevant in the field of academic community where, unfortunately, there is frequent talk about violation of academic honesty and academic integrity. The notion of academic dishonesty is often associated with the notion of plagiarism. According to Rumboldt, violation of academic honesty occurs due to "inventing of non-existent or "adjustment" of obtained data in order to mislead the scientific community and deceitful presentation of own results, disclosing or presenting other person's texts or data as own (plagiarism, i.e. theft or robbery) for the purpose of acquiring false scientific reputation or academic advancement; and due to false authorship, i.e. adding persons who did not substantially contribute to the realization of a certain paper among the authors in order to achieve intellectual, social and often also material gain"[3].

Academic honesty in Croatia was discussed at the Round Table "Academic honesty" in 2013, which gathered experts who focused their work exactly on the research of academic honesty in Croatia. They discussed the situation related to unethical behaviour within the Croatian academic community and issued "recommendations for policy improvement of ethical behaviour in academic life and work" [4]. Among the many discussions that took

place at this round table, one of the last conclusions was that higher education institutions (universities) should have special expert services which would deal with academic honesty [5].

Numerous scientific and professional papers were written about plagiarism within the academic community in which the authors jointly state that plagiarism represents the destruction of academic honesty and integrity. Scientists from the field of medicine in Croatia have published numerous papers on the topic of plagiarism i.e. plagiary. Therefore, a group of authors Baždarić, Pupovac, Bilić-Zulle and Petrovečki in their paper entitled "Plagiarism as a violation of scientific and academic honesty" define plagiarism as "unauthorized taking of other person's ideas, procedures or text without the appropriate indication, with the intention of presenting them as their own" [6]. Rumboldt, in his brief statement "About plagiarism in science," states that plagiarism is "opportunistic taking of essential components of other person's paper for false representation as its own concept"[7]. Cerjan Letica and Letica replace the notion of academic honesty with the notion of scientific indecency. In their paper "Scientific indecency: How to deal with it in Croatia?" they emphasize the necessity of dealing with the phenomenon of plagiarism i.e. academic indecency in the Croatian academic community [8].

According to Marcelić, plagiarisms are divided into seven forms: complete plagiarism; auto-plagiarism (when the author does not indicate himself as a reference when writing the paper, considering it unnecessary since he is the author of both papers); plagiarism by translation (taking a translation of foreign text without stating the reference); co(authorship) (when the person is not the author of the text, rather someone else wrote the paper on behalf of that author); copy and paste plagiarism (the author takes parts of other person's text, without stating the reference) and paraphrasing without reference and quotation outside of context (when the author literally takes or paraphrases particular text and at the same time does not quote it correctly) [9]. Unlike plagiarism, paraphrasing represents retelling in own words parts of other person's text [10]. But in paraphrasing there are also possibilities of plagiarism, and Oraić Tolić lists them as „paraphrasing sins": stealing other person's text, simulation of paraphrasing and stealing ideas and methods [11]. Therefore, it is not disputable that members of the academic community cannot take other person's knowledge, either literally or by paraphrasing certain parts of this knowledge, but it is extremely important that they do so by properly stating that this is the knowledge of other people and not theirs.

Members of the academic community are not just professors and researchers, rather the community also includes student population i.e. students. Within the academic community, unfortunately, students themselves often commit unethical behaviour. This is most evident in writing of their academic papers: seminar, final, graduate and other. Students plagiarise their papers for a number of reasons: due to lack of time, neglect, so they write their papers at the last minute, lack of will or even because of ignorance. The last example is one of the most severe forms of plagiarism, which refers to the fact that student's seminar, final or graduate papers are written by other people who receive money. Apart from great advantages that the Internet and information and communication technology have offered to students, among other things, faster, easier and more accessible obtaining of information which they need for their academic papers, the biggest disadvantage is that students often resort to unauthorized taking of other person's texts from the Internet, i.e. plagiarism. Kim and Wise in their paper titled "Measuring College Students' Perceptions and Attitudes toward AntiPlagiarism Detection Tools and Their Behaviors, Beliefs, and Moral Judgments on Plagiarism" state an example of one research (McCabe 2015) about plagiarism among the student population. The research was carried out between 2002 and 2005 among American students, and the results of the research were devastating: 38% of students stated that they cut & paste from the Internet, 25% of graduated students stated that they used one form of plagiarism, and as much as 80% of them used faculty observed plagiarism [12]. Fjorović conducted survey research on ethical/unethical behaviour of students of the University of Dubrovnik at the end of 2011. The student ethicality was viewed from the teachers' perception. The basic hypothesis of the research was that the University of Dubrovnik needed a Code of Ethics for students. The results of the research have shown that students of the University of Dubrovnik frequently violate moral and ethical principles in order to complete their study programme faster and better [13]. With the aim of preventing plagiarism or reducing the plagiarism procedures i.e. unauthorized taking of other person's texts, the academic communities in the world, and therefore also in Croatia, have resorted to the use of software or computer programs that detect plagiarism. According to Tokdemir Demirel and Gulogl, the basic purpose of any antiplagiarism software is to find similarities between two texts written by two different authors [14]. They state that anti-plagiarism software has a lot of advantages, and also a few disadvantages. They point out that student plagiarism sometimes also happens unconsciously, due to lack of knowledge to properly quote, so this software can help them to check their own paper and at the same time learn to quote properly. [15] One of the anti-plagiarism software currently offered on the domestic and international market is Turnitin, text authentication system, which was also purchased in 2016 by the University of Zadar. Turnitin "compares student papers with papers published in publicly available and commercial databases, currently available and archived websites, and with database of already reviewed student works within the Turnitin system'' [16]. It is important to emphasize that this antiplagiarism software does not determine whether the paper is plagiary or not, rather it points to the similarity or the identicalness of the already existing text, the percentage of such similarities found in the text and which sources were used. Qualities of this system are simplicity in application and the fact that apart from the teachers, students themselves can check their academic papers before submitting them for grading [17]. This software allows teachers to check student papers in terms of plagiarism, but it also points to the insufficient knowledge of students regarding proper quotation and paraphrasing of

works, and thus providing guidelines about which segments of teaching process are necessary to be further upgraded in order to improve the quality of teaching, and thus preserving academic honesty and integrity.

III. METHODOLOGY

The aim of the research is to expand knowledge about the student views on Turnitin plagiarism prevention system during study. The research was conducted by random sampling of students of undergraduate study programme Culture and Tourism and students of graduate study programme Journalism and public relations, Entrepreneurship in culture and tourism and Cultural and natural heritage in tourism at the University of Zadar. Students could complete the survey via Merlin e-Learning system. The survey research was conducted with the aim of answering the following questions: what students consider under the notion of academic honesty, how much they are acquainted with and what they consider under the notion of plagiarism, when did they encounter the notion of plagiarism, to what extent they mastered the skill and technique of academic writing, what sources they use and to what extent in writing of academic papers, to what extent are they acquainted with the possibilities of the Turnitin text authentication system, where they learned about the Turnitin system, how often they personally use Turnitin, how often do their teachers check their papers in Turnitin, to what extent did the Turnitin system help them to improve the quality of writing papers and respecting the academic writing rules, whether they consider and to what extent that the Turnitin system is useful for checking the authenticity and as a system for education and their view about whether the use of the Turnitin system has contributed to the quality of education.

IV. RESEARCH RESULTS

A total of 122 respondents participated in the research, students of undergraduate and three graduate study programmes. The research involved 37 students, 29.6% of all first year students. The share in the research corps is 30.3%. 19 students of the second year participated in the research, 22.1% of the total number of students of the second year. The share in the research corps is 15.6%. 45% of the students of the third year participated in the research. The share in the research corps is 29.5%. 20.5% of all students from the first years of graduate study programmes participated in the research. The share in the research corps is 7.4%. Also, 24.1% of the total number of all students of second years of graduate study programmes participated in the research. The share in the research corps is 17.2%. Of the total number of respondents, 85 (69.7%) are in the status of full-time students and 37 (30.3%) are in the status of part-time students. Most of the respondents belong to the age group of 20 to 24 (60.7%). In the researchparticipated 20.5% of the respondents under the age of 20, 10.7% of age 25 to 29 and 8.2% of age 30 and older.

Under the notion of academic honesty, students of the Department of tourism and communication science mostly consider honesty in the use of other person's sources, 68%, and respect of copyrights, 68%. Follows the correct quotation, paraphrasing and summarizing of other person's words, 63.9%, respect for the legal framework of the higher education institution, 55.7%, independent writing of academic papers, 50%, scientific honesty, 31.1%. 4.9% of respondents answered that they do not know, while 1.6% of respondents answered that they consider something else under the notion of "academic honesty".

From the above mentioned it is visible that the respondents have recognized and associated the notion of plagiarism with one or more offered answers, what can also be the indicator of the acquired degree of knowledge of academic writing, which is necessary for a correct and quality academic paper.

When asked much they know about the notion of plagiarism with the response options, not at all, very little, to some extent, quite and very much, the respondents in the vast majority answered that they were quite acquainted, 46.7%. 17.2% of respondents answered that they are very much acquainted with the notion of plagiarism. Around 30.3% answered that they were acquainted very little 4.9% and one respondent answered not at all, 0.8%.

When asked what they consider under the notion of plagiarism, respondents had the possibility of multiple responses. Nearly all respondents (95.9%) under the notion of plagiarism consider taking of other person's text/paper or part of other person's text/paper without quoting the source, 60.7% of respondents consider stealing of other person's ideas and methods, 41.8% of respondents chose simulation of paraphrasing, when the source is stated, and the text or part of the text/paper is literally taken, 27% of them replied that they consider taking their own previously written text/paper or part of the text/paper without quoting sources. 1.6% of respondents answered that they consider something else under the notion of plagiarism, and one respondent answered that he does not know, 0.8%.

Most of the respondents encountered the notion of plagiarism at the faculty, 55.7%, and 38.5% in high school. 5.7 % of respondents answered that they encountered the notion of plagiarism somewhere else.

	1	2	3	4	5	avg.	stdev
Books	3,28	12,30	15,57	27,05	41,80	3.92	1.17
Proceedings	24,59	34,43	22,95	12,30	5,74	2.40	1.15
Scientific Journals	18,85	30,33	22,13	20,49	8,20	2.69	1.23
Encyclopaedias and Lexicones	24,59	32,79	22,13	13,11	7,38	2.46	1.21
Newspaper Articles	19,67	19,67	21,31	27,05	12,30	2.93	1.32
Texts from the Internet	0,00	4,92	13,11	28,69	53,28	4.30	0.88
Other	27,87	19,67	29,51	11,48	11,48	2.59	1.32

TABLE1. TYPES AND INTENSITY OF USE OF RESOURCES IN WRITING OF ACADEMIC PAPER (values in %)

Description (1 - not at all, 2 - very little, 3 - to some extent, 4 - quite, 5 - very much)

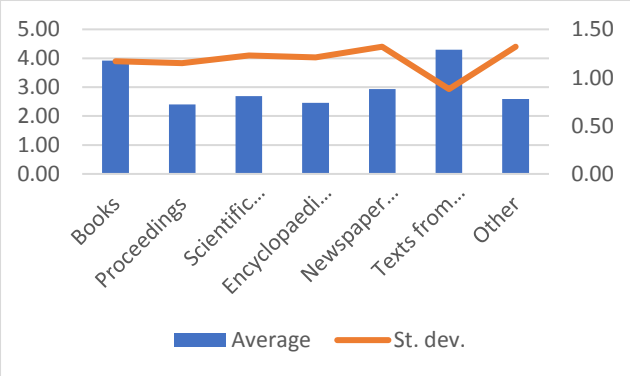
When asked what sources they use and how much when

writing academic papers, answers offered to students were books, proceedings, scientific journals, encyclopaedias and lexicons, newspaper articles, texts from the Internet and the option other. The majority of respondents answered that in writing of their academic papers they very much use texts from the Internet, 53,28% and books 41.80%, then newspaper articles 12.30%, other sources which were not proposed 11.48%, scientific journals 8.20%, encyclopaedias and lexicons 7.38%, and proceedings 5.74%.

Most of the respondents in the writing of their academic papers quite use texts from the Internet, 28.69% and newspaper articles, 27.05%, then books 27.05%, and encyclopaedias and collections by 13.11%, proceedings 12,30% and other 11,48%. 29.51% of them to some extent use sources which were not proposed, then newspaper articles 21.31%, proceedings 22,95%, encyclopaedias, lexicons 21,13% and scientific journals, 21.13%, books 15.57% and texts from the Internet 13.11 %. Given the percentage of respondents who answered other, list of proposed sources should be expanded in the future researches in order to get more detailed information. 34.43% of respondents answered that they use very little proceedings, 31.97%, scientific journals 33,33%, newspaper articles 19,67 and other sources 19.67%, books 12.30%, and texts from the Internet 4.92%.

Of all the proposed sources, only for texts from the Internet all respondents stated that they use them in their papers. 3.28% of respondents do not use books to write academic papers, scientific journals do not use 18.85% of respondents,19,67 of respondents do not use newspaper articles, 24.59% of respondents do not use proceedings, 25.41% do not use encyclopaedias and lexicons, and unlisted sources do not use 27.05% of students.

CHART 1. TYPES AND INTENSITY OF USE OF RESOURCES IN WRITING OF ACADEMIC PAPER (AVERAGE AND STDEV)



With regard to the use of literature in the writing of academic papers during the study, the respondents mostly used (quite and very much) texts from the Internet (average=4.30, stdev=0.88) which can be explained by faster and easier access.The average value for use of books in writing papers is 3.92 (stdev=1,17); for proceedings is 2,40(stdev=1.15); scientific journals 2,69 (stdev= 1,23); encyclopaedias and lexicons 2.46 (stdev=1.21) newspaper articles 2.93 (stdev=1.32),other 2.59 (stdev=1.32)

When asked to what extent they have mastered the skills and the technique of academic writing and with the response options, not at all, very little, to some extent, quite and very much, the respondents mostly estimated that they quite mastered the skills and techniques, 58.2%. 27.9% of them consider that they mastered the skills and techniques of academic writing to some extent. 4.1% of respondents answered that they mastered very little, and 0.8% answered not at all. 9% of respondents estimated that they very much mastered the skills and techniques of academic writing.

Considering the importance of authenticity verification of papers, the research demonstrated that over one third of respondents, in total, are very little (23,8%) or not at all (13,9%) acquainted with the possibilities of Turnitin. Also, over one third of respondents consider that they are to some extent (36,1%) acquainted with the possibilities of Turnitin, less than one third of respondents, in total, considers that they are quite (18,9%) and very much (7,4%) acquainted with the possibilities of Turnitin.

Most of them got acquainted with the Turnitin system, by teachers, 59%, 34.4% of respondents got acquainted by the institution where they study and 6.6% by other students.

When asked how often their teachers check their papers in Turnitin, the majority of respondents responded occasionally, 33.6%. That they often check their work answered 24.1% and always 13.1% of respondents. 22.1% of respondents answered that their teachers rarely check their works in Turnitin, and 6.6% answered never.

When asked how often they personally use Turnitin, have their own account and check the papers, most respondents answered never (66.4%). 15.6% of respondents use it very little, and 17.2% of respondents use it occasionally. Only one respondent uses it frequently, 0.8%. No one has answered that it always uses it.

Regarding the assessment of help in the quality of making the paper and respecting the academic rules, 11.5% of respondents answered that Turnitin system helped very much. 25.4% of respondents think that it quite helped and 23% of respondents consider that it helped to some extent. 9% of respondents stated that it helped very little and 31.1% of students who participated in the research said that the system did not help them by choosing the answer not at all.

We also wanted to know to what extent the respondents thought that Turnitin system was useful for checking the authentication of the papers. The largest number of respondents felt that Turnitin system quite helped them, 45.9%. 29.5% of respondents thought that the system helped them very much. 17.2% of respondents thought that it helped them to some extent, while 3.3% consider that it helped them very little. 4.1% of respondents answered not at all.

TABLE2. THE VIEW OF THE RESPONDENTS ABOUT THE CONTRIBUTION OF TURNITIN TO THE QUALITY OF EDUCATION (VALUES IN %)

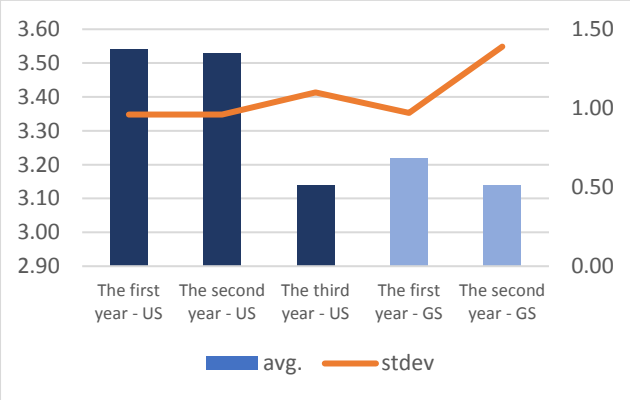
	1	2	3	4	5	avg.	stdev
The first year of undergraduate study	1,64	1,64	9,02	14,75	3,28	3,54	0,96

The second year of undergraduate study	0,82	0,82	4,92	7,38	1,64	3,53	0,96
The third year of undergraduate study	4,1	0,82	13,93	8,20	2,46	3,14	1,10
The first year of graduate study	0,82	0,00	3,28	3,28	0,00	3,22	0,97
The second year of graduate study	4,10	0,82	2,46	8,20	1,64	3,14	1,39
Total	11,48	4,10	33,61	41,80	9,02		

Description (1- not at all, 2- very little, 3- to some extent, 4- quite, 5- very much)

Regarding the assessment of the respondents, whether and to what extent the Turnitin system contributed to the quality of education, 41.80% responded that they felt that it quite contributed. That is contributed to some extent considers 33.61% of respondents, and that it very much contributed 9,02% of respondents. 4.10% of respondents believe that the Turnitin system contributed very little to the quality of education, and 11.48% of respondents consider that it did not contribute at all.

CHART 2. THE VIEW OF THE RESPONDENTS ABOUT THE CONTRIBUTION OF TURNITIN TO THE QUALITY OF EDUCATION (AVERAGE AND STDEV)



DESCRIPTION: (US- UNDERGRADUATE STUDY, GS- GRADUATE STUDY)

By analysing the average value of responses considering the years of study (first three years of undergraduate and two years of graduate studies) it can be concluded that students of higher years of study consider that the contribution of Turinin to the quality of education is lower than it is the case with the students of lower years of study; here it is important to take into consideration that there are greater individual differences in attitudes during higher years of study (Chart 2.)

To the question to what extent they consider that Turnitin system is useful as a self-education system, the vast majority responded that it was quite useful, 34.4%. 27.9% of respondents consider it useful to some extent, and 17.2% consider it very much useful. As a self-education system, 15.6% of respondents considered it very little useful, and 4.9% consider it not at all useful.

V. CONCLUSION

The development of the Internet and information-communication technology has influenced all segments of society, as well as education. Knowledge reaches a much wider dimension than it once did, so today we are talking about knowledge society and lifelong learning. Members of the academic community in their learning and work use new tools that enable them to obtain faster and easier information and knowledge. In this work and learning, academic integrity and honesty can be easily violated, i.e. unauthorized taking of other person's texts or knowledge. This opens up space for plagiarism that is increasingly common among student population. In order to prevent plagiarism, but also to give the opportunity for students to properly quote and paraphrase their papers antiplagiarism software are offered on the market, including the Turnitin software, which is the subject of this research.

Given the importance of academic honesty in the academic world and the prevention of plagiarism, any action in terms of improving the quality of academic paper can be considered as positive. In that direction, it is necessary to continue to take action in order to achieve the highest level of knowledge of academic honesty and academic writing, and with regard to the Turnitin system, make additional efforts, primarily by the teachers, with the aim of extending the student knowledge about the possibilities of the system and thus possible broader and more intense use.

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Automated analysis of e-learning web applications

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***Abstract* - In our paper we are exploring the use of formal methods for testing and verification of interactive e-learning web applications. These programs can be highly interactive and are often used for knowledge assessment and on-line tutoring purposes. They are written in web standard languages and executed in client browsers. Even simpler web applications can have various different interaction scenarios which makes them hard to test reliably. Therefore, we are using formal methods tools such as SPIN model checker and its *Promela* language to improve web application testing process. We create semi-automatically *Promela* process models from web application source code, and run their simulations, as well as verification using SPIN. Using these techniques, we want to identify flaws in web application design, and find and visualize all interaction scenarios using finite state automata. We will present use case example based on tutoring web application from our e-learning system used on our course Fundamentals of Electrical Engineering.**

Keywords - e-learning web applications, testing, verification, SPIN, Promela

I. INTRODUCTION

Web applications are the cornerstones of the modern Web. In broad terms, every website that performs some additional function besides serving static content inside a browser can be considered as a web application. For example, search engines, online dictionaries and translators, social media websites, as well as e-commerce services are all web applications. They are built as distributed applications – they are downloaded from the servers and run in the client browsers. To achieve user interaction and dynamic content generation modern web applications are utilizing client scripting languages (they execute in the client browsers) – the *de facto* standard is *JavaScript*, Ajax techniques (updating without reloading the entire page) and advanced HTML5 features (e.g. multimedia elements). It is hard to effectively test web applications because the *JavaScript* language is very flexible (weakly typed), and the web application source code can get very complex, especially when including external *JavaScript* libraries. In this paper we will propose an automated method for analysing behaviour of web applications using model checking techniques and model checking tool SPIN. We will perform analysis of one of our e-learning web applications used in our e-learning system.

The rest of the paper is structured as follows: in the second section we give an overview of related research, in the third section we present our e-learning web application. In the fourth section we propose a method for analysing web applications using model checking. In the fifth section we present and discuss preliminary analysis results. Finally, we conclude the paper in the sixth section.

II. RELATED WORK

Authors in [1] have presented a comprehensive overview of approaches for analysis and testing of Web applications. They propose building a UML model of the entire web application or a specific module. The web application UML model can be then used to produce test cases semi-automatically.

In [2] authors have developed process crawlers, a variant of web crawlers (programs that automatically explore web pages) that can traverse different execution paths through the web application and then automatically build a behaviour model of the web application as a extended finite state machine. Extracted workflow models can be also used to generate test cases.

Authors in [3] have proposed model based design of web applications that could be then verified using SPIN model checker. To achieve that, authors needed to manually build a *Promela* model of a web application. In our approach we analysed an existing e-learning web application, and utilized an automated method for building its initial *Promela* model that we refined and then simulated and verified using SPIN model checker.

III. AN E-LEARNING WEB APPLICATION EXAMPLE

Our e-learning system *WebOE*[1] is used on freshman year course *Fundamentals of Electrical Engineering* at the University of Zagreb, Faculty of Electrical Engineering and Computing. It was developed in-house at our Department of Electrical Engineering Fundamentals and Measurements [4]. Our system supports various e-learning functionalities – dynamic and static online tests and quizzes, personalized homework assignments, database with detailed educational data about students' performance and exam questions, as well as a repository of mandatory and optional teaching and learning materials (Fig. 1).

[1] https://osnove.tel.fer.hr

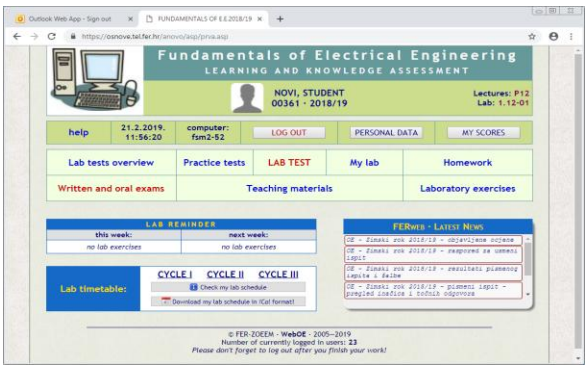

Figure 1. Students' main view after logging in *WebOE*

In the public section the *WebOE* system offers an extensive collection of useful interactive materials[2] about electrical engineering fundamentals – simulations, tools for problem practice and virtual lab exercises. Most of these tools were initially *Java* applets, developed or adapted to Croatian by I. Felja. Recently, a vast majority of those *Java* applets was converted to *JavaScript* and further expanded by the first author of this paper.

As an example of our publicly available interactive materials we will present an e-learning web application[3] for practicing Kirchhoff's circuit laws. This client-based application is written using standard web languages – HTML, CSS and *JavaScript*, as well as *jQuery*. We also used interactive geometry *JavaScript* library *JSXGraph* [5] for drawing electrical circuits and application controls, and *JavaScript* library *MathJax* [6] for displaying mathematical notation.

In this application a user tries to solve a moderate DC circuit problem. After the problem is given a user must correctly set Kirchhoff's equations using Kirchhoff's circuit laws (Fig. 2). Afterwards, the user must solve the resulting system of linear equations and submit its results for evaluation. Furthermore, if all answers are accepted (within 3% of correct values) the user must check and set the correct directions of all currents in the circuit. Finally, users get a formative assessment grade on a 0–10 scale and as an additional feedback advice on improving their understanding and mastery of the topic (Fig. 3).

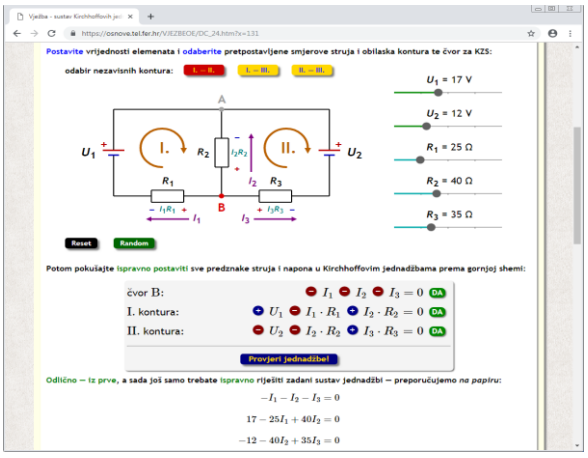

Figure 2. Web application view – problem statement and setting up of appropriate Kirchhoff's circuit equations

[2] https://osnove.tel.fer.hr/VJEZBEOE/vjezbe.asp
[3] https://osnove.tel.fer.hr/VJEZBEOE/DC_24.htm

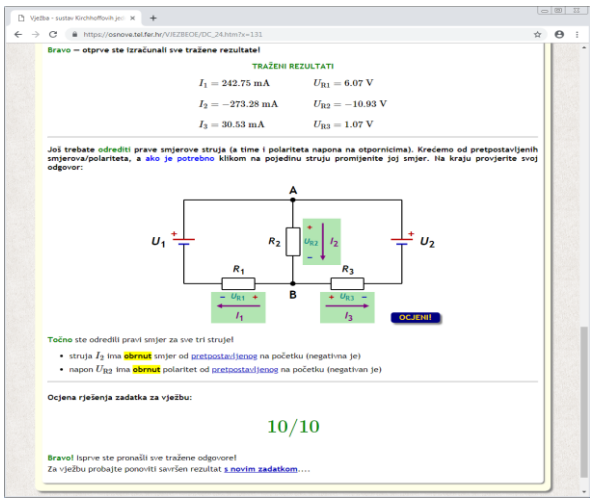

Figure 3. Application view – evaluation of results, setting and evaluation of current directions and final grade

In each practice session our application can randomly generate slightly different problem which requires careful set up of Kirchhoff's circuit equations. Furthermore, a user can manually change all the parameters of the circuit. Using sliders shown on the right of Fig. 2 users can change values of resistors and both ideal voltage sources. Also, by clicking on the circuit elements and arrows in Fig. 2 users can change polarities of voltage sources, choose a node for the Kirchhoff's circuit law, change the assumed directions of all three currents and choose one of three different pairs of independent closed loops, as well as directions of their traversals. Therefore, if we ignore circuit element values our application can generate 2x2x2x2x2x2x3x2x2 = 768 different scenarios (Fig. 4).

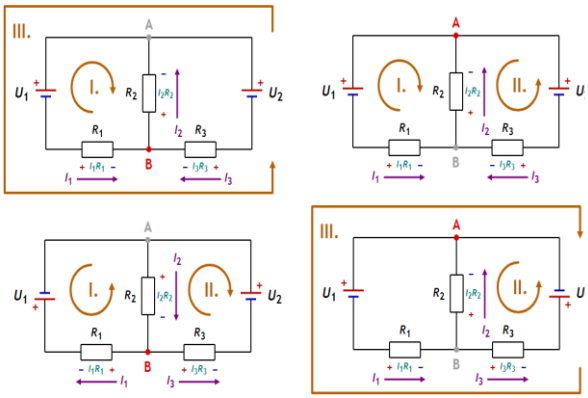

Figure 4. An example of four random DC circuit scenarios

Application provides hints when a user makes three or more successive errors – e.g. an explanation of Kirchhoff's circuit laws or external links to help with solving linear system of equations. Also, after multiple incorrect answers application offers skipping that part of the practice and displaying the correct answers. Afterwards, the user can continue with the practice session, but the final grade will be lowered.

Even if the presented web application might not seem very complex, its *JavaScript* code is not trivial. It dynamically draws annotated DC circuit, prepares and renders mathematical notation using *MathJax*, and reacts to all user clicks and inputs. Therefore, testing and analysis of such applications can be very challenging.

IV. PROPOSED METHOD FOR AUTOMATED ANALYSIS OF WEB APPLICATIONS

In this section we will present our preliminary method for analysing web applications written in widely used client-side scripting language *JavaScript*. First, we will introduce and describe model checking technique and the tool we used – the SPIN model checker.

A. Model checking

Model checking is a method for examining if a model of a hardware or a software system meets defined specifications. System's model is built as a finite state automaton – a mathematical structure in a form of directed graph. Specifications are written using mathematical logic formulae, e.g. as propositional or temporal logic formulae. Automated tools and techniques are used to verify a model against a specification. Main goal of the model checking is to identify system behaviour that leads to serious errors – system deadlocks or system crashes. Model checking is used for verification of network protocols or distributed software systems, and especially for verifying critical parts of complex systems [7].

B. SPIN model checker and Promela language

SPIN model checker is one of the industry standard tools for systems' model verification and simulation. First version of the SPIN tool was made in the late 1980s at the Bell Labs by American computer scientist G.J. Holzmann, and since 1991 it is freely available and regularly updated [8].

SPIN model checker uses its own language *Promela* to define process models that describe system's behaviour. The syntax of *Promela* is very similar to the standard C language, but its semantics is not identical. For example, when SPIN executes a *Promela* conditional statement (*if-then-else* construct) with multiple *else if* branches it will execute randomly one of the *else if* branches whose conditional expression is true – this will not always be the first possible *else if* branch as in the C language. This simple *Promela* command is an easy way for introducing non-determinism in process models.

Defined process models in *Promela* can be simulated using SPIN tool – each simulation run will be executed randomly if there is non-determinism in the process models. Simulations are very useful for obtaining different possible sequences (*traces*) of executed commands in the process model. Nevertheless, even running many random simulations cannot guarantee that a flaw in the model will be found. Therefore, we should use more rigorous technique of model verification to ensure there are no critical errors in defined process models. SPIN tool offers a mostly automated way for verifying defined process models. From the *Promela* process model SPIN can automatically create source code of a process analyser (*pan.c*) written in C language. Using standard *gcc* C compiler we can then compile it to create a process analyser executable file (*pan*). Process analyser will automatically run the verification of the initially defined process model and report back the verification results. During the verification run all the possible execution paths will be traversed in the search for an error. If an error is found (e.g. a deadlock), process analyser will generate a trail file that records all the steps taken before the error was encountered. Afterwards, we can execute this trail file with SPIN tool, and follow the error path in detail.

For advanced usage we can specify additional properties using Linear temporal logic (LTL) that the process model must satisfy.

It must be noted that the verification procedure is computationally very expensive because of the vast search space that must be explored. Therefore, it is not always feasible to verify complex and long computer programs. However, verification can be effectively used to thoroughly check critical program parts or smaller program modules.

C. Proposed method for analysing web applications

Our goal was to create a *Promela* model of a web application and analyse it using SPIN tool. To achieve that goal, we have made few important assumptions:

- We were interested only in client-based *JavaScript* web applications where the scripting code is executed inside the user's browser and can be easily inspected by the user.
- As we have stated in the third section web applications can be highly interactive and event driven. Therefore, we have assumed that the *JavaScript* code will be organized into named functions. Each function call can then be viewed as a single action, e.g. when a user clicks on a control or enters some input.

Code behind web applications can be quite complex and can be written in different *JavaScript* coding styles. Therefore, creating an accurate detailed model of the web application could prove to be very difficult. For this reason, we decided to create high-level design model of the web application that will provide a useful overview of its behaviour without going into details of each *JavaScript* function. We have written *Perl* scripts that help to automate the process of building *Promela* models, as well as the process of their analysis. All scripts can be run in Linux or inside *Cygwin* environment in Windows. Overview of our method is shown in Fig. 5, and afterwards described in more detail.

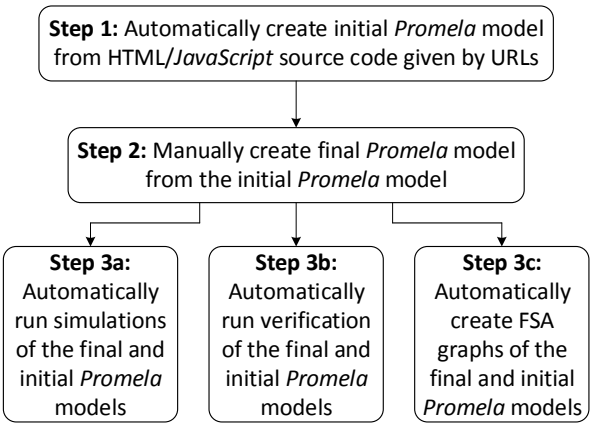

Figure 5. Our method for web application analysis

Step 1: A *Perl* script called *create_promela_model* retrieves HTML and *JavaScript* source code from given URLs using command *wget*. As the URLs we must enter web application address and if necessary, also addresses of external *JavaScript* files. *Perl* script then analyses the downloaded source code – using regular expressions it extracts declarations of all identified functions, and then checks which functions are used in the web application (called at least once). Afterwards the script starts to build simple *Promela* file. Each used function name is placed inside a *Promela printf* statement. Those *printf* statements represent named transitions between states in the finite state automaton. To facilitate the simulation and the verification process, script also prepends to this sequence of *printf* statements a pre-set header of *Promela* commands. Also, script completes the *Promela* process model by adding a pre-set footer and stores the resulting initial *Promela* model. Finally, the script prints out the number of used functions, and lists all names of unused functions, which can be useful for code optimization.

Step 2: We must check if the automatically created initial *Promela* model should be refined or rearranged, so it better reflects the functionality of the web application. For example, we can wrap parts of *Promela* code inside non-deterministic conditional *if-then-else* statements and *do* loops.

Step 3a: Now, we can automatically run simulations of the prepared *Promela* models. A simple *Perl* script called *simulation* runs the SPIN simulations of the final or the initial *Promela* models, and automatically stores the output of each simulation run – one possible sequence of actions. When the verbose mode is enabled, simulation also returns additional information (e.g. number of simulation steps and values of global variables).

Step 3b: It is also possible to verify prepared *Promela* models. To facilitate the verification process we have written a *Perl* script called *verify*. It automatically runs the following sequence of commands – it creates SPIN process model analyser source code, compiles the process analyser using *gcc* compiler, and then runs the verification by executing the process analyser. Finally, the script stores the verification results. Verification will fail if it does not reach regular end state in at least one execution path.

Step 3c: In this last step of the method we can visualize prepared *Promela* models as finite state automata (FSA) using the SPIN tool. We have written another *Perl* script called *automaton* that automatically performs this task. First, the script creates process analyser as in the Step 3b. With a command *./pan -D* process analyser stores automaton state table in *.dot* format. Afterwards, *GraphViz* tool *dot* converts generated *.dot* file into a *PostScript* file. Finally, tool *ps2pdf* creates a PDF file that displays the finite state automaton as a directed graph. If the resulting directed graph FSA is too large, we can enable state merging (*./automaton -merge*). Directed graph FSA could then become more readable, because chains of nodes will be compressed into a single node.

V. RESULTS AND DISCUSSION

In this section we will present and discuss initial results of our method for web application analysis. We will analyse an e-learning web application for practicing Kirchhoff's circuit laws that was described in the third section.

When running the automatic *Perl* script *create_promela_model* we only need to pass it the web address of our e-learning web application. The central *JavaScript* code of the application is embedded in its HTML header. We decided not to add URLs for other external *JavaScript* libraries used in the application (*jQuery*, *JSXGraph* and *MathJax*), because they deal with specific implementation details that are not essential to this analysis. The *Perl* script successfully creates an initial *Promela* process model and prints out the lists of 26 used function names. The output of the *create_promela_model* script is shown in Fig. 6.

```
$ ./create_promela_model

Report:
-------

Created initial promela model:
model_original.pml

Number of used functions: n = 26

List of names of unused function (n = 0):
```

Figure 6. Output of the *create_promela_model* script

Automatically built initial *Promela* process model and a refined final model are both shown in Fig. 7 side by side for comparison. In presentation of our results all *printf* statements (function names) were translated to English.

```
byte end = 0;
int program_run = 0;

active proctype FSA01_initial () {
start:  printf("start\n");
        program_run = program_run + 1;
        printf("showMemo\n");
        printf("defaultSettings\n");
        printf("drawExperiment\n");
        printf("resetTask\n");
        printf("setParametersManually\n");
        printf("randomTask\n");
        printf("setRealData\n");
        printf("hideEquationResults\n");
        printf("hideEquationEvaluation\n");
        printf("setEquations\n");
        printf("resetSign\n");
        printf("setSign\n");
        printf("showHelpKirchhoff\n");
        printf("checkEquations\n");
        printf("printEquationSystem\n");
        printf("calculateKL\n");
        printf("calculateDet3\n");
        printf("hideSolutionEvaluation\n");
        printf("resetSolutions\n");
        printf("evaluateSolutions\n");
        printf("showHelpMath\n");
        printf("checkAllSolutions\n");
        printf("printSolutions\n");
        printf("showDirectionCheck\n");
        printf("drawDirectionCheck\n");
        printf("finalGradeAdvice\n");
        if
        :: goto start;
        :: end = 1;
        fi;
        printf("programEnd\n");
}
```

```
byte end = 0;
int program_run = 0;

active proctype FSA01_final () {
        if
        :: printf("showMemo\n");
        :: skip;
        fi;
        printf("defaultSettings\n");
        printf("drawExperiment\n");
start:  printf("start\n");
        program_run = program_run + 1;
        printf("resetTask\n");
        if
        :: do
           :: printf("setParametersManually\n"
           :: break;
           od;
        :: printf("randomTask\n");
        fi;
        printf("setRealData\n");
        printf("hideEqautionResults\n");
        printf("hideEquationEvaluation\n");
        printf("setEquations\n");
        printf("resetSign\n");
        do
        :: printf("setSign\n");
        :: printf("showHelpKirchhoff\n");
        :: printf("checkEquations\n");
           if
           :: break;
           :: skip;
           fi;
        od;
        printf("printEquationSystem\n");
        printf("calculateKL\n");
        printf("calculateDet3\n");
        printf("hideSolutionEvaluation\n");
        printf("resetSolutions\n");
        do
        :: printf("evaluateSolutions\n");
        :: printf("showHelpMath\n");
        :: printf("checkAllSolutions\n");
           if
           :: break;
           :: skip;
           fi;
        od;
        printf("printSolutions\n");
        printf("showDirectionCheck\n");
        printf("drawDirectionCheck\n");
        printf("finalGradeAdvice\n");
        if
        :: goto start;
        :: end = 1;
        fi;
        printf("programEnd\n");
}
```

Figure 7. *Promela* models – automatically generated model (*FSA01_initial*) and refined final model (*FSA01_final*)

It can be observed from the Fig. 7 that the sequences of *printf* statements in both models are almost identical. The only major difference is in the placement of the line with the label *start*, which marks the beginning of a new practice session. In the final model it was moved downwards, because it is not necessary to redraw the entire experiment board containing the DC circuit and other control elements each time a user retakes the practice. It can be also seen that we inserted non-deterministic *if-else* statements and *do* loops in the final model, as to better describe the actual functionality of the web application.

Instead of analysing the *Promela* model source code, it can be more useful to visualise the basic functionality of our web application by running *automaton* script form the Step 3c of the proposed analysis method. We will get a finite state automaton of the final *Promela* model in the form of a directed graph that is shown in Fig. 8.

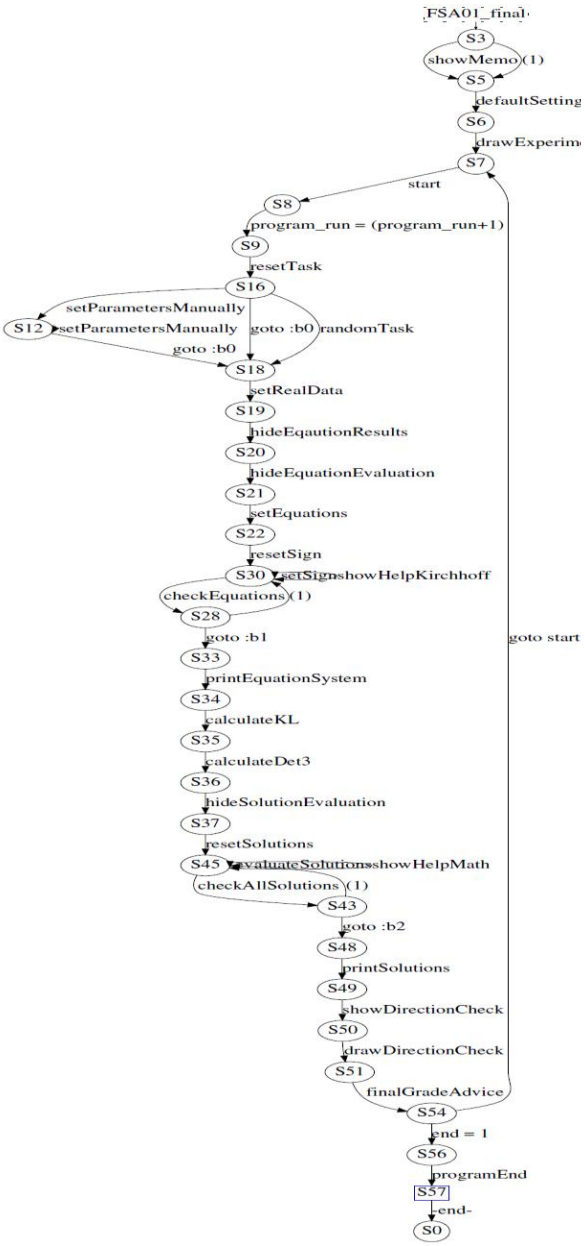

Figure 8. Finite state automaton of the final *Promela* model

Now, we can identify all the key decision nodes in the FSA in Fig. 8. From the initial state S3 users have an option of opening a memo about Kirchhoff's laws before continuing. Next, from the state S16 users decide which task they will try to solve. They can choose a default task, take a randomly generated task or they can set all task parameters by themselves. Later, from the state S30 users start to set positive or negative signs of variables in the prepared Kirchhoff's equations. From the state S30 they can also ask for help if they get stuck. Users can continue with the task solving only after all their Kirchhoff's equations are set up correctly. From the state S45 users start to submit their results of Kirchhoff's equation. Each submitted result is evaluated, and only if all results are correct users will continue to the final part of the task. Again, if users encounter problems when solving the equation system, they can ask for help and return to state S45. Finally, after completing the task and getting final grade and additional advice users can from the state S54 decide to end the practice session or to go back to state S7 and take a new practice task.

When dealing with large *Promela* models we can get complex FSA directed graphs. In those cases, we can automatically simplify the generated FSAs. For example, by executing the *automaton* script with enabled state merging (*./automaton -merge*) we obtain the simplified FSA with 14 states and 24 transitions shown in Fig. 9. It is more readable than the FSA in the Fig. 8 that has 30 states and 40 transitions. Furthermore, we can see that all of the discussed key states and transitions from the FSA in Fig. 8 are preserved in the compressed FSA in Fig. 9.

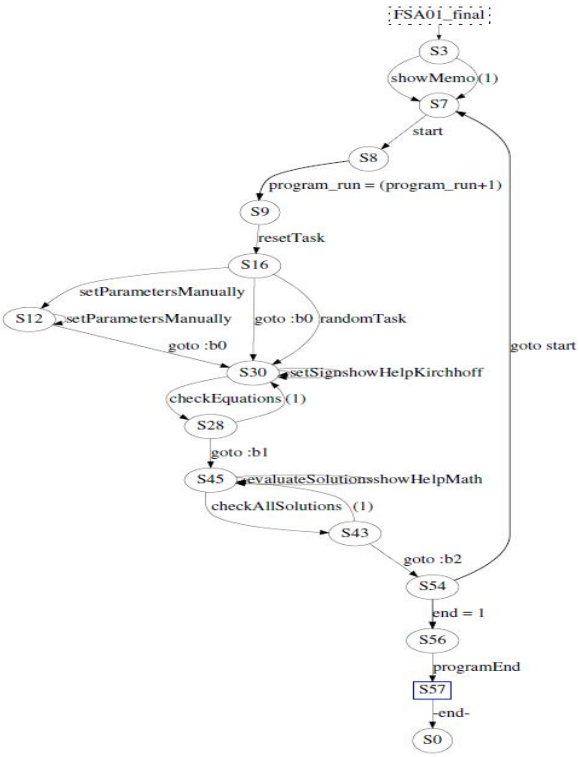

Figure 9. Simplified FSA of the final *Promela* model

To perform a more thorough analysis of the web application behaviour we can run the *simulation* script, which will run the simulation of the final *Promela* model with the SPIN model checker. We have run multiple

random simulations to obtain different usage scenarios of our e-learning web application. At each of the key decision nodes in the FSA in Fig. 8 a user can take a different path through the practice session. Some of these random traces are shown in Fig. 10.



Figure 10. Output of three random simulation runs

Looking at the automatically generated random traces in Fig. 10 we can argue that this is the main benefit of our web application analysis method. These traces illustrate on a high-level of abstraction the users' interaction with the web application. They can serve as test cases examples that should pass before deploying the web application in production. Also, these traces can help authors to try to identify critical parts of their web applications, where users might become stuck and decide to leave the application without finishing the intended task. In our example of a e-learning web application we added various help options at the critical places, and among them even an option of skipping some steps and revealing correct answers.

We plan to add additional *Ajax* functionalities to the web application so we can track and store information about users' practice sessions. Afterwards, we will analyse them using process mining techniques to identify patterns of users' behaviour when solving practice tasks. We could compare the process mining results with the simulation traces and FSAs generated by our analysis method. From the educational perspective it will be very interesting to see will the provided help options and hints be overused.

When running the *verify* script we can automatically perform the verification of our final *Promela* model. After running the verification, we find that there are no unreached states in the *Promela* model.

Finally, we must also comment on some of the drawbacks of our proposed analysis method. For these preliminary research results we made some assumptions that we already listed in the fourth section. Also, we did not consider obfuscated *JavaScript* code that would be harder to parse without first using some of the deobfuscation techniques. Furthermore, we made some intentional simplifications in the final *Promela* model of our e-learning web application. In the actual application a user can decide in any step of the practice session to quit solving the given task and start over. This would make FSAs in Fig. 8 and Fig. 9 very complex and unreadable. Also, in our final *Promela* model users can request help immediately, and not only after three or more wrong answers as in the actual web application.

VI. CONCLUSION

In this paper we have presented our preliminary method for web application analysis using SPIN model checker. We applied this method to one of our e-learning web applications. We found that our method can give a high-level overview of the application's behaviour, by providing a finite state automaton of the application and automatically generated list of possible usage scenarios.

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Critical Thinking and Creative Thinking - the self-assessment of Algebra University College students

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Abstract - **During the twentieth century, it became clear that national economies can make progress only by investing in human capital. Knowledge increases human productivity and creativity, and society can prosper only through human self-awareness, understanding of the world around them and by increasing the quality of their lives. In the information age, progress was made through information and technology, with particular emphasis on critical thinking. But in the conceptual economy of the 21st century, influenced by three key developments; over-supply, outsourcing, and automation, it has become clear that critical thinking, even with the help of high technology, is no longer sufficient to make a living or to be competitive in the labor market. In the 'Value age,' these capabilities need to be complemented by highly conceptual and highly sensitive traits. The integration of critical and creative thinking is a fundamental factor in personal productivity and the essential condition for achieving sustainable economic development. The self-assessment of Algebra University College students was designed to investigate the extent to which students integrated critical and creative thinking into their own circumstances and to explore whether there is a correlation between the type of thinking they are more inclined to and their study programs.**

Keywords - critical thinking, creative thinking, conceptual age, value age, self-assessment

I. INTRODUCTION

The understanding of the 20th-century economy was based on the premise that future development depended on specific qualifications and experts, for example, lawyers because of their abilities to provide legal services, business administrators because of their abilities to provide financial services and computer programmers because of their abilities to provide software services.

But that understanding was brought into question under the influence of three forces; over-supply, outsourcing, and automation, as it was described by Daniel H. Pink in his book *A Whole New Mind* published in 2005. Throughout history, the lives of humans were defined by scarcity. The abundance of things has satisfied, or even over satisfied the material needs of hundreds of millions of people, and freed them from the struggle for survival in a broader context. The focus has moved from rational to sensibilities such as beauty, spirituality, and emotion. In business it no longer enough to create a product that has a reasonable price and it is functional, now it also has to be beautiful, unique and meaningful. In the age of abundance, appealing only to rational, logical and functional needs is insufficient. Engineers still must figure out how to get things to work. But due to many other options, if things are not also pleasing to the eye or compelling to the soul, only a few will buy them. There is also the paradox of prosperity where even though people are liberated by prosperity, they are not fulfilled by it and more and more people are searching for meaning. At the same time, more and more labor is now done overseas, in Asia, North Africa, South America, and Eastern Europe at significantly lower costs than in the advanced world, as well as IT jobs; software and information technology industry. This is forcing knowledge workers to do what foreign workers cannot do, at a much lower price. Automation is the third force that is making a great impact on today's worldview. It is eliminating rote tasks because people cannot compete with the machines when it comes to logic and calculations. Technological progress is such that software can perform complex actions to the extent that it can perform preliminary medical diagnoses and some software can even write software. In the conceptual economy of the 21st century, it has become clear that people have to develop aptitudes that machines cannot replicate[1].

The capabilities that are arising from a logical and linear way of thinking, that was dominant in the Information Age need to be complemented by highly conceptual and highly sensitive traits in the Conceptual Age. In the 'Value Age', as is it also called, along with the intellectual capital, the greatest values are emotional capital, ideas, design skills, storytelling, and meaning. An increasing need for creative authors and artists shows that the integration of critical and creative thinking is a fundamental factor in personal productivity and today's sustainable economic development. Also, qualities such as intuition, creativity, and game-based approaches are becoming more and more important, as well as an extensive teamwork ability and an understanding of diverse cultures in the global context.

The research conducted through self-assessment of the Algebra University College students was intended to investigate the extent to which students integrated critical and creative thinking and have developed the most important and desirable skills required for the future.

II. TWO HEMISPHERES OF THE MIND

When Roger Wolcott Sperry, the Nobel Prize Laureate in Physiology or Medicine 1981 was still an undergraduate student and enrolled in the course Introduction to Psychology in the 1930s, taught by R. H. Stetson, on the first page of Sperry's notes taken in that class two questions were written that referred not only to the theme of the course but also to his own professional life: 'Where does behavior come from (nature or nurture)'? and 'What is the purpose of consciousness'[2]? Those were the questions he tried to answer throughout his scientific career while performing a series of medical and psychological experiments that have become famous.

Essentially, Sperry and his students showed that the left hemisphere controls the speech, and was considered dominant in all activities involving language, arithmetic, and analysis. The right hemisphere is mute and capable only of simple addition (up to about 20). However, it is superior to the left hemisphere in, among other things, spatial comprehension, such as understanding maps, or recognizing faces. Until Sperry's studies, it had been doubted whether the right hemisphere was even conscious. By devising ways of communicating between two hemispheres, he showed, to quote him: "indeed a conscious system in its own right, perceiving, thinking, remembering, reasoning, willing, and emoting, all at a characteristically human level, and … both the left and the right hemisphere may be conscious simultaneously in different, even in mutually conflicting, mental experiences that run along in parallel." Discovery of this duality of consciousness opened new fields of researches, considerations, and discussions of a new generation of biologists, philosophers, and many others[3].

III. A WHOLE (NEW) MIND: INTEGRATION OF CRITICAL THINKING AND CREATIVE THINKING

Professor George Land with Beth Jarman in 1968 conducted a research study to test the creativity of 1,600 children ranging in ages from three-to-five years old who were enrolled in a Head Start program. This creativity test was also devised for NASA to help select innovative engineers and scientists and the assessment worked so well that he decided to try the test on children. It was a longitudinal study in which the same children were re-tested at 10 years of age, and again at 15 years of age. The astounding results showed that the proportion of people who scored at the "genius level", were[4]:

- 98% amongst 5-year-olds;
- 30% amongst 10-year-olds;
- 12% amongst 15-year-olds;
- 2% among 280,000 adults (average age of 31).

The primary reason for this, according to Land, is that there are two approaches to thinking processes regarding creativity:

- *Convergent thinking:* judging ideas, criticizing and/or refining them, combining and improving them, all of which happens in our conscious mind.
- *Divergent thinking:* imagining new ideas, original ones which are different from what has come before but which may be rough to start with, and which often happens subconsciously.

He highlighted that during education, children are taught to try and use both kinds of thinking at the same time**,** which is not possible. Instead of that, people should be allowed to split their thinking processes into various different states which would make each of them more effective[4].

Daniel H. Pink notes that there are usually two misconceptions about the human brain and mind which 'are opposite in spirit but similar in silliness'. The first considers the right brain a savior; and the adherents of this approach believe the right brain is the repository of all that is good, just and noble in the human condition. The second considers the right brain is a saboteur and although the adherents of this approach acknowledge the right hemisphere's legitimacy, they believe that using right-brain thinking creates a risk of sabotaging the economic and social progress made by applying the force of logic to human lives. Bu the reality is the right hemisphere will neither save us nor sabotage us and as is so often the case with reality, it is more nuanced.

After more than three decades of researches on the brain's hemispheres, the findings can be distilled into four key differences:

1. The left hemisphere controls the right side of the body; the right hemisphere controls the left side of the body.
2. The left hemisphere is sequential; the right hemisphere is simultaneous.
3. The left hemisphere specializes in the text; the right hemisphere specializes in context.
4. The left hemisphere analyzes the details; the right hemisphere synthesizes the big picture.

But instead of using lateralized brain functions as a metaphor for two different styles of thinking or attitudes to life, he suggests the terms L-directed and R-directed thinking he perceives to be operating in modern Western society and both are needed in order to craft fulfilling lives and build protective and just societies:

- *L-directed thinking* is sequential, literal, functional, textual, and analytic

while

- *R-directed thinking* is metaphorical, simultaneous, aesthetic, contextual, and synthetic.

The thrill of reductionist, binary thinking is changing and dramatically reshaping our lives. L-directed aptitudes are still necessary, but they are no longer sufficient. Instead, the R-directed aptitudes such as artistry, empathy, taking the long view, pursuing the transcendent, increasingly determine who soars and who stumbles. It is a dizzying, but ultimately inspiring change[1].

In the Conceptual Age, the L-directed reasoning needs to be complemented by mastering six essential R-directed aptitudes. These six high-concept, high-touch senses combined together can help to develop the whole (new) mind this era demands.

1. It is not just a function that matters but also *DESIGN*. It is economically crucial and personally rewarding to create something that is beautiful, whimsical, or emotionally engaging.

2. It is not just an argument that matters but also *STORY*. The essence of persuasion, communication, and self-understanding has become the ability also to fashion a compelling narrative.

3. It is not just focused that matters but also *SYMPHONY*. Greatest demand today is not analysis but synthesis i.e. seeing the big picture and, crossing boundaries, being able to combine disparate pieces into an arresting new whole.

4. It is not just logic that matters but also *EMPATHY*. The ability to understand what makes their fellow woman and man tick, to forge relationships, and to care for others will distinguish those who thrive.

5. It is not just seriousness that matters but also *PLAY*. Too much sobriety can be bad for career and worse for general well-being. In the Conceptual Age, all people need to play.

6. It is not just an accumulation that matters but also *MEANING*. A world of material plenty has freed humans to pursue more significant desires: purpose, transcendence, and spiritual fulfillment[1].

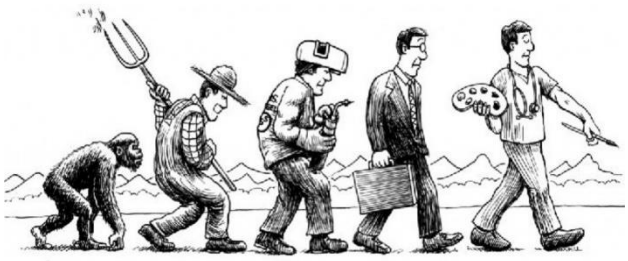

Image 1. Metamorphoses of human intelligence[5]

The movements in the global knowledge economy confirm findings of all researches mentioned, which place increasing demands on flexible intellectual skills and ability to analyze information, but in a way that integrates diverse sources of knowledge in solving problems so one can be able to deal with changes quickly and effectively. Increasingly more and more employers are looking not for employees with highly specialized academic skills, but those with 'good' thinking and communication skills. Employees who learn quickly and can solve problems, think creatively, gather and analyze information meaningfully are the most valuable and needed in the 21st century. Critical thinking is defined as thinking about one's thinking in a manner designed to organize and clarify, raise the efficiency of, and recognize errors and biases in one's own thinking. Critical thinking is not 'hard' thinking nor is it directed at solving problems[6].

Critical thinking is inward-directed with the intent of maximizing the rationality of the thinker, and one does not use critical thinking to solve problems—one uses critical thinking to improve one's process of thinking. It includes the ability to engage in reflective and independent thinking but it does not mean being argumentative or being critical of others. Although critical thinking skills can be used in exposing fallacies and bad reasoning, they can also be used to support other viewpoints, and to cooperate with others in solving problems and acquiring knowledge. Clear and systematic thinking can improve the comprehension and expression of ideas, enhance language and presentation skills.

A breakthrough point, as stated Ljiljana Arar and Željko Rački[7], for more systematic creativity exploration was a famous lecture by Joy Paul Guilford, at Pennsylvania State College in 1950, entitled "Creativity"[8]. In this lecture, he emphasized how the measures of achievements (primarily school tests) are based on issues that point thinking to a one specific previously determined answer. As a counterpoint to that convergent thinking, the attention started to move to the, by then disregarded, the divergent thinking[7]. Guilford first proposed the concept of divergent thinking and later introduced its developed model as the main ingredient of creativity. Thus he associated divergent thinking with creativity, appointing it several characteristics: 1. *fluency* (the ability to produce great number of ideas or problem solutions); 2. *flexibility* (the ability to simultaneously propose a variety of approaches to a specific problem); 3. *originality* (the ability to produce new, original ideas); 4. *elaboration* (the ability to systematize and organize the details of an idea in a head and carry it out)[9]. The creative talent has central significance for industry, science, arts, and education [10] because, as he described, creativity is *sensitivity to problems*; *divergent thinking* and *ability to generate multiple ideas*[11], *creation of new patterns*, *a transformation of knowledge and meaning* or *use the functions of objects in a new way*[12].

The suggestion that critical thinking is incompatible with creativity is a misconception, as creativity is not just a matter of coming up with new ideas. A creative person generates new ideas that are useful and relevant to the task at hand. Critical thinking plays a crucial role in evaluating the usefulness of new ideas, selecting the best ones and modifying them if necessary. It is important to become aware of the connection between critical thinking and creative thinking skills. Future economic growth and social progress in the information age rely on innovation. In addition to technical know-what and know-how, the core skills for innovation are critical thinking, creativity, problem-solving, global collaboration and communication[13]. The top ten skills in the 21st-century workplace that are considered essential according to the World Economic Forum[14] are as listed in Table 1.

2015	2020
1. Complex problem solving	1. Complex problem solving
2. Collaboration with others	**2. Critical thinking**
3. People management	**3. Creativity**
4. Critical thinking	4. People management
5. Negotiation	5. Coordinating with others
6. Quality control	6. Emotional intelligence
7. Service orientation	7. Judgement and decision making
8. Judgement and decision making	8. Service orientation
9. Active listening	9. Negotiation
10. Creativity	10. Cognitive flexibility

Table 1. Top ten essential skills in the 21st-century workplace according to the World Economic Forum.

The Lee Watanabe-Crockett created a similar list of the ideal set of skills to strive for i.e. the most important characteristics and_universal traits and integrated values that the effective critical thinkers (should) posses[15]:

- *Curiosity* - about a wide range of topics and generally have broad interests. They tend to have a healthy inquisitiveness about the world and about people. An understanding of and appreciation for the diversity of cultures, beliefs, and views that encompass humanity are one of the hallmarks of a great critical thinker. This also makes them lifelong learners.
- *Compassion* – embracing the emotional and instinctual as much as the intellectual. They act as much with their hearts as they do with their minds. There is already enough judgment and segregation in the world, much of it stemming from lack of a clear understanding of one another's secret history of perseverance through often unimaginable suffering.
- *Awareness* – of the fact there are opportunities in which to apply critical thinking skills all around us as well as always being alert about the chances to apply their best thinking habits to any situation. A desire to think critically about even the simplest of issues and tasks indicates a desire for constructive outcomes.
  They never stop asking questions and enjoy exploring all sides of an issue and the deeper facts hiding within all modes of data. As such, those who think critically also tend to be instinctual problem solvers.
- *Decisiveness* - many situations that call for critical thinking also call for quick and decisive action. When they think critically, it is important to weigh options and imagine the outcomes at the moment with speed and clarity and being able to put aside fear when it comes to making decisions. In essence, critical thinkers like to move things forward rather than moving backward or procrastinating, because they thrive on progression. In addition to this, choices often have to be made even when we do not have all the information we need to make them with confidence. When facing any kind of a challenge, someone often has to take the lead and make the hard decisions others shy away from. Effective critical thinkers realize that, more often than not, it is necessary to take the initiative and make a decision even if it ends up being the wrong one. To them, that is preferable to not making any decision at all.
- *Honesty* - is important in any sense, but it is especially important in regard to critical thinking. Moral integrity, ethical consideration and action, and global citizenship practices are all hallmarks of effective critical thinkers. It is not a surprise that honesty resides at the core of all these things. We see in such people a strong desire for harmony and fulfillment in the world, and the part of attaining this involves pursuing honesty in all endeavors and relationships.
- *Willingness and flexibility* - encompass a number of key considerations for the critical thinker. They include but are not limited to things like the ability to: learn from their own personal mistakes and shortcomings, challenge the status-quo when the need arises, open-mindedly embrace other opinions and views that challenge their own, reconsider and revise their opinions in the wake of new evidence, listen actively rather than simply wait for their turn to talk and constantly improve, learn, and excel.
- *Creativity* - there's no question that effective critical thinkers are also largely creative thinkers. Creativity has unquestionably defined itself as a requisite skill for having in the collaborative modern workforce. Critical thinking in business, marketing, and professional alliances relies heavily on one's ability to be creative.

IV. THE RESEARCH METHODOLOGY

A. Research Goals and Methods

The aim of research conducted during January 2019 among the Algebra University College students of computing (technical field), digital marketing (social sciences field), and design (artistic field), was to determine if students integrated the traits of critical and creative thinking into their own thinking process.

The questionnaire was anonymous and it consisted of 12 questions with the possibility of choosing between 3 answers, as well as 12 claims with which the students were asked to express their attitude according to the 5 degrees of the Likert's scale of agreement.

The questions were categorized according to the 6 traits stated by D. H. Pink. The results of the survey themselves are analyzed according to them. Through these survey questions and claims, the research addressed the extent to which the students are ready to integrate critical and creative thinking traits, while determining which type of thinking the students were more prone to based on their particular study program and gender.

A quantitative method was used for the research results analysis, and the data processing of the survey results was made by the Microsoft Excel tool.

B. Participants

113 students were polled in the survey. The overall ratio of all participants according to gender is 73% male to 27% female participants. 7% of surveyed student are graduate students and 93% are undergraduate students. The highest percentage of student population sample included study computing (Applied Computing and Multimedia Computing), followed by social sciences (Digital Marketing) and the lowest percentage study design (Visual Communication Design and Creative Design and Communication Management). The participant structure according to their study program is visible from Chart 1.

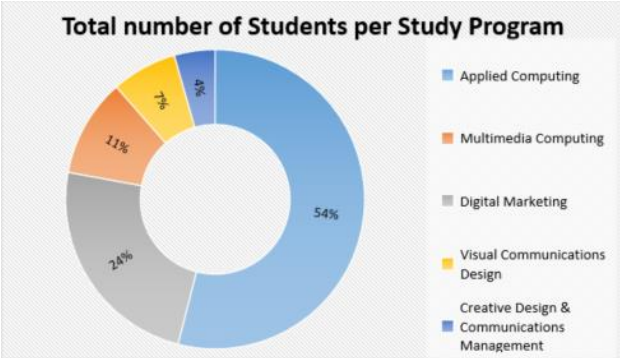

Chart 1. The participants' structure per study program

C. *Research Results*

The data of the poll itself were interpreted through the 6 categories named by D. H. Pink. Furthermore, three dimensions the first of which is the participants' study program, are taken into account. Apart from the names of the study programs, the first dimension further entails the field of studies, i.e. technology, social sciences, and arts. The second dimension is possible the gender differences and the third dimension is possible differences in students' opinions that arise from the distinction of their private and professional life.

Interpretation of results by categories:

1. Functionality vs. Design

By the first category questions, the intent was to determine whether students consider that the functionality of an object is more relevant or the design of an object is more relevant, or they perceive them as equally important. The same question was asked specifically for private and specifically for the business environment. The survey results showed that 49% of technology students deem functionality relevant, while only 29% of art students share their opinion. Contrary to that, only 2% of technology students think the design is relevant, with 15% of art students feeling the same way. The largest percentage of students of all study programs, around 60%, believes functionality and design are equally important. The results also showed there is no significant difference in opinion in regard to the participants' personal and professional life.

2. Arguments vs. Story

The second category question was aimed at mastering new knowledge, i.e. whether in these situations the arguments or the story told and the added context was more relevant. The survey results showed that the students of all study programs find arguments and the story told equally relevant. This was confirmed by 68% of technology students, 70% of social sciences students and 77% of art students. In addition, no significant difference was found in regard to their private and professional life.

3. Details vs. Big picture

In the third category, students were asked whether it was more relevant for them to focus on details or the big picture. It is visible from the Chart 2. that the students of all areas find it equally relevant to focus on details and the big picture.

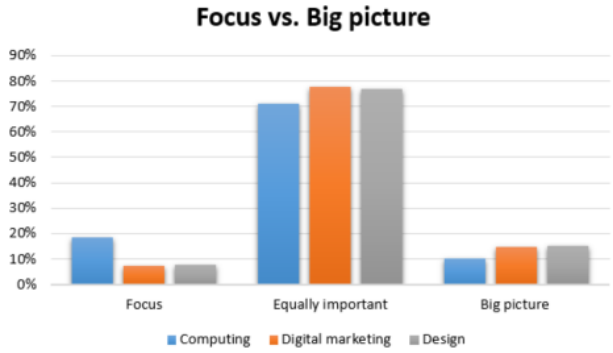

Chart 2. Distribution of the answers to the question about the importance of *Focus in regards to Big picture*

4. Facts vs. Empathy

The fourth category refers to facts and empathy. The Chart 3. shows that to students facts are more relevant in a professional environment (cca 60% find facts more relevant), while in personal live facts and empathy are equally important (according to 80% of the participants). No significant difference in students' opinions is observed in regard to the area of their studies.

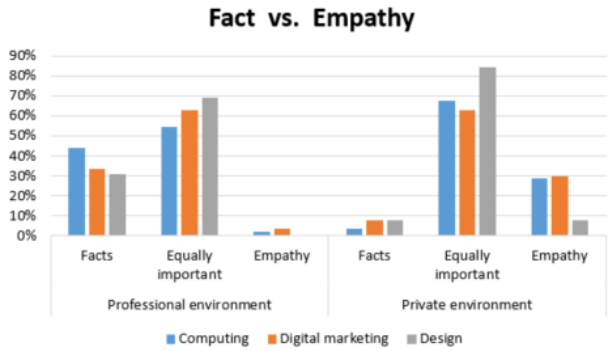

Chart 3. Distribution of the answers to the question about the importance of *Fact in regards to Empathy*, both in a professional environment and in a private environment.

5. Seriousness vs. Play

In the fifth category, the students were asked about the importance of play in regards to seriousness in a professional and a private environment. The results showed students think that in a professional environment seriousness is more important (cca 60% of them) than play, while in personal life the majority considers play and seriousness are equally important (cca 70%). No significant differences in opinions were observed in regard to the participants' study programs.

6. Accumulation vs. Meaning

In the sixth category, the students were asked whether material (accumulation) or spiritual wellbeing (meaning) is more relevant. The results have shown that for the majority of students material and spiritual wellbeing are equally important, both in their professional and their personal life. Students percentage agreed that the material and spiritual wellbeing are equally important, both in a professional and personal environment, is listed in Table 2.

Study program	Professional environment	Private environment
Computing	69%	59%
Digital Marketing	70%	78%
Design	69%	54%

Table 2. Percentage of the students that agreed with the statement: *The material and spiritual wellbeing are equally important*, both in a professional and personal environment.

Based on gender, three notable differences were observed:
1. when solving a problem, more male students prefer working step by step, one section at the time (75%) than female students (60%);
2. more male students (66%) than female students (50%) prefer to act based on their own ideas and to come up with their own solutions than to follow specific predetermined rules and structures;
3. more male students (36%) than female students (20%) do not like unpredictable things.

D. Limitations and recommendations for future researches

It is important to emphasize the difficulties encountered during the research and ultimately its limiting elements; the method of distributing the survey was limited to sampling, and a smaller number of design students is generally enrolled in the art study programs compared to computing students at this time on Algebra University College. In future research, it would be advisable to conduct research on an equal sample of students of each study field so that more relevant data can be acquired.

V. CONCLUSION

The majority of all surveyed students consider that function and design matter equally, it can be noticed that design students nevertheless give a much greater advantage to design than functionality.

Also, the majority of all surveyed students find arguments equally relevant as the story, both in their private and professional life, as well as the majority of participants, focus on the details consider equally important as the big picture. But, according to their opinion, the arguments are more relevant in a professional environment, while in personal live arguments and empathy are equally important. Also, they think that in a professional environment seriousness is more important than play, while in personal life the majority considers play and seriousness are equally important. It can be concluded that empathy and play are not yet included in the professional environment to the extent that it would be instructive, and that rational thinking overcomes creativeness.

However, for the majority of students accumulation and meaning are equally important, both in their professional and their personal life.

It is evident that in an ever-changing human existence and world, the one thing remains the same: by adopting the new ways of thinking and behaving, such as in this time integrating the critical and creative thinking, people can again piece together the longtime split mind into a whole (new) mind and thus adapt to new environment by creating a whole (new) world.

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Metamodeling SNAP, a Multi-Criteria Method for Effective Strategic Decision Making on e-Learning Issues

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***Abstract* - Many e-learning decision-making problems are multi-criteria problems, and their analysis requires the application of appropriate decision-making method. Since e-learning is a domain which is characterised by the existence of influences and dependencies between the decision-making elements, some of the most suitable methods for the multi-criteria analyses are the Analytic Network Process (ANP), Weighted Influence Non-linear Gauge System (WINGS) and Social Network Analysis Process (SNAP). ANP is the most well-known and most often used multi-criteria decision-making methods appropriate for the domains which are characterised by the existence between influences and dependencies between the decision-making elements, such as the e-learning domain. This paper presents the basic steps of the relatively new method, SNAP method, and its ERA metamodel. The SNAP method combines two methods, ANP and Social Network Analysis. (SNA) The integration of those two methods diminishes some of the weak-points that appear in the application of the ANP. The role of the ERA metamodel of SNAP is double: it helps in the understanding of the SNAP steps, and it is a base for potential SNAP software support development.**

Keywords - e-learning, decision making, ANP, SNAP, ERA, model

I. INTRODUCTION

Strategic planning on e-learning requires multi-criteria analysis of many aspects of e-learning. The decision-making analysis of e-learning issues often requires the application of specific multiple-criteria decision-making (MCDM) methods. There are many MCDM methods, and firstly, we have to decide which one of those to apply.

From the position of this paper, we will divide MCDM methods into two groups:

- MCDM methods that do not enable modelling influences and dependencies between the elements of decision-making problem,
- MCDM methods that support modelling influences and dependencies between the elements of decision-making problem.

Elements of the decision making structure are decision-making goals, criteria (grouped) into clusters and the alternatives. Examples of the MCDM methods from the first group are Analytic hierarchy process (AHP) [1], [2], Electre, Topsis, Promethee, and many others. Examples of MCDM methods from the second group are Analytic Network Process (ANP) [3]–[5], Weighted Influence Non-linear Gauge System (WINGS) [6], and Social Network Analysis Process (SNAP). The number of methods in group 1 is much higher than the number of methods in group 2.

Let's see a simple example presented in Figure 1. The figure shows a simple decision-making problem that is consist of four criteria (1, 2, 3, 4) and the task is to determine the weights of the criteria.

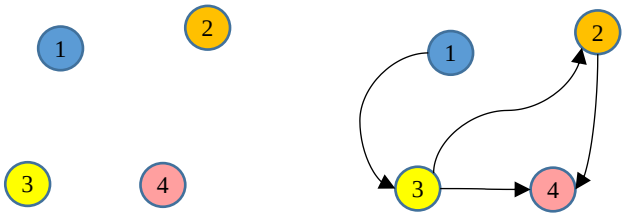

Figure 1. Decision making problem without (left) and with (right) influences between decision-making problem elements [7]

If we have the situation as presented at Figure 1 (left), then any decision-making method can be applied, and if we have the situation as in Figure 1 (right), then we should not apply the decision-making methods from group 1, but only decision-making methods from group 2. If we apply MCDM methods from group 1 in this situation, then we will get the results that are not accurate.

When talking about e-learning decision-making problems, some previous researches discussed that most of them are similar to the fight situation in Figure 1 [8], [9]. Criteria in MCDM problems influence each other and to get accurate results which should apply the method that will take into account those influences. However, in many situations, actually, in most situations, when e-learning issues were discussed, some method from group 1 has been applied. In most cases, this was the AHP method [10].

The most well-known method that enables modelling influences between the elements in decision-making structure is the ANP. However, this method has many characteristics that are not favourable and because of which users avoid application of ANP and use AHP instead.

Those characteristics are discussed in detail in [11]. They are primarily related to the complexity of the ANP, but also some other features. One of those is that the ANP models influences between criteria, but does not take into account their strength (general importance of the criteria with respect to the goal).

Newly developed method called SNAP (Social Network Analysis Process) has the feature that both components are incorporated into criteria weighs: (internal) strength/importance of the criteria and the intensity of affecting/influencing other criteria.

In the next section, we will present SNAP method and demonstrate it on one example, and after that, we will present the ERA model of this method and compare it to ANP ERA model.

II. SOCIAL NETWORK ANALYSIS PROCESS (SNAP)

SNAP method has been developed as the alternative to the ANP method which has many weak-points regarding complexity. SNAP combines ANP (AHP) with SNA in a way that weak parts of the ANP are replaced with specific steps of the SNA which have lower complexity. Those two methods are first time combined in the paper [9] where just the idea of integrating those two methods has been presented. After that, a full first version of the SNAP method has been presented in paper [12].

The steps of the decision-making method SNAP are [12]:

- Component 1: identify the strength of each criterion (AHP) (adapted from [13], [1]):
  - —Create matrix *A*, dimension is $n \times n$, where n is the number of criteria
  - —Do pairwise comparisons of each two criteria with respect to the goal by using Saaty's scale and fill the matrix *A*, $a = \frac{1}{a_{ji}}$ holds
  - —Calculate $\sum_{i=1}^{n} a_{i1}, \sum_{i=1}^{n} a_{i2}, \dots \sum_{i=1}^{n} a_{in}$,
  - —Make matrix B, the dimension is $n \times n$,
$$b_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}$$
  - —Create matrix C, dimension is $n \times 1$, $c_{i1} = \frac{\sum_{k=1}^{n} b_{ik}}{n}$
  - —The strength of criterion *i* is in the *i*-th row of matrix *C*
  - —Calculate inconsistency (calculate $CR = \frac{CI}{RI}$, where RI is a random index defined as the consistency index of the matrix randomly generated by pairwise comparisons; CI is the consistency index calculated as $CI = \frac{\lambda_{max} - n}{n-1}$ and λ_{max} is the biggest eigenvalue of the matrix *A*)
- Component 2: identify the intensity of the influences between criteria:
  - —Create a matrix of influences, *D*, D_{ij} represents the influence between criteria *i* and *j*; if there is more than one decision maker who gave their input in terms of influences (values 0, 1, 2, 3 and 4 represent the range from "no influence" to "very high influence"), we can average them
  - —Calculate $P_D I(N_i)$ and $P_D O(N_i)$ [14]
$$P_D I(N_i) = \sum_{j=1}^{N} w_{ji}, (i \neq j)$$
$$P_D O(N_i) = \sum_{j=1}^{N} w_{ij}, (i \neq j)$$
  - —Calculate $P_D O(N_i) - P_D I(N_i)$
  - —Normalise the $P_D O(N_i) - P_D I(N_i)$
- Aggregate the strengths of criteria (from Component 1) and intensities of the influences between criteria (from Component 2) to final criteria weights.

To demonstrate SNAP method and compare it to ANP, we will use an example presented in [12], but it will be changed in a way that two clusters of criteria will be formed to describe the difference between ANP and SNAP better. The example is related to the case *evaluation of the scientists*, and the problem structure is consist of three clusters: goal, cluster of criteria related to the teaching (courseware – co, grades from students – gr) and cluster of criteria related to the science (papers – pa, projects – pr, citations – ci). The structure is presented at the Figure 2. The black arrows represent dependencies of five criteria on decision making goal (G), and red arrows represent dependencies between the criteria.

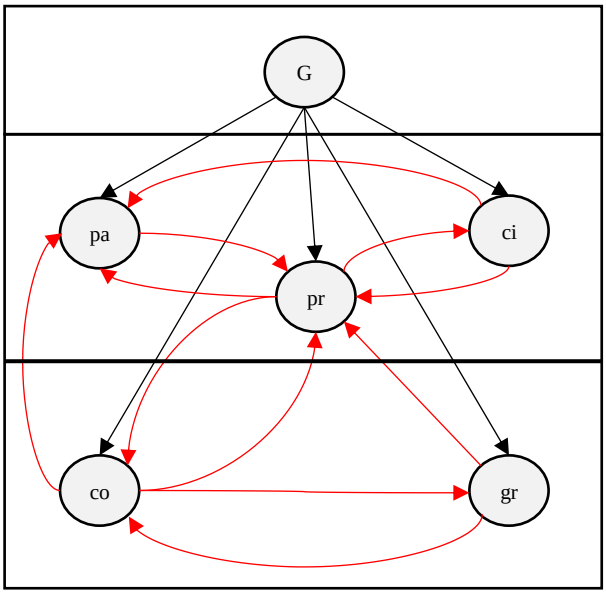

Figure 2. Decision making problem structure – evaluation of the scientists (adapted from [12])

Methods from group 1 (a division of MCDM methods in the Introduction part of this paper) takes into account the black arrows when calculating the criteria weights. On the other hand, the ANP takes into account the red arrows. Finally, the SNAP method takes into account both, red and black arrows. Actually, the ANP can obtain data about black arrows as well, but in future ANP steps those data do not have any influence on the finale criteria weights (to understand this better, you can consult the paper [11], section 4.2.).

After the problem has been structured (Figure 2), in ANP we should do the following steps in terms of giving inputs:

1. Comparisons on the node level using the Saaty's scale:
   a. Comparing criteria in cluster *teaching* with respect to the goal,
   b. Comparing criteria in cluster *science* with respect to the goal,
   c. Comparing *pa* and *pr* with respect to the *co*,
   d. Comparing *pa* and *pr* with respect to *ci*,
   e. Comparing *pa* and *ci* with respect to *pr*,
2. Comparisons on the cluster level using the Saaty's scale:
   a. Comparing *science* and *teaching* with respect to *goal*,
   b. Comparing *science* and *teaching* with respect to *teaching*,
   c. Comparing *science* and *teaching* with respect to *science*.

For users, especially complex and fuzzy are the comparisons 1cde and 2bc. It is often hard to understand for the user what they are comparing. In step 2, we have to three times compare the same two clusters, every time with respect to a different cluster and users often do not differentiate those three comparisons.

In SNAP, for this example, we have to do the following to give inputs about the decision-making problem:

1. Steps 1ab and 2a from the ANP steps list,
2. Identify the intensities of influences between criteria (red arrows at Figure 2).

We can see that step 2 in SNAP replaces the most misunderstanding steps of the ANP. The result of the SNAP step 2 is presented in Figure 3.

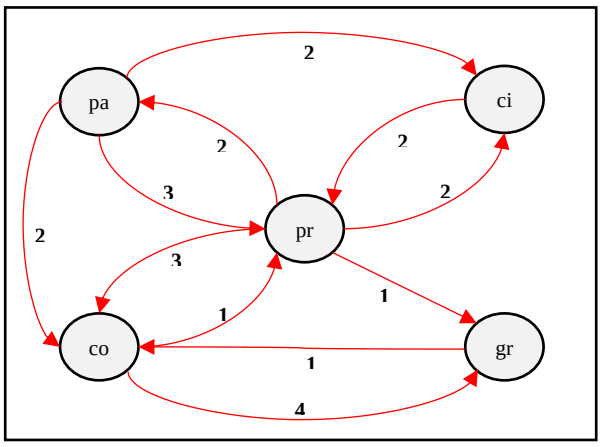

Figure 3. Influences between the criteria in the problem evaluation of the scientists ([12])

After the inputs are identified, other steps of the ANP and SNAP can be automatically implemented. Finally, we will get the results that are presented in Table 1.

TABLE 1. CRITERIA WEIGHTS BY SNAP AND ANP

Criteria	SNAP	ANP
pa	0.2794809	0.305
pr	0.2535056	0.418
gr	0.1557129	0.013
co	0.1706002	0.095
ci	0.1407004	0.167

III. METAMODELLING SNAP

The research of SNAP and detailed comparison with ANP can be found in the paper [15]. In this paper, we will present ERA metamodel of both methods, ANP and SNAP and compare them and finally, evaluate their complexities.

Metamodeling is the analysis, construction and development of the frames, rules, constraints, models and theories applicable and useful for the modelling in a predefined class of problems. This concept is composed of the notions of the terms *meta* and *modelling*. Thus, metamodeling is the construction of a collection of concepts within a certain domain, a precise definition of the constructs and rules needed for creating semantic models [16].

In Figure 4 we can see the ERA metamodel of the ANP method. The ERA metamodel is consist of the following tables:

1. *Goal* – it contains data about the decision-making goal,
2. *Clusters* – this table contains data about the clusters of criteria in the decision-making problem,
3. *Criteria* – this table contains data about the criteria in each cluster,
4. *CompGoal* – this table contains data about the comparisons of both, criteria and clusters, with the respect to the decision-making goal (analogy with steps 1ab, and 2c in the previous section)
5. *CompCriteria* – this table contains data about the pairwise comparisons of criteria with respect to other criteria considering the dependencies between the criteria (red arrows in Figure 2) (analogy with steps 1cde from the previous section). This Table is connected with the table of Clusters because, in ANP, we compare the criteria from the same cluster only.
6. *CompClusters* – this table contains data about pairwise comparisons of clusters with respect to other clusters (analogy with steps 2bc in the previous section).

There are eight relationships in the ERA model. The data about the decision-making problem that is the most confusable for users to input are written in tables *CompCriteria* and *CompClusters*.

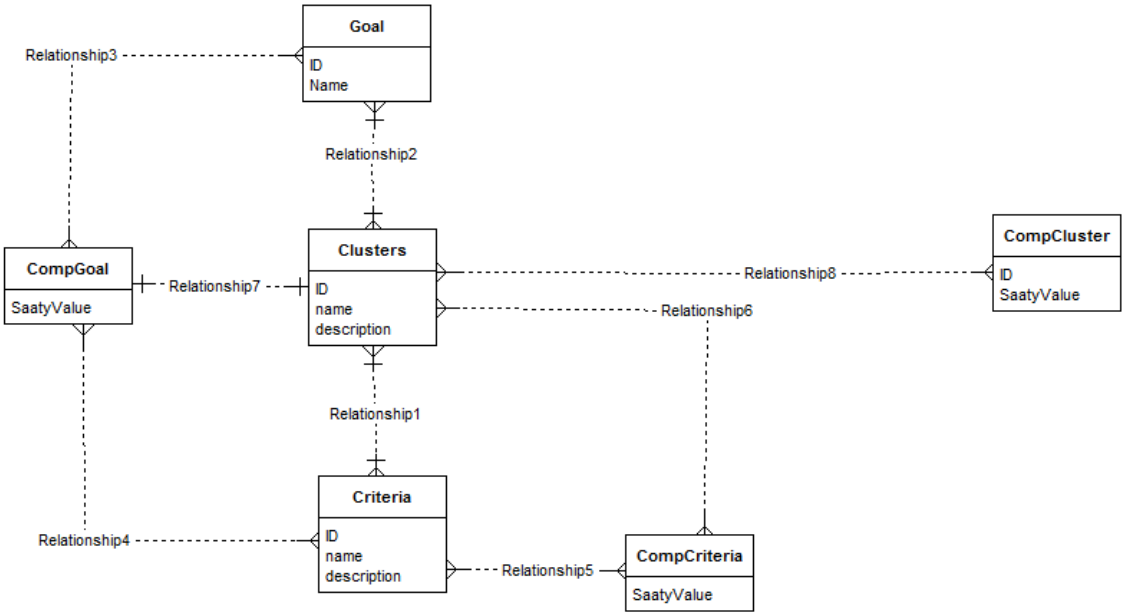

Figure 4. ERA model of the ANP method

The ERA model of the SNAP method is presented in Figure 5. This model includes four tables from ANP ERA model – the first four tables from the previous list. In addition to that, SNAP ERA model contains a table *Influences* which covers the data about absolute influences between the criteria (analogy with Figure 3) that are needed for calculating priorities for Component 2 of the SNAP method. The concept of influences is opposite to dependencies – this is why arrows in Figure 3 have the opposite direction than the arrows in Figure 3. In the ANP, we model dependencies, in SNAP we model influences.

The table *Influences* is prerequisite for applying the SNA part of the SNAP method – calculating the incoming and outcoming centrality degree of specific criterion in the decision-making model. The procedure of giving inputs for this table replaces all steps in the ANP that are misunderstood to the users – steps 1cde and 2bc from the previous section. The reason why this table can replace those steps in ANP is in the fact that - when we make comparisons of the criteria with respect to other criteria (1cde) and comparisons of the clusters with respect to other clusters (2bc), our reasoning should start from the intensities of the influences between the criteria.

Finally, when comparing the raw number of the tables and relationships of presented two ERA metamodels, we can see that the number of both, tables and relationships, is

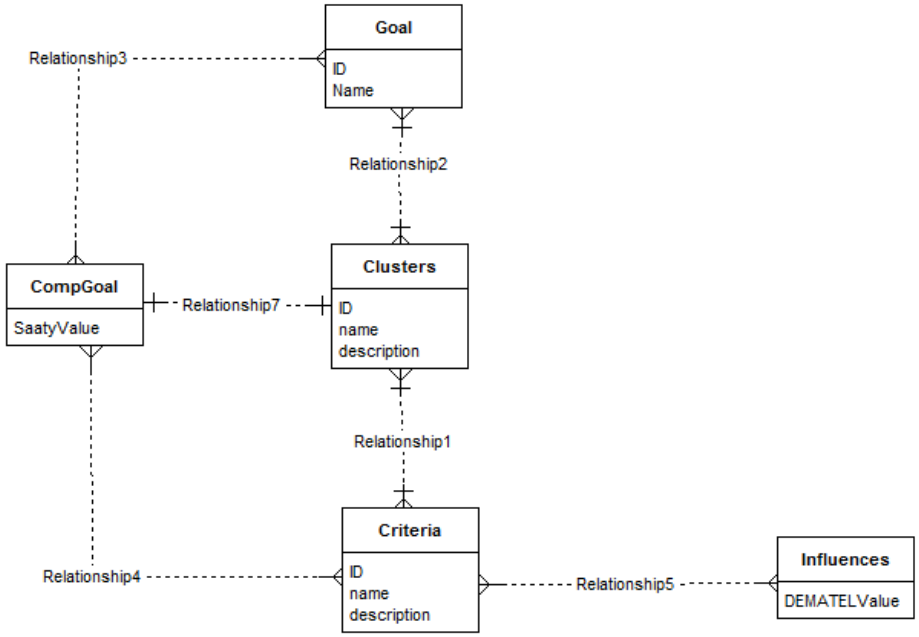

Figure 5. ERA model of the SNAP method

lower in SNAP metamodel which additionally proves the lower complexity of the newly developed method when comparing to the ANP.

IV. CONCLUSION

Many e-learning decision-making problems are multi-criteria problems. Their analysis requires appropriate methods. Since there are influences and dependencies between decision-making elements in e-learning problems, methods that support this feature are welcome. The most well-known method with this feature is ANP. However, there are some weak-points of ANP which demotivates users to use it. This is why the SNAP method has been developed. SNAP is an integration of ANP method with SNA method which is less complicated than the original ANP method.

In this paper, we presented the method SNAP and gave its metamodel. The metamodel is essential because of several reasons:

1. ERA metamodel can help us to understand the SNAP method better,
2. By comparing the ERA model of SNAP with ERA model of ANP, we can additionally argument the lower complexity of the SNAP considering the ANP.
3. The provided ERA metamodel can be a starting point in developing software support for the SNAP. Of course, additional modification will be required.

ACKNOWLEDGEMENT

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Information Technology as a Support to Education

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***Abstract* - The right to education is guaranteed to all persons by the international system of human rights based on the Universal Declaration of Human Rights, a document that was adopted by the international community seeking better and humane future after the two world wars.**
To secure the right to education for blind and visually impaired persons, the Department of Information Sciences of the Faculty of Philosophy in Mostar, together with the Faculty Library, has launched a project for the adaptation of teaching materials for blind and visually impaired persons.
The question is how to tailor the teaching materials and literature needed for learning blind and visually impaired persons as well as selection of the proper method for adaptation. Through the pilot project we have tried to find out what is happening with the information the listener receives by signals through the audio channel and whether the information is better perceived when the signal is human speech rather than artificially synthesized sound on the computer.
Methodology: The audio recording of the teaching units has been made from several teaching courses, after which the recordings were edited for reproduction. That was the first test set.
The second test set was a textual teaching material adapted for sound reproduction on a computer using computer speech synthesis software.
The purpose of the research was to find the optimal solution for adapting teaching materials to blind and visually impaired in order to provide such persons with the same opportunities as persons without such impairments.

***Key words* - information processing, teaching materials, technology in education**

I. INTRODUCTION

Contemporary education demands changes of knowledge and skills acquired in the new educational environment. Changes in education and lesson presentation can be noticed in changes of the materials and mediums on which the learning material is prepared. Education is also different by technology usage, intermediation of lesson content applied to the capabilities and features of students, and teacher's skills of teaching and technology usage in class.

Everyone has a right to education due to the international system of human rights which arose from General human rights declaration, a document with which, at the end of two world wars, the international community decided to work on the better and more humane future.

Exercising that right gives everyone a chance to develop their capabilities and gain intellectual, spiritual and social independence by acquiring knowledge, skills, values and attitudes.

On state level, there is no reliable data about the number of people with disabilities included in higher education, it can be safely assumed that this number is low. At the same time, the rights to education of the students with disabilities are guaranteed by series of legal acts and specific rule books of institutions.

Convention about the rights of disabled people which clarifies what the realization of human rights means in the context of disabilities, defines disability like this: "(…) Disabled persons include those who have long-term physical, mental, intellectual or sensory damage, which, paired with different obstacles, can prevent their full and efficient involvement in society of equal basis with the others."

Despite the fact that laws and rule books do not state the forms and ways of offering adjustments to the students with disabilities, continuous work is performed on design of help with inclusion, on equal rights. Bosnia and Herzegovina ratified the Convention in the March of 2010 and obligated the Ministry of human rights and refugees for its implementation. Council for people with disabilities, founded by Council of ministers of BiH and consisted of representatives of different levels of government and non-government organizations oversees their work. In realizing this right, the signatory states are required to:

a) Persons with disabilities cannot be excluded from the general education system based on their disabilities.
b) Reasonably adjust to the individual needs,
c) Within the general educational system, provide necessary help to people with disabilities to ease their effective education.
d) Offering effective and individualized means of support in the environments that contribute the most to the academic and social development, in harmony with the goal of total inclusion".(...)

Sadly, regardless of all the conventions and laws, the everyday of people with disabilities is filled with obstacles - movement obstacles, obstacles regarding the communication with others, obstacles regarding everyday tasks others often do not think about.

When talking about the right to education under equal rights, the first question directed to the faculties is always about the type of adjustments and the type of support they offered regarding the disabilities of students. Sometimes adjustments can be offered, but they are not individualized enough which means that specific obstacles a certain student runs into were not dealt with. It is very important to listen to these students because they are the ones who know best about the way they learn and function. In some cases, students, despite the corresponding adjustments, fail to meet the academic standards, but that can happen to any other student without these disabilities. A special problem can be the attitude of certain professors to free these students of certain obligations or to lower the criteria instead of finding the alternative way that the student can fulfill regarding his possibilities.

To realise and consummate their rights, people with special needs, especially the blind and visually impaired, need the possibility of adaptation to realize their rights. In this context, right to education demands adjustability.

Adjustability implies that education is flexible, meaning that it can be adjusted to different needs of different students, instead of students adjusting to the school, which is, sadly, a common situation in practice.

To ensure the right to education to the blind and visually impaired persons, the department of Information Sciences of the Faculty of Humanities and Social sciences of the University of Mostar, working with the faculty library, has started the project of preparation of learning materials for the blind and visually impaired persons.

To the Faculty, as an educational institution, this project was especially interesting for more reasons. The first one was to learn how to act in a specific case regarding the preparation of learning materials. The second interest rose from the realisation that additional knowledge and skills were essential for preparation of these learning materials, which indicated the need of education of teachers in order to apply this new educational technology. Faculty of Humanities and Social Sciences educates teachers of various profiles and one of the tasks of the Department of Information sciences is to educate teachers who will, through their assignments in school, work on inclusion and education on technology usage. From this project rose the question of methodics of information and IT education or what we call the literature of the new age which is essential in the new educational environment. In this context arose the question of curriculum of the very Department of Information sciences and what should be included in the program. This was supposed to give birth to the recommendation to the faculty in the sense of improvement and defining the Office and work with people with disabilities.

II. ADJUSTMENTS IN EDUCATION

In contrast to the classical paradigm of educational system which is centered around educational issues, new directions are born through Declaration of educational rights under equal conditions, job market that implies usage of ICT. This definitely implies changes to the educational system. Today's market of all educational profiles expects the improvement of all existing competences, and, parallel to that, acquiring new ones. Information, IT and digital competence imposed themselves as one of the essential contemporary competences that contemporary students and future employees, must learn to successfully compete during job search. Since large emphasis has been put on digital competence which has its center in IT education, big changes are happening in the whole classical education paradigm which needs to be modernized in the form of its ICT and digital version. Regarding this, big changes, conditioned by widespread digital revolution, are happening in the educational content of all profiles of teachers, especially in the educational contents in the area of IT teachers education. Contents are being modernized according to the demands of the job market. Digital revolution greatly influences the features of contemporary students who completely belong to the digital generations. According to changes these students are a part of, their teachers should change too and also adjust their teaching to this new generations of students. All these changes are conditioned by modernized educational technology whose cornerstone of educational activity is realized through available technologies and e-learning systems.

Changes influencing the classical educational process are in its digital version, especially visible in the contemplations of presenting the educational contents to students, which manifest themselves based on the usage of teaching methods appropriate to the e-environment. The other stimulus is the Declaration of rights to education which stimulated the inclusion of people with disabilities to the education system where the search for the adaptation of learning methods and teaching emphasised the interest which is directed towards creation of new teaching methods and ICT usage in class for realisation of right to education and improvement of access to the educational materials and the adjustment of educational materials for learning.

The phenomenon of learning, in a particular lesson, is based on three tasks of teaching; material, functional and educational. Material task refers to the need of a student to acquire certain facts in a lesson. Based on the acquired facts, generalizations are based, but also new facts are based on generalizations. Functional task of class diverts the attention to the development of intellectual, expressive, sensory and practical abilities, while through the moral task of education, physical, work, moral and aesthetic values are attempted to be developed [11]. These three tasks will not differ on any of the educational levels, they will only be accentuated differently based on the educational level. The tasks are, in contemporary lesson, expressed in the form of the goal of educational process which is described through the results of learning which are, based on the Bloom taxonomy of learning, classified in three domains. Since we are talking about higher education, we took the taxonomy of the cognitive area which develops cognitive abilities through acquiring different levels of knowledge which are classified in six

stages; factual knowledge, understanding, application, analysis, synthesis and evaluation [4]

In the very process of education, firstly connected with the student, it is important to emphasise the process of teaching which is firstly connected with the teacher [9]. The teacher, during the lesson, helps the student with the acquisition of knowledge, on the higher level of education it is expected that the student explores and acquires knowledge based on the source. Since these sources are learning materials in the form that needs adjustment to be used by blind persons, the idea of research was to find an answer on the question of adapting the learning materials and literature necessary for the learning of blind and visually impaired people and which method to choose for that adaptation. Through the pilot project we tried to find out what happens to the information the listener receives by signaling sound through the audio channel and whether the perceived information is better when the signal is in form of human speech or artificial sound created on a computer.

Educational content needed adjustment since in the very process of teaching, the participants are the participants of the didactic triangle; the teacher, the student and the educational content.

Audio file of lessons from several classes was made, and the recordings were adapted for reproduction. This was the first test group.

The second test group were the educational contents in textual form adapted for sound reproduction on a computer by using a computer speech synthesis program. There were no overlaps between the test groups.

The amount of perceived information was measured for both test sets and comparisons were made. The results we got and working on this research opened up questions we wanted to discuss in this paper. This is the question of education of teachers and of usage of ICT in education. The question of adaptation of learning materials, but also the education of future teachers for the creation of these materials and teaching others to use them through technology in education led us to the question of what can we do as a faculty.

By expanding the basic didactic triangle, to which two more elements were added (intent and conviction), the process of teaching can be observed from five perspectives; transmission, development, apprenticeship, nurturing and the perspective of social reform. The transmission perspective is, as the name says, focused on transmission. This perspective of teaching firstly focuses on the teacher who needs to be well versed with the educational content so he could, as its sender, transmit it to his students who are in the role of recipients. The development perspective is focused on the development of the student's knowledge which the teacher entices by using a multitude of examples that serve for using the students acquired knowledge as a basis for acquiring new knowledge. Apprenticeship perspective refers to the usage of practical assignments the teacher has adapted to certain students, with the goal of realizing the development of the student that is getting more and more independent. Nurturing perspective is kept by the teachers who teach their students that they will certainly succeed based on the effort they put in. The last perspective is of the social reform that is used by the teachers who want to prepare their students for the inclusion into the existing society in order to improve it with their actions [12].

To prepare teachers for communication in education in digital surroundings means to prepare them for using communication in the form of communication model published by an American mathematician Claude Elwood Shannon in 1948. Shannon's communication model from 1948 consists of five parts. The first part is the source of information from which the whole or partial message starts. The message can be of different types, it can consist of words, music or images. So if one, for example, articulates a sentence vocally, the source of that sentence (information) is ones brain. The second part is the sender. The senders role is coding the message that is coded into a signal. In the previously stated example, the sender would be the human voice. The coded message travels by the third part of this communication model, and that is the communication channel. Coded message travels by the communication channel from the sender to the recipient. Since we are talking about articulated sentence, the communication channel it travels by is the air. The fourth part of this model is the recipient who, based on the received signal, decodes the received message. Articulated sentence is received by recipients ears. The last, fifth, part of this communication channel is the destination i.e. the person or a thing the message is meant for. In this case, it is the recipients brain. Another, the sixth, added element that disturbs the uniformity of the message is referred to as the source of the noise in the communication channel [13].

Teaching methods involve the teacher and the student during the whole educational process in all its constituent stages. This is why it is talked about teaching methods because they pertain to the teacher, and learning methods pertaining to the student [3].

There are changes present that, in a digital education environment, demand higher education curriculum changes, demanding from the educational system to be modernized by using ICT in education process and improve digital competences of the teachers [8].

The teachers role is changed in a sense that the teachers now teach the members of the Digital generation who are different students than those of previous generations.

We recognize changes that need to be implemented into the teacher's calling as a teachers role in a frame of e-education in which it is possible to realize a quality level of education if the teacher knows the features of the second generation of Digital students, the technology and new media. The first condition that is required is education of teachers and access to technology. Besides the need to provide the technology, the teachers need to be provided appropriate education about the technology itself, and one of the ways to achieve that is that the colleagues that know more about the technology teach their colleagues who know less. But the systematic education needs to start through formal education. Here is

the role of the faculty. Through the change in the teacher's curriculum, but also through the change of the curriculum of education of the teachers of IT, the faculty can entice the use of IT in education. Relating to this, digital competence becomes the part of every class which means that all teachers should be educated for the use of IT in their educational process. For the beginning it can be a common class for all of the teaching majors.

The second part of the questions, which were opened to us during the research of ways of adapting the teaching materials and the questions which are connected to the right of education for everyone and especially the right to education to people with disabilities, is how, as service providers, provide the support that should be determined according to the specifics and the individual problems of students with disabilities which would include information given to the teaching staff.

What we, by researching literature and the examples of different universities and study programmes, saw, was the existence of the Office for students with disabilities on the Faculty.

III. CONCLUSION

Through the project that started with the goal of adaptation of the education materials to the blind and visually impaired people on the Faculty of Humanities and Social Sciences, questions that we tried to systematically answer in this paper in an attempt to secure equal rights to education with the usage of ICT singled themselves out. Through the research we made students and teachers aware that it is needed to be educated about the characteristics of people with disabilities, education in applying ICT in education, preparation of teachers for usage of technology in digital surroundings. We started with solving one problem, but in solving it, we got a lot of segments aware of technology usage in education and education of people with disabilities. It was shown that a lot of things were legally defined, but the practice and realization is far from what was legally said. The idea that we should try to do, as much as we can in our own surroundings, leaning on what is enabled and what we can, actually falls under the Faculty mission.

The first question to the Faculty is always of the adaptations and the type of support it secures regarding the disabilities of students. Sometimes adjustment can be offered, but they are not individualized enough which means that specific obstacles a certain student runs into were not answered. It is very important to listen to these students because they are the ones who know best about the way they learn and function. In some cases, students, despite the corresponding adjustments, fail to meet the academic standards, but that can happen to any other student without these disabilities. A special problem can be the attitude of certain professors to free these students of certain obligations or to lower the criteria instead of finding the alternative way that the student can fulfill regarding his possibilities. All of these questions can be answered by the Office for people with disabilities which would be based on a volunteered basis and would consist of students, teachers and a lawyer.

Still, this problem can only be solved in the long-term by introducing extra classes on the faculties that will prepare the future teaching staff for work with students with disabilities and/or special needs. Libraries also contribute to education of the blind and visually impaired people. This presents a possibility that through student practice the learning materials can be digitized and prepared for learning by using technology and computer speech synthesis software or recording the materials and making audio files of lesson units and literature, and in this way enable the right to higher education, and in doing so, the right to use a series of adjustments and resources meant for them.

This means special services or regulations do not need to be made, but within the existing ones, it is needed to additionally clarify how some rights or services can realize people that are different than the average, so, with respect to all forms of human dissimilarities, disability being only a part of it. In such situations we question each individual case, and establish individual the circumstances

The greatest problem we see in the system of education in Bosnia and Herzegovina is the lack of systematic support. Under systematic support, we mean consistent offer of support services through allocation of sufficient financial resources to the educational facilities in order to improve accessibility, technical apparatus, learning assistance, staff in the Offices for students with disabilities, digital textbooks, colleague support and formalization of procedures to offer and support with the continued education of the teaching staff.

Acknowledgment. This work was supported by Federal Ministry of Education and Science, Bosnia and Herzegovina [Grant No. 05-39-2388-1/17].

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Teaching Business Mathematics Using Computers

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We are living in the digital world. Are universities actually ready to educate the future experts? Are we ready to teach our students for the future globalized competitive labor market for the jobs that today don't exist? Zagreb School of Economics and Management started the new four year undergraduate program Business Mathematics and Economics for challenging this issue. The main point is in educating the experts who will fill the gap between business practice and the developing digital technologies and STEM. We are teaching business mathematics through case studies, real data and optimization algorithms. How do we do it? In this work we will present some case studies from our university practice where we use the technology for more dynamic mathematics class.

Keywords - digital technology; business mathematics; case studies; dynamic math class

I. INTRODUCTION

Zagreb School of Economics and Management (ZSEM) started a new undergraduate program Business Mathematics and Economics (BME) four years ago to challenge the digital and STEM issues in business practice. Since the companies have to adapt to these trends and execute the digital transformation the question is do they have the right experts to do it. Our students should fill the gap between technical and business people since the companies have the real problems in the communication between these two worlds. BME includes the combination of mathematics, statistics, economics, business administration, finance and computer science. The point is that we teach all these subjects trough case studies, discussions, problems solved using computers and software, projects, presentations and internships.

We also conducted a survey among the mathematicians from the Croatian business practice in order to collect insights about the specific business practice's needs. The results suggest the intensive use of digital technologies and open source software for problem solving. Besides this, the students should get soft skills which will enable them to be good communicators when they have to present their quantitative results to their colleagues from other fields.

Based on all these facts we developed the curriculum which includes an intensive use of digital technology for solving mathematical and economics problems. In the following chapters we will describe how this looks like in our university practice. In chapter II we will describe the problem in a way how we are describing it to our students. In chapter III we will present the solution procedure and the results with economic interpretations. In the chapter IV we will comment some students' impressions, and in the chapter V we will give the conclusions.

II. RELATED WORK

There are not too many related works on this topic. Mostly of the scholars are writing about using computers in teaching mathematics in primary and high schools, but not teaching business mathematics. The paper [1] This paper discusses the impact of the Teaching and Mastering Calculus Computer Courseware (TEMACCC) on the results of the students in the subject Calculus. But the paper doesn't discuss the exact application of computers. In [2] the authors did an experimental study and compared the effect of Computer Assisted Instruction (CAI) and Conventional Method on the performance of undergraduate students in Calculus at Indian institutions, but also without exact examples of the applications. In [7] the examples from business mathematics are given but for the high schools and pupils not having the deeper knowledge of business mathematics.

III. PROBLEM DESCRIPTION

As an example how to illustrate our way of teaching mathematical methods applied in economics, business administration and finance we are considering a case from supply chain management. The students were asked to solve the following tasks.

(1) Based on the data given in Table I model the demand function as a linear function using the linear regression in Excel.
(2) For which prices the model (1) has economic sense?
(3) Determine the inverse demand function.
(4) Determine the total revenue function as a function of demand quantity.
(5) Graph the total revenue function in Wolfram Alpha.
(6) Determine the demand quantity for which the total revenue is maximum and calculate this maximum revenue.
(7) Determine the price for the quantity from (6).
(8) Based on Table II model the total costs function as a linear function of production quantity using Excel.
(9) Determine the fixed and the unit variable costs.

TABLE I. DEMAND AND PRICE DATA

Price	Demand quantity
1	95
5	92
8	80
12	72
18	66
25	55

TABLE II. PRODUCTION AND TOTAL COSTS DATA

Production quantity	Total costs
96	1050
90	1010
84	960
76	850
64	750
50	620

(10) Determine the profit function as a function of production quantity using the total revenue function (4) and total costs function (8).
(11) Graph the profit function using Wolfram Alpha.
(12) For which production quantities the company is profitable?
(13) Determine the maximum profit and the production quantity for which it is obtained.

(14) Determine the average costs function.
(15) Graph the average costs function and comment its rise and fall (increase and decrease).
(16) Determine the coefficient of elasticity of the profit function at the production level 25 and then 60. Comment.
(17) Approximate the profit function with linear function at the production level 20 and comment.

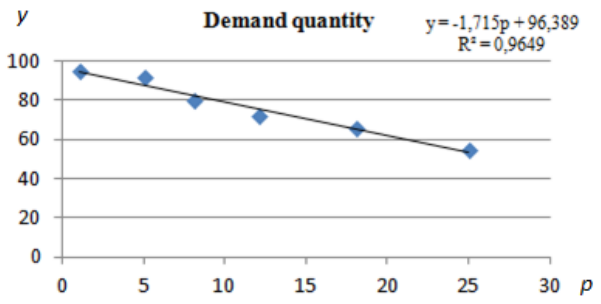


Figure 1. Scatter graph with trend line

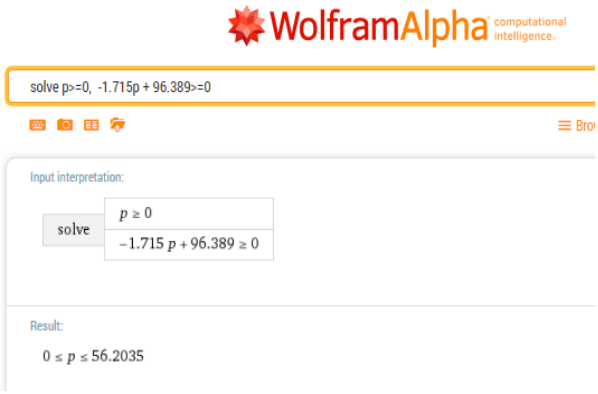


Figure 2. Solution of system (2)

IV. SOLUTION OF THE PROBLEM

To model the demand function we used Excel. First we introduced the scatter graph based on the demand data, Figure 1. Clicking on one of these points we introduced the trend line on the figure with corresponding equation.

$$q(p) = -1{,}715p + 96{,}389 \tag{1}$$

In order to answer the question (2), we have to solve the following system of inequalities:

$$p \geq 0, q(p) \geq 0 \tag{2}$$

We used Wolfram Alpha. The result is on Figure 2. Thus the solution is the interval

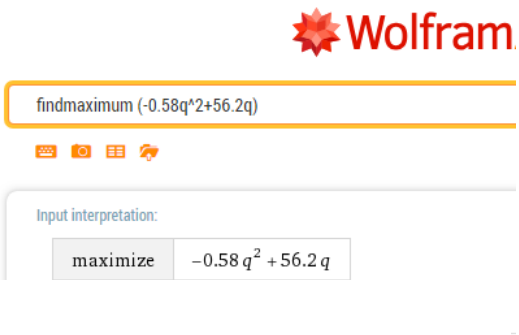
$$0 \leq p \leq 56.20 \tag{3}$$

Inverse demand function can be obtained with Wolfram Alpha and is $p = 56.20 - 0.58q$. The revenue function as a function of demand quantity is now

$$\begin{aligned} R(q) &= p \cdot q \\ &= (56.20 - 0.58q) \cdot q \\ &= -0.58q^2 + 56.20q \end{aligned} \tag{4}$$

The graph of the revenue function is on Figure 3. We can see that the revenue is a quadratic function whose graph is oriented down words. It means that its extreme point is maximum point.

To find the maximum revenue we can use Wolfram Alpha, but also Excel Solver. In Wolfram Alpha the syntax is "findmaximum -0.58q^2+56.2q". Using Excel Solver we have the interface as on the Figure 4 and 5. Thus, till the demand quantity 48.45 the revenue increases while for higher quantities the revenue decreases. Since the price is determined as a function of quantity ($p = 56.20 - 0.58q$) it means that with the higher quantities it is lower and it makes the revenue lower too.



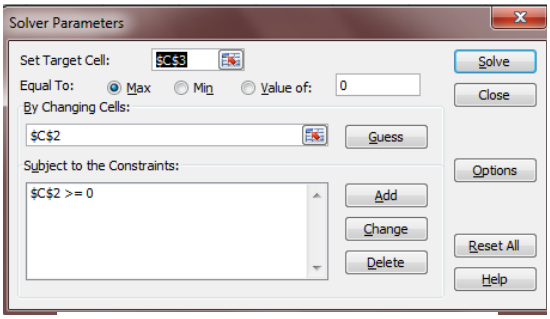


Figure 4. Maximizing revenue function

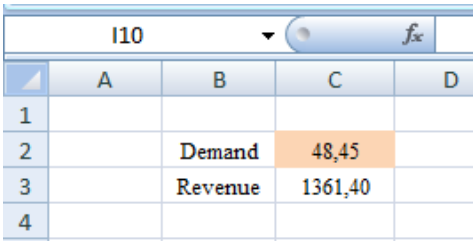


Figure 5. Result from Excel Solver

This discussion is usually very clear to the students due to the graph. The beauty of using computers is that now we can simulate and analyze the revenue behavior depending on the input changes (sensitivity analysis).

Using Linear Regression (Add – in Data Analysis in Excel) we are obtaining the total costs function (Figure 6), $C(q)=9.6164q+136.07$ The fixed cost is $C(0)=136.07$ and unit variable costs 9.61. Using Wolfram Alpha, we are calculating the profit function (Figure 7).

$$P(q)=R(q)-C(q)$$
$$=-0.58\,q^2+46.5836\,q-136.07 \quad (5)$$

The graph of the profit function is in the Figure 8. From this graph we can observe the quantity interval of company profitability and the maximum profit.

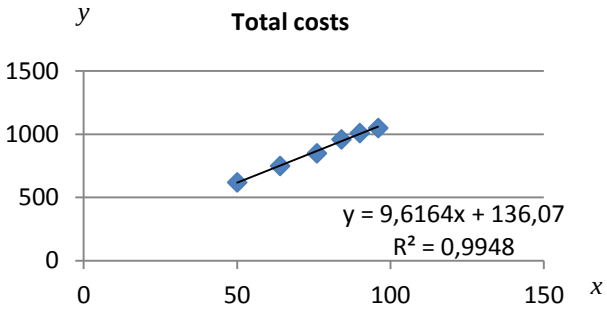


Figure 6. Total costs function

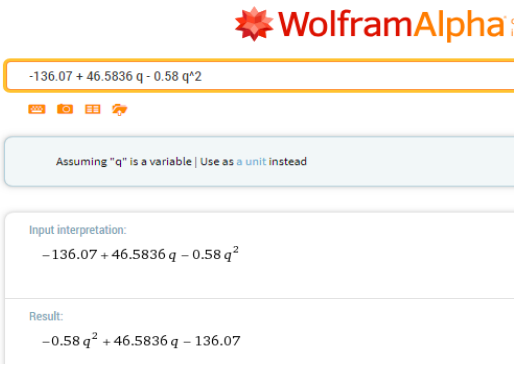


Figure 7. Profit function

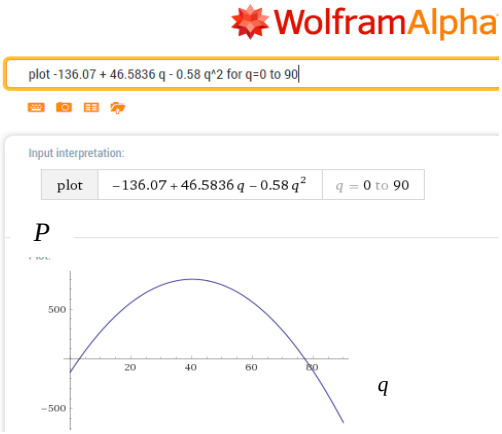


Figure 8. Profit function graph

Calculation gives us the maximum profit 799.29 at q=40.158.

The average costs function is $AC(q)=\frac{C(q)}{q}=\frac{9.6164q+136.07}{q}=9.6164+\frac{136.07}{q}$ (the graph is in the Figure 9). The syntax is "plot 9.6164+136.07/q for q=0.01 to 80".

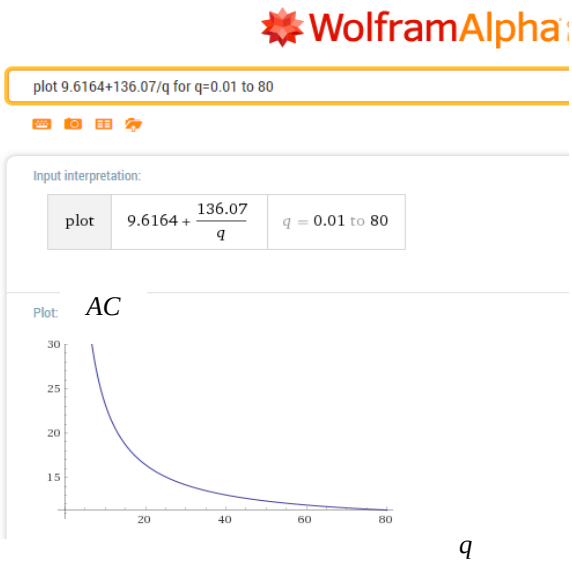


Figure 9. Average costs function

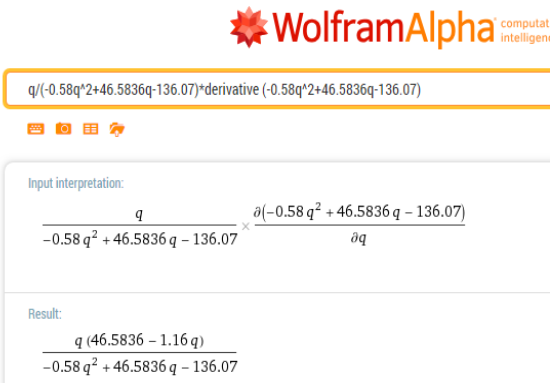


Figure 10. Coefficient of elasticity

In order to approximate the profit function with the linear one we can use Wolfram Alpha and the instruction "series". The syntax is "series -0.58q^2+46.5836q-136.07 at q=20 of order 1". The graph of a linear approximation is the tangent line. The linear approximation is used in economics very often since it's easy to analyze. The economic interpretation of the slope is the marginal value. In our case, the slope represents the marginal profit at the production level 20.

V. IMPLEMENTATION AND STUDENTS' REACTIONS

BME study program is organized as a very applied mathematics and computer science in economics, business administration and finance.

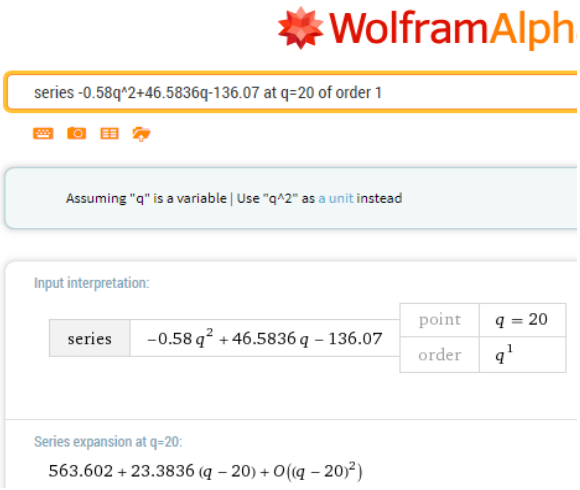


Figure 11. Linear approximation

Every topic that we teach has to include all these issues. And students like this.

At our web site, https://www.zsem.hr/en/study-programs/undergraduate/business-mathematics-and-economics/program/, one can see that at the first year we teach the foundations of mathematics, Mathematical Analysis and Linear Algebra. These courses are the classical courses offered at every mathematics program. The students develop their analytical skills and acquire the fundamental knowledge.

After the first year all the courses are applied and are using the computers, digital technology and, mostly open source, software. The point is to apply. The point is to teach students how to use all the technologies available today. The point is to make them able to solve any problem using the knowledge that they have and can find in their environment very quickly. We are preparing them for the jobs that today don't exist. Thus, we have to teach them to be independent, self confident, agile, flexible, analytical, but also to give them the knowledge.

The material that we prepare for the students is uploaded on Moodle platform which is used by our students very often. They download the files on their laptops or the computers in our computer lab. In Figure 12 the evaluation results on the scale from 1 – 5 related to Moodle usage are presented. The students that answered the question are the students of the second year.

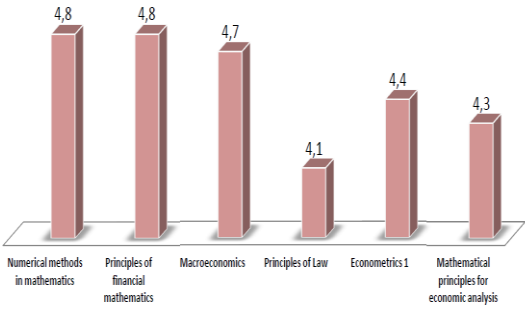


Figure 12. Moodle usage evaluation

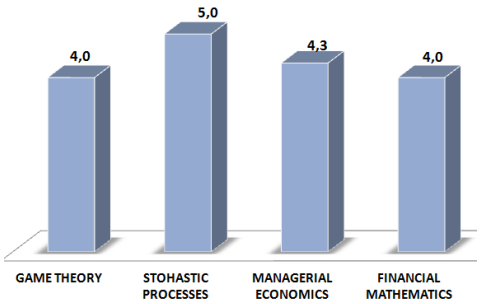


Figure 13. Applicability

When we asked the students from the third year about the applicability of the courses, the evaluations were about 4 (Figure 13). We have to emphasize here that the courses are mostly offered with the work in the computer lab and the material on Moodle. The students are solving small projects and can use the computers wherever they think computer can help.

Also, the midterm exams are organized including the theoretical and practical part. While the theoretical part is a closed book examination, in the practical part they download the data sets or some other related files from Moodle and solve the problems using computers (similar to chapter II).

They are also asked to search on the internet for some topics and then to type their critical opinion in a word file which is submitted for evaluation at the end of the midterm exam. Here is one example from the course Optimization.

Example. A tool box costs $55 to produce. We are considering charging a price of between $150 and $180 for this tool box. For a price of $150, $160, $170 and $180, the marketing department estimates the demand for the tool box in the three regions where the tool box will be sold (see the table). Use Excel.

Price	Demand (in 000)		
	Region 1	Region 2	Region 3
150	38	38	26
160	34	26	18
170	26	22	12
180	22	16	9

(a) Estimate the linear functions for demands as functions of price in all three regions.
(b) Determine the total demand function.
(c) Determine the profit function as the function of price.
(d) Maximize the profit using Excel Solver with the condition that the price we are searching for has to be between $150 and $180. Write the optimal solution and the maximum profit.
(e) Write the estimated demands for all three regions.
(f) Maximize the profit using Excel Solver with the condition that the price we are searching for has to be between $160 and $180. Write the optimal solution and the maximum profit.

Students like this kind of work and examination. They don't have to learn by heart, they are more asked to apply the knowledge from the books and the internet in the problems from the real business practice.

We have many partners from the business practice providing us the data and the problems for our students. Very often the problems are created based on the real problems from the bank industry, retail industry, production, transportation, telecommunication, etc.

The students are offered the programming languages R and Python, and the elective course Machine Learning. The big accent is given to all the digital technologies that can be helpful in business practice.

Our students are going on international exchange and come back home with the opinion that they are very competitive to the foreign students because they study this interdisciplinary program. The classes are in English which contributes to this competitiveness for sure.

Students are also participating in administration of our Facebook page, https://www.facebook.com/zsem.bme/. We often post the problems that we are solving during the class to popularize the application of mathematics and computer science in business practice.

VI. CONCLUSIONS

Four years ago ZSEM started a new four year undergraduate program BME. The program is an interdisciplinary program including mathematics and computer science applied in economics, business processes and finance. This curriculum is a result of the market needs, ZSEM market reaserch and consultations with the Croatian employers.

Following trends of business school digital transformation, the usage of computers, digital technologies and software is very intensive. Besides working in the computer lab and using open source software, we insist on using the digital technologies for solving mathematical problems applied in economics, business processes and finance.

The classes and exams are organized in the sense of strongly digitally oriented processes. The students show their satisfaction in the evaluations executed in the framework of assesment of learning process.

In this work some examples of how to use computers in teaching business mathematics are described, solved and interpreted in the implementation framework.

ACKNOWLEDGMENT

The author thanks to her collaborators who are contributing to deliver this new program at ZSEM.

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Artificial Intelligence Yesterday, Today and Tomorrow

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***Abstract* - Artificial Intelligence (AI) is one of the current emerging technologies. In the history of computing AI has been in the similar role earlier - almost every decade since the 1950s, when the programming language Lisp was invented and used to implement self-modifying applications. The second time that AI was described as one of the frontier technologies was in the 1970s, when Expert Systems (ES) were developed. A decade later AI was again at the forefront when the Japanese government initiated its research and development effort to develop an AI-based computer architecture called the Fifth Generation Computer System (FGCS). Currently in the 2010s, AI is again on the frontier in the form of (self-)learning systems manifesting in robot applications, smart hubs, intelligent data analytics, etc. What is the reason for the cyclic reincarnation of AI? This paper gives a brief description of the history of AI and also answers the question above. The current AI "cycle" has the capability to change the world in many ways. In the context of the CE conference, it is important to understand the changes it will cause in education, the skills expected in different professions, and in society at large.**

Keywords - Artificial Intelligence, Learning, Deep learning, Lisp, Prolog, Expert Systems, Fifth Generation Computer, Emerging technology, Frontier technology, Computer-supported decision-making, Computer and education.

I. INTRODUCTION

Technology analysis is an important field of applied research. It gives an understanding of technological changes and their consequences in daily life and society. Every educator at all levels should be familiar with this topic, because they are educating people for the future and for future professions. Some technologies affect work life dramatically – some professions are disappearing, some are being born and almost all are changing, many of them becoming enriched. New technologies – *innovations* - are triggers that, when adopted by the users, cause changes in society. The changes may be *incremental* (improvements in a current trend) or *radical* (step up to a new level and continuing the existing trend there). In some cases innovations may cause *changes in technological systems* (combining several innovations provides new opportunities to adopt the innovation) or in *paradigms*, creating the foundation for changes in society [1]. The authors have discussed the principles of technology analysis in some of their earlier papers [2; 3]. We will not repeat the topic in this paper, but encourage the reader to study them to get a good understanding of the principles of technological forecasting and analysis.

Several market research companies analyze technology trends and publish their findings in annual reports. The best known and most followed are Gartner Group, IDC, Forbes, Forrester, Fjord, and Cisco. Their reports are both general and focused on certain areas. Quite useful studies are also available in a variety of national sources, which focus on country level expectations and changes. A good example of this in the Finnish context is a report [4] which lists the expected effects and opportunities provided by more than a hundred radical technologies in Finnish society. Again, these changes must be taken into account in education.

Emerging technologies are technologies whose development, practical applications, or both are still largely unrealized or have just reached the breakthrough phase. The time span related to their significant adoption in practice is often set at five years. The essential point is that the emerging technology includes innovation potential – competitive edge – in practical applications (modified definition by the authors). In our paper [5], we collected data from sixteen technology analysis sources in 2017. The findings were classified into seven main sectors: AI was one and maybe the most important of these. The analysis included more than 100 emerging technologies causing significant changes in the time span of 10-20 years. To continue our story, in this paper we will focus on discussing aspects related to Artificial Intelligence (AI).

Artificial Intelligence (AI) is the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. It is often connected to the features of a computer system that have elements of human behavior (modified definition by the authors). The overall *research problem* handled in this paper is "*The role of Artificial Intelligence in the current and future society*". We have divided the topic into the following research questions: 1. What are the essential elements of AI now and in the past? 2. Why does AI reappear in cycles and have renewed innovation power almost once a decade? 3. What kind of opportunities AI does offer current society?

To answer RQ1, we will give a short analysis of the evolution of AI since the mid-1950s (Section 2). Section 3 provides (at least partially) an answer to RQ2. Section 4 focuses on the opportunities provided by the current AI-related technologies and answers RQ3. Section 5 concludes the paper.

II. Evolution of Artificial Intelligence – The Four Cycles

A. Motivation

Some technologies appear repeatedly in cycles at the top of the list of emerging technologies – they appear, the effects of their innovative role are remarkable for a while, then they disappear only to reappear again. In our paper [6] we called this phenomenon the "*reincarnation cycles of technologies*". The paper briefly introduced two such technologies – *AI* and *Data Management*. It also included a similar phenomenon that is based on the *evolution of concepts* in the course of time; *software quality* was handled as an example of this.

We consider the importance of AI in current society to be so high that we wish to return to the reincarnation issue in this paper in more detail. The *fourth cycle of AI*, which is ongoing, will have a dramatic effect on jobs, employment, data handling, and many other things, *education* included. In the following, we start with a brief, simplified *history of AI*. After that the reasons behind its cyclic reappearance are explained: the main elements are a *constant demand* for such applications and the *renewed possibilities* to implement intelligence in a new way and in new contexts. The first reason (*demand*) should be clear: people want to have more intelligent, easy-to-use systems and applications helping their life both in private and in business. They want to automate boring, repetitive routine work. They would like to have intelligent assistance and augmented support in their daily routines. We will return to this issue in the discussion part at the end of this paper (Section 4). The second reason (possibilities) is explained by the progress in technology. We will deal with this issue briefly as a separate topic (Section 3).

Why examine and explain history? To understand the opportunities for tomorrow, it is important to understand the path to today. The same factors have been driving progress for decades. The development tends to be continuous (trend-based) and history largely determines the future. Sometimes something unforeseen happens; this means discontinuity in the trend in the form of *radical changes*, or even in the form of *changes in technological systems*, or as a transfer to a *new paradigm* in social systems (these innovation steps are explained in [1] and also handled in [3].) All of this provides us with the means to analyze the continuation of the cyclic progress of AI. If the cyclic progress continues, we may ask: What are the future cycles? When are they coming? What are the driving forces behind them? The final question might be whether there is any reason to believe that there will not be any more new cycles? Our historical overview points out two additional aspects. The first is "*What is the reason for the delay between the theoretical foundations and the appearance of certain technologies?"* Our answer is that the enabling technologies needed are not yet mature enough. The second aspect is "*What happens to an innovative technology at the end of its life cycle?*" Every technology has a life cycle with four phases: *embryonic*, *growing*, *mature*, *aging and decline*. The technology is mainly adopted for normal use in the growing and mature phases (benefit to use it is highest, uncertainty about its usefulness is low). After that (aging, decline), innovative technology becomes embedded in the daily infrastructure and no longer has any meaningful competitive edge.

B. Historical Overview

AI has its roots in antiquity in the form of myths, stories and rumors of artificial beings endowed with intelligence or consciousness by master craftsmen [7].

Where the "ancient" AI left these ideas at a theoretical (story) level, the invention of the digital computer *enabled* these ideas to be put into practice. However, a lot of ancient philosophical foundations (theories about the human mind and human way of thinking) have been useful as a theoretical foundation in AI research.

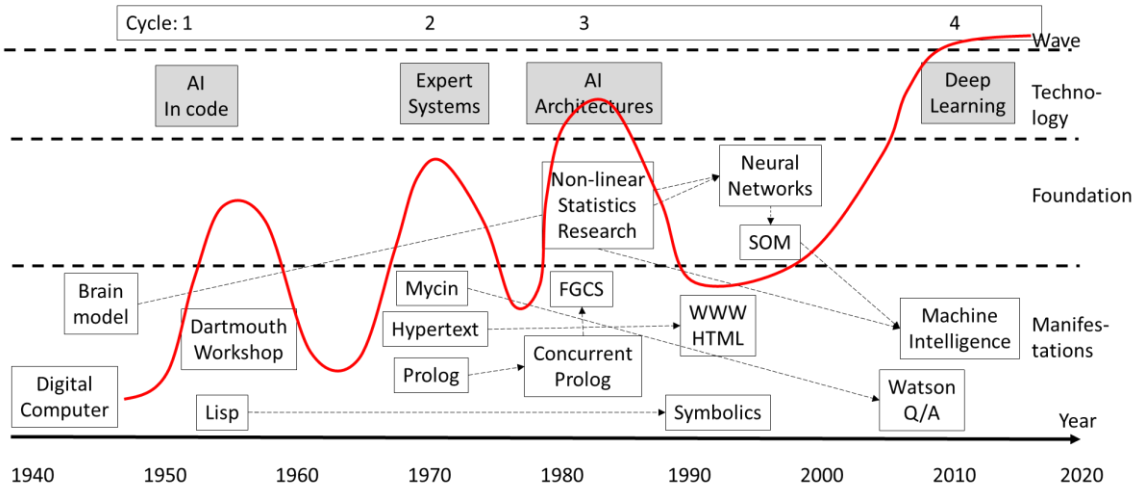

Figure 1. A short, simplified history of artificial intelligence focusing on the viewpoints of this paper.

The milestones of the "brief " history of AI are collected in Figure 1 and explained in the rest of this section. We have also added a "wave line" to describe the cycles – rises, falls, and transfers to a new cycle. The term "AI" was coined by *John McCarthy* in 1955; he is the inventor of the *Lisp programming language* and also a key person in organizing the workshop held on the campus of *Dartmouth College* during the summer of 1956. This workshop was the starting point of current *AI research*.

In analyzing the progress of AI it is worth keeping in mind that the traditional electronic programmable computer was and still is developed for *fast complex calculations* on algorithmic bases, not for modeling the *inference/reasoning* type operations of the human brain. There is still the same mismatch (with the exception of the third wave discussed below) between the computing logics and inference/reasoning based operations needed in AI. These operations are still transferred to normal algorithmic operations and conducted by "*brute force*" bases that have advanced *algorithms* as the key factors.

C. The first wave - 1950s

The *first wave of AI* in the role of emerging technology focused on *programming languages* like Lisp (in the 1950s) and later Prolog (early 1970s; Alain Colmerauer and Philippe Roussel.)[1]. In Lisp the novelty was *modifiable code* – the program (application) was able to modify itself in runtime. This can be seen as a simple *learning capability* of the computer program – the opportunity to react to the state of the computer. *Prolog* is a "*logic programming language*" in which the expressions are rules to be executed, able to create new rules and to modify the behavior of the old ones. Typical of this wave is the fact that the *knowledge needed to solve the problem is in the program's algorithms and known only by the programmer* and used to cast the solution method in terms of algebraic formulas.

D. The Second Wave - 1970-1980s

The second wave relates to expert systems (1970s – 1980s). An *expert system* is a computer application that reasons using knowledge to solve complex (dedicated) problems. Three principal approaches were used in implementing expert systems. In *rule-based expert systems* the problem solving was based on a predefined (modifiable) rule base, which was used to solve the problem given to the system. In *frame-based expert systems*, the problems were solved by matching the problem to the frames in the system's frame base. We have taken the freedom to categorize *hypertext* in the category of expert systems. This technology was born at the same time as expert systems and has radical consequences in the way we use computers today. *Hypertext systems* are intelligent text systems in which the text (and other type of) "documents" are connected to each other with flexible references (hyperlinks). These hyperlinks in a way provide the means for building "intelligent" document systems – paths to move in the document set in a way to solve the problem. Hypertext is one of the key concepts of the *World Wide Web (WWW)* and its implementation technologies. Whereas in first-wave technology the knowledge needed to solve the problem lay in the program's algorithms, in expert systems the *problem solving logic is known by its users*.

The first expert systems were launched by Stanford University. The research group led by *Edward Feigenbaum*[2] – known as the father of expert systems – developed systems that were able to handle the expertise of highly valued and complex application areas. This work resulted in the first known expert systems in the 1970s: *Mycin* for diagnoses of infectious diseases and *Dendral* for identifying unknown organic molecules. The best known expert system – or actually computer system and application platform - is *Watson*3, which is a question-answering system capable of answering questions posed in natural language and used in a variety of application areas. Its knowledge resources are also available via APIs to third parties to develop their intelligent applications. Watson connects another important component to the system intelligence – the *user interface*, which in this case is *natural language*. Progress in natural language interpretation and its use as a system interface also has a decades-long history; we have excluded it from this paper, but wish to point out that in most cases an easy-to-use interface is connected to the success of intelligent systems.

In the area of hypertext, three names are worth mentioning. In the middle of the 1960s, *Ted Nelson*[4] coined the terms *'hypertext'* and *'hypermedia'*. These were a part of his model for creating and using linked content. He started implementing a hypertext system called *Xanadu*; its first public release was completed thirty years later in 1998. *Douglas Engelbart* [5] worked at the Stanford Research Institute in the project developing the NLS *collaboration system* in the early 1960s. The preliminary version of the system, demonstrating a 'hypertext' (meaning editing) interface was launched to the public in 1968. The revolutionary breakthrough in hypertext happened in the 1980s, when *Tim Berners-Lee* [6] created his hypertext database system (ENQUIRE) for CERN in 1980. This was the foundation for the hypertext-based worldwide web concept. At the turn of the 80s/90s, he specified the HTML language, implemented web browser and server software, and developed the first operative version of the HTML protocol over the Internet. The rest of this progress is well-known everywhere.

E. The Third Wave - 1990s

The mismatch between the logical structures demanded by AI operations (inference/reasoning) and computer architectures was disturbing for some quarters?? – and breaking this mismatch was seen as a remarkable

[1] About Lisp: https://en.wikipedia.org/wiki/John_McCarthy_(computer_scientist); About Prolog: https://en.wikipedia.org/wiki/Prolog.
[2] Feigenbaum: https://en.wikipedia.org/wiki/Edward_Feigenbaum; Mycin: https://en.wikipedia.org/wiki/Mycin; Dendral: https://en.wikipedia.org/wiki/Dendral
[3] About Watson: https://en.wikipedia.org/wiki/Watson_(computer)
[4] About Ted Nelson: https://en.wikipedia.org/wiki/Ted_Nelson
[5] About Engelbart: https://en.wikipedia.org/wiki/Douglas_Engelbart; NLS: https://en.wikipedia.org/wiki/NLS_(computer_system). Engelbart is also known as a developer of the first computer mouse and window-based user interface, among many other remarkable innovations..
[6] About Tim Berners-Lee: https://en.wikipedia.org/wiki/Tim_Berners-Lee

opportunity for innovation. In the 1980s, efforts to remedy this mismatch were undertaken by developing *specialized computer architectures* – and thus the third wave started. The two programming languages mentioned above – Lisp and Prolog – were used in developing intelligent software. If these could be implemented in computer architecture, processing of such software would become much more effective.

The biggest initiative came from Japan, where an enormous national project called "*New (Fifth) Generation Computer System*" (FGCS)[7] started in 1982. The *Institute for New Generation Computer Technology (ICOT)*[8] had a revolutionary ten-year plan to develop large computer systems, which were applicable for knowledge information processing; it was open (exceptionally) even for foreign partners and covered activities in the area of computer architecture, software, and (intelligent) applications. The computer architecture was based on the derivative of Prolog – *Concurrent Prolog* – developed by Ehud Shapiro[9], who was invited to ICOT in the role of visiting research fellow. The execution of Concurrent Prolog allowed *parallel processing* following the idea of *dataflow architectures*. The plan was for a PSI (Personal Sequential Inference machine) to act as a work station and a PIM (Parallel Inference Machine) to act in the role of central "super computer"; it was based on massively parallel architecture (thousands of processors). The processing power of these was calculated in LIPS (Logical Inferences Per Second) instead of traditional MIPS (Million Instructions Per Second).

However, the project did not succeed in commercializing these advanced computers. The *Mitsubishi Melcom* computer is the only one we managed to find from the material. In the scope of advances in technology knowledge, the project was *a huge success*. Japan became one of the leading countries in computer systems development (parallel architectures especially), skills in software development rose dramatically, and Japanese research in the area of advanced applications (image processing, speech recognition, natural language processing, online language translation, etc.) gained a significant fillip. Even the Web Ontology Language (OWL), which is a family of knowledge representation languages for authoring ontologies, has its roots in this project and is widely used as a formal way to describe taxonomies and classification networks, essentially defining the structure of knowledge for various domains[10]. The lesson learned in this case is that the *secondary results* may be of high importance, even though the main goal (new computer architecture) was not so successful.

The effort required to commercialize the results came from the USA. In Symbolics[11], Lisp was implemented in the processor. Symbolics Inc. had its roots in MIT (Cambridge, Massachusetts). Symbolics computers were produced in the 1980s; however, they never became a commercial success and finally disappeared from the market.

To conclude, AI support on the architecture level only remained potential, in spite of enormous investments in Japan and marketing efforts in the case of Symbolics. Why was this? One reason is that ultimately there was not the demand which would have provided a push for these advanced architectures. The growth of the processing power in traditional computers was a strong competitor to these "one matter"/"single issue" architectures. The 30 years since these efforts are good evidence of this. Will these solutions come back some day? Such activities are again in the air.

F. The Fourth Wave

Intelligence is based on learning – first in the taught subject matter and then in self-learning. The human way? In the *fourth wave of AI* today the key element is the system's ability to learn: The system is first taught to understand certain basic facts of the target problem and after that it learns about mistakes, wrong decisions, and the reactions of its environment. Very human like? The key elements in this are the ability for the fast processing of massive amounts of data and the availability of such data. Two *technologies* in these applications play a central role – *neural networks* and *deep learning*. We will not go into detail about these technologies, but a short review of the history concerning the topic is necessary so that it will be possible to understand the message of our paper.

The idea of a *neural network*[12] is to build a model that resembles the structure of a human brain – both the structure and "calculation." The roots of this theory date from the 1940s, when Warren McCulloch and Walter Pitts introduced their model of the human brain combined with a mathematical logics based computation model. Neural networks use "what-if" based rules and the network is taught (supervised learning) by means of examples. In this way, the network learns the non-linear dependencies between variables. Otherwise, the neural calculation resembles statistical linear models. The Self-Organizing Map (SOM)[13] is a type of neural network that is based on *unsupervised learning.* It was developed by Finnish academician Teuvo Kohonen in the 1980s. A multidimensional input (learning) data set is organized into low-dimensional geometric relationships (layers) that can be represented as a two-dimensional (low-dimensional) map. It can be used as an abstraction of the real data space. The advantage of SOM over a traditional neural network is its self-learning capability, including the capability of error correction. *Deep learning*[14] theory has its roots in the 1980s in the work of Geoffrey Hinton. It is based on the independent learning of masses of data. The learning algorithms are based on the use of nonlinear statistics and the learned data is organized in a multi-layered neural network.

[7]About FGCS: https://en.wikipedia.org/wiki/Fifth_generation_computer

[8] The key persons in ICOT were Hideo Aiso, Tohru Moto-oka, Koichi Furukawa and Kazuhiro Fuchi.

[9] About Ehud Shapiro: https://en.wikipedia.org/wiki/Ehud_Shapiro

[10] About OWL: https://en.wikipedia.org/wiki/Web_Ontology_Language

[11]About Symbolics: https://en.wikipedia.org/wiki/Symbolics

[12]About Neural networks: https://en.wikipedia.org/wiki/Artificial_neural_network; https://fi.wikipedia.org/wiki/Neuroverkot

[13] About SOM: https://en.wikipedia.org/wiki/Self-organizing_map; https://fi.wikipedia.org/wiki/Itseorganisoituva_kartta

[14] About deep learning: https://en.wikipedia.org/wiki/Deep_learning; https://fi.wikipedia.org/wiki/Syv%C3%A4oppiminen

G. The Waves Concluded

It took more than thirty years to make the theories work in practice as part of current AI applications. *Parallel computing* and *big data technologies* have made this possible; earlier, data was the bottleneck (to quote Professor Aapo Hyvärinen's seminar presentation, Helsinki, August 31st, 2017). AI today provides revolutionary opportunities in a wide variety of applications that replace human work, or support humans in their work, in the form of robotics, as part of a variety of intelligent devices, in the transfer toward *human computing* (coming independently of our will), etc.

The four cycles of AI can be synthesized in the following way:

- *first cycle - programming*: the implementation tool was the programming language; the intelligence built into the system was in the algorithms and only programmers had a profound understanding of their details; programming languages provided an application-independent tool to be used in developing different applications;
- *second cycle – expert systems*: intelligence was built into the tool (knowledge engineering application) and knowledge about its operations was openly available in the system specifications; expert systems were built for specific purposes only;
- *third cycle – AI architectures*: intelligence was in a way built into the platform, which provided its services to the applications in an effective way; the platform did not limit its usage from the applications' point of view;
- *fourth cycle – self-learning applications*: deep learning and machine intelligence provide the means for the use of AI in a wide variety of contexts; the key (value) components are *algorithms and data*. Still these applications are dedicated to certain (narrow) application areas.

The progress described above covers the period from the 1950s to 2019 – approximately 70 years. The time between cycles 1->2 was 20 years, 2->3 15 years, and 3->4 20 years. We have already earlier stated that two conditions must come true in order to make a new cycle operative: continuous demand (*demand pull*) and technology supporting the implementation (*technology push*). In our examples, we have stated that specific theories were available decades before they were utilized. The *continuous demand* seems to be true: people expect more and more intelligent applications to help their daily life or to improve the productivity of their work. We believe that this demand will remain permanent in AI applications.

So what is left? The key trigger in the progress must be technology. This is also *our hypothesis.* A consequence of this is that *by following the progress in technology we are able to forecast future changes in the AI sector* – even the existence of the fifth cycle, its appearance, time, and form. To make our forecast, we have to understand the major changes in the *enabling technologies*, look for the *gaps* in the existing intelligent services, analyze the reasons for the gaps, and find technology that is able to fill them.

Enabling technologies are the triggers that provide an opportunity to make the desired changes come true (fill the gap) or prevent it (the gap still exists). The analysis of the cycles introduced the three key elements of enabling technologies: *computing power and memory capacity (= VLSI, circuit technologies), data storing capacity*, and *data transmission speed*. These technologies also largely explain the cyclic behavior in the context of continuous demand (for new applications). Every cycle starts when it is triggered by an innovation (in practice, handling capacity) in an enabling technology. Every innovation has a limited capability to maintain changes and finally it is embedded in the "normal" (as noted earlier in this paper). The gap between invention and its utilization follows the same formula. Non-applicable theoretical foundations remain potential as an application gap that will finally be filled when the triggering technologies become available.

III. THE CYCLES EXPLAINED – ENABLING TECHNOLOGIES

Our hypothesis above covers three enabling technologies. Additional ones can be listed, but ultimately they are in some way derivatives of and connected to the progress in the three key technologies discussed below. All these technologies seem to have continuous exponential growth, allowing the use of computers in new applications.

The book [8] handles a wide variety of laws that are based mostly on empirical observation. In our particular case the following laws are relevant:

- *processing capacity* - Moore's law: the price/performance of processors is halved every 18 months (transistor density);
- *data storage* - Hoagland's law: the capacity of magnetic devices increases by a factor of ten every decade; and
- *data transmission* - Cooper's law: wireless bandwidth doubles every 2.5 years.

These and some additional laws are discussed below to build a scenario explaining the cyclic reappearance of AI.

Moore's law [8, pp. 244-247; 9] – the original article [10] – refers to the co-founder and chair of Intel in the 1960s, Gordon Moore. The law deals with the packing density of transistors, which is predicted to double every 18 months. Its practical consequences are *doubling processor capacity in 18 months* and *memory capacity in 15* months for the same price. Although the law was based on Moore's observations in the late 1950s, it is still valid and the physical limits of chip materials have not yet slowed down the progress.

Hoagland's law [8, pp. 247-249; 9] deals with the capacity of the data storage devices in current use – magnetic disks. It predicts the capacity of magnetic devices to *increase by a factor of ten every decade* (i.e., *doubling every 18 months*). The law is attributed to *Albert Hoagland*, who was one of the developers of the first magnetic disks. Let us take a look at the periods introduced in Figure 1. The first cycle was the time of punch cards, the second was mainly magnetic tapes and small capacity disks, and from the third cycle on, magnetic disks have practically superseded all other devices. Its new competitor is SSD-based mass memory, which is not yet (and maybe will never become) competitive in storing big masses of data.

There are several laws indicating the growth of data transmission. *Cooper's law* [8, pp. 249-250] (Martin Cooper, Motorola) reports the growth of data transmission in *wireless networks*, which is predicted to *double every 2.5 years*. Gerry Butter (Bell Lab's / Lucent Optical Networking Division) predicted that the amount of data one can transmit using *optical fibers doubles every nine months*, which means that the cost of transmission by optical fiber is halving every nine months (*Butter's law*) [9]. Nielsen's law [11] summarizes the transmission speed from the users' point of view; according to Nielsen's law, *users' bandwidth grows by 50% per year* (i.e., doubling every 20 months, which is 10% less than Moore's law for computer speed). The new (version of the) law incorporates the data from 1983 to 2018. The report by Cisco [12] summarizes the progress in practice. It provides evidence on the fast growth of *mobile traffic*: the Compound Annual Growth Rate (CAGR) in 2016-2021 is forecast to be 47% (total in the period from 7 to 49 Exabytes). The traffic has grown 4000-fold over the past 10 years and almost 400-million-fold over the past 15 years. It also indicates the transfer towards applications having high bandwidth consumption (streaming, VR (CAGR 60%), AR (46%), MR).

VLSI technology is the kernel of all the enabling technologies. The progress in VLSI technology indicates fast growth in processing power (doubling every 18 months) and memory capacity (more? available for the same price in 15 months). These capabilities indirectly also drive the progress in data transmission (switches and network devices) and data storage (controllers) in addition to their basic technologies. Table I represents the changes in essential computing capabilities in the period from the 1950s to today (divided into cycle steps in Figure 1; includes some rounding errors to simplify the presentation).

TABLE I. CAPACITY CHANGES 1955-2019, PROJECTED TO 2030

Double capacity in months (m)	1955	1975	1990	2019	2030
Computing 18m	1	2^{13}	2^{23} (2^{10})	2^{42} (2^{19})	(157)
Memory 15m	1	2^{15}	2^{28} (2^{12})	2^{51} (2^{23})	(445)
Mass memory 18m	1	2^{13}	2^{23} (2^{10})	2^{42} (2^{19})	(157)
Transmission 20m	1	2^{12}	2^{21} (2^{9})	2^{38} (2^{17})	(97)

The figures in Table 1 represent changes in capacity from the base year 1955 (first cycle) over the three other cycles; the base year value is 1. The numbers in parentheses are changes from the earlier cycle (changes between columns). The last column provides a scenario ten years *from now*: computing power is 157-fold, memory capacity 445-fold, mass memory 157-fold, and data transmission speed 97-fold compared to the *capacity of today*. In data transmission we used Nielsen's prediction, which may be somewhat pessimistic. If something is not possible today, maybe it will be in ten years' time (based on continuous demand). In 10 years from now, we will be able to run more complex software and handle greater amounts of data (in primary memory) for fast processing, we will have access to bigger data repositories and faster data transmission will allow the use of distributed data and also distributed parallel processing (to increase the processing capacity). Today, when applications are mostly based on the cloud-type of services and most of the user terminals (smart phones, laptops, PCs, tablets) also have significant (local) processing capacity, the processing needed for problem solving is distributed between terminal and "cloud". What kind of problems will we be able to solve at the terminal level (locally) in ten years' time that are not yet possible? What about taking the whole computing infrastructure into account on a general level?

IV. ARTIFICIAL INTELLIGENCE IN PRACTICE – DISCUSSION ON THE SITUATION IN 2019 AND BEYOND

The present wave in AI is focused on *learning*. As introduced in Section 3, the key technologies are *deep learning* and *artificial multilayered neural networks*. It is justifiable to say that currently a lot of business value is bound to data and the algorithms handling it in an intelligent way. Yuval Noah Harari addresses the role of algorithms in current society in his book "Homo Deus," with reference to Facebook (FB) and Google: "The algorithms of FB and Google follow all our activities (on the Internet). Algorithms compare our behavior to the behavior of others and based on that are able to predict our behavior" (freely interpreted by the authors of this paper). We are profiled by intelligent algorithms, which have an enormous amount of data organized in the form of "learned knowledge" of human behavior.

However, the current AI boom is mostly based on w*eak (narrow) AI*, which is focused on one specific task and does not understand the data it handles – data is just data. *Weak AI* does not have its "own sense" related to the data it handles, nor its own will about how it should be handled. The next step will be *strong AI*, which understands facts and their relationships; it also has features of human beings, like *common sense*. It does not have its own will either; rather a kind of understanding of its surroundings.

The path towards this "general AI" is unknown but is generally accepted by scientists. [15]. The first alternative is to continue the current trend (deep learning) with more data processing power. The second alternative is to follow the proposal of Andrej Karpathy (Tesla). He has introduced the concept of *Software 2.0*. Current algorithmic programming produces an exact algorithm that a computer follows instruction by instruction. In Software 2.0, the programmer produces only a skeleton program that specifies a goal the program should reach and the software platform produces the full solution to the task. Idealistic? – time will tell! /we do not know as yet! The third path would be a merging of

[15] This discussion is a free interpretation of the column of Professor Heikki Ailisto in the Finnish ICT journal Tivi, February 2019. ISSN 2342-4001.

deep learning, semantic methods, and common knowledge about the application context

Two Finnish reports [13; 14] list ten *core competences* in the area of AI: (1) Refined *Data analytics*; (2) *Sensing and situation awareness* (of autonomous systems); (3) *Natural language understanding and cognition*; (4) *Interaction with humans* (advanced interaction tools and methods); (5) *Digital skills* (work life, education, training); (6) Machine learning; (7) System level and systemic impact (AI technologies on the whole); (8) Computing equipment, platforms, services, and ecosystems; (9) Robotics and machine automation (the multidisciplinary physical dimension of AI); and (10) Ethics, morals, regulation, and legislation.

As can be seen, AI is not just a single technology but a collection of technologies, methods, applications, and schools of research and thought. It must also be seen as a part of the larger trend of digitalization.

The report [4] deals with the opportunities provided by new technologies for Finnish society in the time frame from the present to 2037 (at the time the report was written, a 20-year time span). In spite of having the focus on one economy its findings are very appropriate for a global context. The report lists the following high importance application areas of AI: (1) Speech recognition, speech synthesis, and interpretation; (2) Neural networks and deep learning; (3) AI platforms; (4) Face and emotion recognition; (5) Verbot/chatpot – interacting robots; (6) Real-time 3D sketching of the environment; (7) 3D imaging; and (8) Teaching materials for AI applications.

AI applications are processing-intensive and need a lot of computing capacity. Most of the AI applications are still run by conventional computers. Some manufacturers have started to develop special architectures to speed up the processing capability. This has become reasonably easy thanks to advances in VLSI technology (compared to the situation in the third wave of AI). Although applications are able to learn even with a relatively small learning data set – especially if they know the conceptual model of the application, the exactness of results would improve with larger amounts of learning data. A new method is to use one AI application to generate learning material or to give feedback to another one. In any case, AI learns from every experience.

We conclude this part of our paper by referring to our earlier paper [5], which lists a variety of findings related to emergent technologies based on our review of leading technology analysts, and to Gartner group's report "Gartner Top 10 Strategic Technology Trends for 2019" [15]. Gartner lists the following emerging technologies: (1) *Autonomous things*: Robotics, Vehicles, Drones, Appliances, and Agents; (2) *Augmented Analytics*: By 2020, more than 40% of data science tasks will be automated; (3) *AI-driven development*: AI is embedded into applications and AI is used to create AI-powered tools for the development process; (4) *Digital twins*: digital twins mirror a real-life object, process or system; (5) *Immersive technologies*: technologies such as augmented reality (AR), mixed reality (MR), and virtual reality (VR) create added value even to AI applications in the form of a user interface to the real application; (6) *Smart spaces*: A smart space is a physical or digital environment in which humans and technology-enabled systems interact in increasingly open, connected, coordinated, and intelligent ecosystems; and (7) *Digital ethics and privacy*: Even Gartner lists this topic at the top. This is because data has become an important resource and people are aware of its usage. Three items (out of ten) in Gartner's list are beyond the scope of the topic discussed in this paper.

V. CONCLUSION

Is AI a science or not? An interesting critical debate is available in three "discussions"[16] we found when preparing this paper. The first reference (Maurizio Matteuzzi) discusses the topic "Why AI is not a science." An interesting perspective (different to ours) to the history of AI is given by Güven Güzeldere and Stefano Franchi in the second reference. The third reference lists interesting quotes about AI. All three of these sources represent criticism of AI. We will leave these to the reader to prove that the topic encompasses many dimensions.

The paper described the progress of AI from a historical and contemporary perspective. The motivation to write this paper was the observation that some technologies tend to reappear in the role of emerging technologies from time to time – mostly irregularly. We have analyzed its "reincarnation" cycles and found two factors in the background: *continuous demand* and *progress in enabling technologies*. Continuous demand includes such problems that cannot be tackled using existing technology; as a result, they remain to be solved in the future. Eventually, when improvements in enabling technologies allow, the new cycle will start to satisfy the "*unsatisfied need*." In 2030 (Table I), we will be able to satisfy needs that demand 157-fold computing power, 445-fold main memory size, 157-fold mass memory capacity, and 97 times faster data transmission compared to the situation today.

What happens to the applications that appeared in older cycles? Nothing – they just remain and are *embedded into the "normal"* without any significant innovation power. What is the next cycle and when will it occur? The current AI can be characterized by systems capable of "mechanical learning". The system learns and can use the learned facts to create new knowledge; however, without understanding their relationships or use context. In our paper we listed three scenarios. According to our understanding, the most probable future step is the transition to *strong AI*, in which the learning capability enables understanding of facts and their relationships and has human features like *common sense*, including a kind of awareness of its surroundings. A human-computer "mental connection" will become (and already is partially) possible, when the human brain and

16
(1) Maurizio Matteuzzi: https://web.stanford.edu/group/SHR/4-2/text/matteuzzi.html
(2) Güven Güzeldere and Stefano Franchi: ttps://web.stanford.edu/group/SHR/4-2/text/introduction.html (see the pictures in the article)
(3) Quotes: https://en.wikiquote.org/wiki/Artificial_intelligence

computer can be connected in such a way that human neural signals can be utilized by computer applications.

Why have we submitted this paper to the CE conference?. AI changes society and affects future work: professions will appear, some will disappear, and many of them will undergo significant changes. Such changes are AI-supported citizen development, software robots in the production of routine newspaper articles, intelligent chatbots in customer service, service robots, expert systems in routine decision making, and a robot analyzing complex contracts on behalf of a lawyer for instance.

What about *AI in the field of education*? First of all, there is an international journal " International Journal of Artificial Intelligence in Education" published by Springer. This point out the importance of the topic also in the field of education. We made a rough article search in Scobus – it resulted close to 3.000 peer-reviewed papers in the period of 2017-2019. Similar search in Google Scholar resulted over 37.000 references. The analysis of publication forums listed by Scobus search indicates that the papers are mostly published in the journals having clear topic related context – medicine, agriculture, engineering, computing, chemistry, human behavior, manufacturing, nursing, etc. For further readings we collected some material related to the role of AI in education – please see [17; 18; 19; 20; 21; 22]. To go in detail in these we need an another conference paper. In general, the papers cover a wide variety of ideas and some frameworks about using AI as a pert of teaching process. An interesting view of the future is published by Fast Future Research [16]. It creates a vision to jobs of the future – if some jobs are lost because of intelligent applications, some new are needed.

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How much has technology dehumanized us in school

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***Abstract* - The world of education is changing and the changes affect all its aspects. The development of education is directed toward learning processes that aim at acquiring basic knowledge, the capability to solving problems and preparing one for the challenges of the future by developing skills and lifelong learning. In this context, the information and communication technology has made great progress. Today, after we started using computers in teaching and learning, we ask ourselves how much we gained and how much we may have lost in the process. This paper researches and analyzes the attitudes of the teachers to the use of ICT in teaching and the use of computers in learning. In our efforts to direct education towards the labour market and look at certain professions from that aspect, we grow distant from Humboldt's concept of education and lose the humanistic aspect. How do we maintain education as a development of independence, competence, innovativeness, capability to maintain and renew skill by shaping better and more humane mutual social relationships.**

Today, considering the needs and demands of the modern world, the orientation of education toward ICT seems necessary and inevitable. The question is where does one set the limit. This paper addresses the importance of ICT in teaching and education. Special attention is given to the issue from the aspect of national minority schools where the use of ICT means a more open and cheaper access to study materials from the country of origin, while from the aspect of teaching we shall address the issue of ICT competition for teachers.

The aim of this paper is to present the usage of ICT in teaching and learning as well as the attitudes of teachers and students.

Key words - education, ICT, school

I. INTRODUCTION

Conversations about education and education reform are a constant story at all times. With every technological revolution we came back to technological issues whose task in education has always been significant. School as a result of education also experienced constant changes that reflected on changes in teaching methods and methods of education.

When we look back to the story of education and use of technology in education from the Spartan process of developing character traits, values and which make a man, to today, when we have included very sophisticated ICT in education, the question of negative sides of technology threatening us seems inevitable. How much education have we actually left to technology or relied on it. Education as a process of teaching and forming a positive personality also includes impacts through education, the environment, the family and the media. Education as an organized learning for the development of cognitive abilities and acquisition of knowledge and skills is different but parallel to the process of upbringing. There is no education that does not have any upbringing effects. The same situation is with the use of technology that serves us in education and is part of education.. In Ancient Rome, before attending the education of a student a teacher had to study the students' natural tendencies and hence organize content and learning. His special task was not to burden the students and emphasized in particular that punishment was shameful and humiliating for the students. The first medieval universities were founded by scientists, city authorities and residents interested in the development of science.

New teaching methods were introduced and the teacher was at the center as an unquestionable institution that as for technology has its own voice, board, and chalk. Very few students had access to education. Only with Janom Amos Comenius (Comenius), the initiator of didactics and pedagogy of the new age, organizational change in teaching is established: drawing up a curriculum, lecture instructions, introduction of a school year, introduction of teaching hours, repetition and training, maintenance of discipline and introduction of holidays. The principles in teaching are: vividity, gradualness and systematicness. We have not yet moved away from these principles, but we may have moved away from the central role of the teacher as a moderator, turning him into someone who is relying on technology and almost unable to teach without it. I think we have tyo accept the fact that without information communication technology as learning aids and learning resources, there is no good education in the digital environment.

However, we must certainly realize the good and bad sides that technology in education carries and choose a sustainable relationship with it. Technology should only be seen as an aid in implementing the teaching process itself and should not be its basis, which means that the priority should be given to pedagogic rather than technological issues.

In the digital environment it is difficult to reduce the impact of technology, nor is it necessary, but it needs to be

controlled. The changes that are taking place are visible in the fundamental educational competences that modern education represents as a whole comprising eight key competences (European Commission, 2007, p. 3); communication in the mother tongue; communication in foreign languages; mathematical competence and basic scientific and technological competence; digital competence; learn how to learn; social and civic competences; a sense of initiative and entrepreneurship and a cultural awareness and expression.

Information, information and digital literacy, and then the competences that come from possessing basic information, information and digital skills, i.e. using a computer to search, locate, collect, evaluate information in a systematic manner with critical evaluation and communication exchange, required by students and teachers, are certainly something that contributes to education.

The concept of education for the time we live in is "learning how to learn", which means the ability to organize a learning process whereby new knowledge and skills are acquired in a well-organized time, and upgraded through the art of using technology.

In the aspiration for a market oriented education and individual market-based professions, we all distance ourselves from the humboldtian concept of education. How to keep education as a development of independence, competence, innovativeness, ability to maintain and renew skills by shaping the higher quality and humane relationship between technology and people in education. Today, given the needs and requirements of the contemporary environment, the educational orientation towards ICT is indispensable, but the question is where the boundary is.

This paper deals with the importance of using ICT in teaching and learning. We will especially look at the aspect of the national minority school, which through the use of ICT has a more open and favorable financial access to learning materials from the home country and from the teachers' side, we shall adress the problem of ICT teacher competition.

II.21ST CENTURY EDUCATION

21st century education has turned to market demands through the pursuit of securing competencies that are referred to as the 21st century competences. Each of these competences is also needed for teachers who work in the 21st century education.

None of the competences exists independently, but several of them intertwine with one another because of their narrow areas of action. And each of these core competencies needed in the 21st century requires constant professional training and is impossible without using ICT. On the other hand, it is evident that all competences work together as a community because on the basis of their competences, a person should be prepared to function in both the private and business sphere.

The intertwining of information, computer and digital competencies is visible in the fact that the acquired skills and knowledge provide the learner and teacher with faster access to resources and problem solving. Digital competence in literature combines with competence to learn how to learn because in today's digitally accelerated world, digital competence enters human life from the earliest days. In school, teachers primarily focus on a digital way of teaching, as students are also more readily able to learn in a digital way. Learning is increasingly based on information, computer and digital literacy. On the other hand, on the basis of cultural and national consciousness, a person belongs to a certain national and cultural circle.

Accordingly, in order to reach such a complex mode of action, these three competencies must certainly be observed in their communion for each of the learning phases.

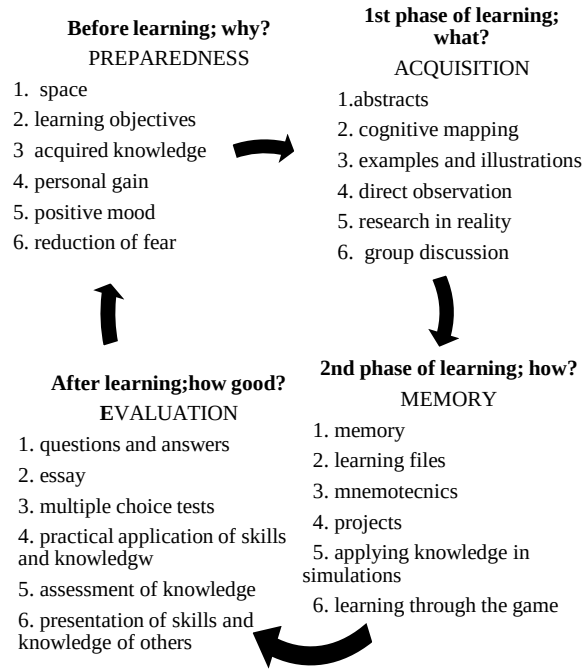

Figure 1. Learning phases

Today, teachers and learners will use ICT in each of these phases.

As an example, we will use the research we carried out within the PhD thesis that was defended at the Faculty of Philosophy in Zagreb at the PhD course in Information Science. From this research, only the answers to questions related to ICT and use in teaching were taken for this paper.

The students who participated in the research belong to the digital generation but in their use of ICT are not information and computer literate enough. The same can be said for 50% of teachers, according to the answers.

It is expected that a large number of teachers and students will use the computer as a tool to help them learn and continue to search for information. As the school does not have an e-learning system or a teaching material repository, students consider it would be useful for revision and learning. Teachers at the same time do not approve the creation of a teaching material repository that would be available to students. They feel that it would be good for them (teachers) but that the students (most of them) would be distracted from "live" classes.

Technologies that teachers have evaluated as non-teaching are social networks, while students particularly appreciate the role of social networks.

It is interesting that students and teachers, when asked whether they consider themselves to be information literate, respond that they are but they do not seem to know what makes them information literate.

Teachers use computers the most to present the content of the subject. Teacher's informatic literacy is low especially in creating multimedia presentations. Both teachers and students prefer to use the Internet not only for the purpose of learning new information, but also for learning purposes.

A number of researches in the world have been carried out on this topic and one of the first comparative researches carried out by Fraillon, Ainley, Schulz, Friedman and Gebhardt (2014) on digital competence of students and teachers with a particular emphasis on the use of information and communication technology. It was a major study that showed that students, apart from extracurricular activities, use information and communication technology to a large extent for school activities. Particularly mentioned are teaching subjects and activities within these subjects for which students use the computer.

Globally, if we compare the responses we have received from our students and teachers, there is no difference in principle (the comparison should not be scientifically based, because the answers we used were not obtained from the full research of the topic), for a valid comparison we should do a complete research with the same issues, which we did not do for this work. However, these questions and answers should only serve as an indicator of the use of technology in teaching because we are aware of the role of teachers in education as pedagogues, not only as teachers, but also as educators.

III. The Role of Technology and its Use in the National Minority School

This part only suggests some additional advantages of using technology in the environment of a national minority school. Learning languages through a variety of good learning and simulation programs, the availability of e-textbooks from your home country and contacts, which, at times of less funding, do not knock out direct communication.

Access to digital educational materials, access to presentation software, word processing software, databases or table calculators that are actually funded by the parent country and the ability to use e-learning systems used by schools in Italy. Depending on the program according to which a National Minority School operates, the participation of the mother country through the use of ICT is financially more favorable.

The vivid presentation that ICT provides through software simulation, facilitates the teaching process for teachers and students. Positive aspects are also reflected in the very forms of teaching. The simulation can also be used in group work, but also in individualized learning, during which the student determines their own pace of progress.

On the other hand, it is important for the students of the national minority to establish communication with native speakers and situations in the parent country, which is certainly important also for their emotional development.

The quality and original simulation programs do not require additional activities in terms of material translation because the school in which I work is based on program A in which the teaching is conducted in minority language in all subjects.

IV. Conclusion

Aware of the educational environment today, we certainly do not advocate not using technology. We believe that its role and task is inseparable from the task of education and the results for society in general. What matters is to know what are the good things and how to use quality technology for education.

Sustainable development technology in accordance with the core tasks of the area in which it is used. Today, regardless of the fact that in secondary education the accent is placed on education, it should not be forgotten that the teacher is the one who also brings students up through the process of education. If technology is used well, through its educational but also formational segment it will mostly show its good side. But that is precisely why education is needed. We need to humanize technology and not dehumanize the teacher.

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Teaching Computer-assisted Translation: A Proposal for Course Content

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***Abstract* - With wider adoption of machine translation and its integration in the standard translation workflow, the job of translator developed into various forms – post-editors, revisers, translators, proof-readers, etc. In this paper we argue for the inclusion of the post-editing, pre-editing, and machine translation content into the course on computer-assisted translation and give proposal for the course content. We also argue for the inclusion of added value services such as subtitling and localization. The course should be mandatory for all the graduate students studying a language. The content is influenced by the experiences gained from teaching a similar elective graduate-level course.**

Keywords – computer-assisted translation course; course content; translators' technical competence; added value services

I. INTRODUCTION

It is clearly obvious that pen-and-paper translation has come to an end [1]. As the author in [2] puts it, everyone agrees that there is need to train translators to meet the existing demand and to face rising volumes in the future. Neither those who graduate from a translation study, nor those who are trained "at the job" are necessarily good translators. It turns out that the major concern is how to train well in order to get good translators.

Users may be prevented from using machine translation (MT) due to a lack of awareness of the current capabilities of MT systems and lack of technological know-how [3]. Insights into the practice can be gained from the survey in [4].

According to the standard ISO 17100 [5] translators have at least six competences. Technical competence relates to the knowledge, abilities, and skills required to perform the technical tasks in the translation process by employing technical resources including the tools and IT systems that support the whole translation process. In addition to this, there is also research competence which requires experience in the use of research tools and the ability to develop suitable strategies for the efficient use of information sources available.

An elective course ICT for translators started to be conducted at the University of Rijeka as of 2016/2017. However, the course was offered only to students of single or double major Informatics. In such a way only students of a language in combination with Informatics could be enrolled to the course. There are four language departments at the University of Rijeka – Croatian, English, German, and Italian. Due to a positive feedback, in September 2017 a one-day workshop was organized through which the most representative processes of the professional translation workflow tried to be approached. The course is as of 2017/2018 open to students of all university constituents, not only language graduates, in line with the opinion in [2]. The experience gained is drawn and a proposal for the obligatory course of a graduate study in Translation Studies is given.

Section II introduces basic concepts in the field of MT and computer assisted translation (CAT). Related work is presented in section III. Section IV gives the course outline. Evaluation is provided in section V, and a short conclusion is presented in section VI.

II. BASIC CONCEPTS

Standards can be seen as minimum requirements which must be accounted for by training institutions if they want to ensure market-oriented training [6]. The standard ISO 17100 sees the training of translation service providers as a life-long learning process. As the author in [6] points out, successful translators continuously work on their self-improvement.

According to the standard, the translators should have:

- a degree of the first academic level in translation or linguistic studies or language studies which include translation training, or
- a degree in the domain and two years of full-time professional experience in translating, or
- at least 5 years of full-time professional experience as a translator.

From the definition of the standard it is obvious that translator tasks are so diverse that it is not possible to have a unified educational framework. A non-exhaustive list of added value services is included in the appendix of the standard.

Since there might be some confusion about the terms and different roles that translators take in the translation workflow, a definition of the basic roles is given in Fig. 1.

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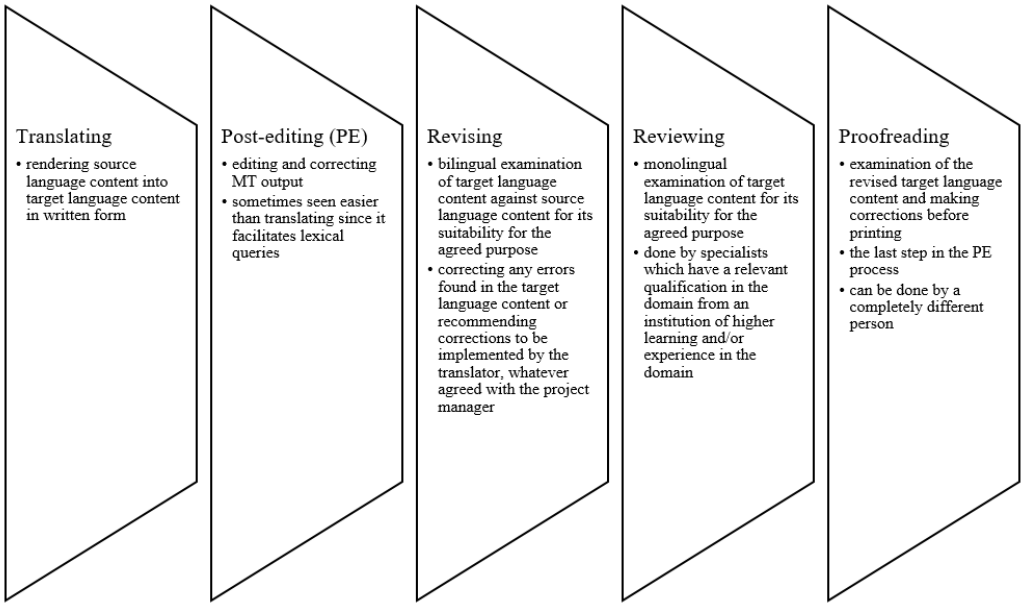

Figure 1. Different roles of translators

The author in [7] makes a distinction between PE on one hand, and translating and proofreading on the other. While in PE it is of crucial importance to check every sentence against its source counterpart in order to identify "tricky" MT mistakes, proofreading checks meaning, comprehensibility and idiomaticity.

III. RELATED WORK

The significance that software expertise has for translators is underlined in numerous research papers [1, 7, 8]. Not only should the basic version of a translator's workstation be taught, but also tools for subtitling and localization. A basic introduction to MT is also important [9]. A holistic approach to the integration of MT into translator training programs that empowers and not marginalizes translators, along with a non-technical overview of statistical MT is presented in [10]. The design and evaluation of the related syllabus is presented in [11].

The aim, as the author in [2] puts it, should not be to train students for a narrowly defined market, but to empower them to apply for a wide range of positions in translation. IT as an ever-growing set of tools should ensure mastery of all technology available in a state-of-the-art translator's workstation, the ability to analyze and appraise any software package, and the ability to train colleagues in the use of such tools [2]. The author in [2] goes even further and says that among other things, translators must master all the translation-localization (and revision) techniques, methods and procedures and be totally proficient in the use of all the equipment and software they are likely to come across in their professional environments. Even back in 2007 the market was eager to take on people trained in special skills areas such as software, web site, and videogame localization, post-editing, etc. The author in [12] defines professional translation even as one form of human-computer interaction.

The need for post-editor training has been emphasized already in [13]. Training post-editors is further highlighted as necessary in [8, 14, 15]. PE skills should be taught because of the increasing demand for translation and for faster production times, and because they differ from translation skills. Teaching these skills could improve the uptake of MT technology by improving translators' perceptions of MT and its capabilities [8]. Since PE skills are developed gradually, companies implementing MT would benefit if translation graduates were comfortable with PE. Hence, graduates would be given better employment opportunities. A strong argumented case for teaching PE is given in [8]. Knowledge of MT, understanding the history, and understanding the future prospects of MT are important in gaining appreciation for MT and understanding its limitations and possible improvements. Post-editors should be taught how to code dictionaries and manage terminology databases (TB). They should be acquainted with multiple terminology management tools and exchange formats. Post-editors should also have the knowledge of controlled language and controlled authoring tools in order to play the role of an intermediate editor who authors source texts with the aim of improving MT output. The objective of the work in [15] is to model PE behavior in order to design specifications for computer-aided PE and a training program for new post-editors. PE serves multiple purposes. It perfectly fits the scenario of MT evaluation because it gives concrete measures of translation quality like time and effort spent in PE, and it reveals the gap between MT output and human translations [16]. Students can be organized in groups in order to devise guidelines for different types of PE themselves, bearing in mind how long a correction will take and whether a correction is necessary. They should do all kinds of PE on the same text in order to see the difference more clearly. Students should work from the foreign language to their native in order to suppress the fear of PE making them learn incorrect models. The triad of controlled languages, MT

systems, and post-editing processes, coupled with other CAT tools such as translation memories (TMs), is called *controlled translation* by the authors in [17]. A machine translation and post-editing course which combines this triad is presented in [18].

Specialization by job and technology and domain was a marked major trend fifteen years ago meaning that translators identified themselves primarily as localizers, or subtitlers, or revisers, etc. The author in [2] advocates that all students give priority to anything that goes by the name of localization since no one can predict the combination that will prevail for any individual student.

The potential of the online platform Crowdin for the education of future translators is highlighted in [19]. It is used for translating of websites, mobile and desktop applications, etc. Since it supports crowdsourcing, it can be used even without the need to create special content.

The author in [2] emphasizes that all students have to have the necessary language skills and competences required for translator training courses. We take a bit different approach and treat this course as independent of the language skills. We aim to develop the necessary IT skills which can be blended with language skills from the very beginning, gradually during the course, or afterwards.

IV. BUILDING BLOCKS

The aim of the course is not to master all the tools with respect to the time dimension, but only to familiarize students with types of tools out on the market. Similarly to [20], we believe that basic competence can be built on once the students begin to work as professional translators. The course is divided so that each theoretical component is followed by a practical one. Practical labs take place in computer labs with specialized software.

In the course proposal a special attention is paid so that as many of the non-exhaustive list of added value services are included. A selected subset of these services consists of pre and post-editing, localization, revision, subtitling, translation memory alignment and alignment of bilingual parallel texts, and, lastly, terminology management. These services increase employability of translators and engagement of language service providers (LSP).

The course is envisaged as a hands-on experience and all the focus is put on practical work. As emphasized in [4], effective teaching in these fields requires hands-on practice in computer labs and the use of dedicated software. During class, students are guided through exercises followed up by real-world homework assignments. The class is divided into eight assignments and a final exam in the form of a project (Fig. 2). The Moodle platform is used for distributing materials and collecting assignments. For their final exam students have to pick or propose a topic which can be an extension of a class lab or a new topic, such as video game localization, tutorial for a software, comparison of different tools, etc., and they have to cover its theoretical and practical aspects. Examples of projects suggested and conducted by students are given in Table 1.

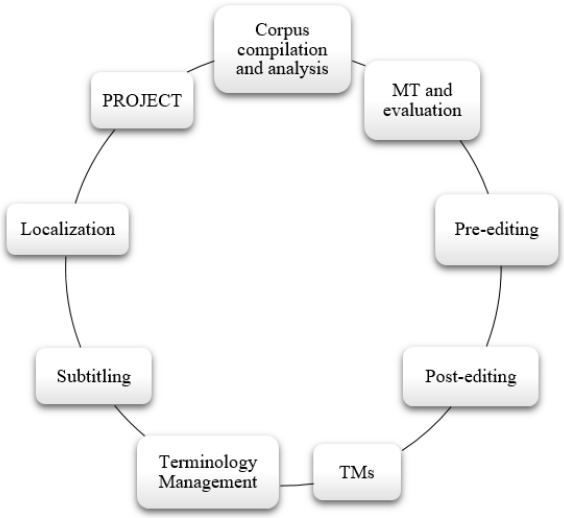

Figure 2. Assignments

Since most of the tools and services are free and/or open-source, many assignments can be done at home in the form of distance learning, similarly as in [11]. This is important due to the sudden acceleration of technological changes affecting the profession which raises the need for continuous education and training.

Besides the building blocks described in the remainder of this section, one session should be reserved for a practicing professional as a guest-lecturer and a significant amount of time should be devoted to the question-answering section.

A. *Corpus comilation and analysis*

This section of the course is concerned with getting the best out of electronic corpora. C*orpus use for learning to translate* and *learning corpus use to translate* are two complementary approaches to the use of corpora in translation. The latter is concerned with helping students to become autonomous users of corpora as part of their translation competence [21]. We take, as [22] puts it, more macroscopic perspective in that students themselves have to compile the corpora before they can apply them to

TABLE I. EXAMPLES OF STUDENT PROJECTS

Project	
Lesson	***Description***
PE + automatic evaluation	PE is done using PET tool on randomly selected sentences of the Workshop on MT (WMT) testset translated by Google Translate (GT) from English into Croatian and from Intalian into Croatian. Correlation of the editing time and a chosen autometic metric result per sentence is calculated.
Subtitling	Karaoke in language learning
Error analysis + automatic evaluation	Three text types are translated from German into Croatian by GT. Automatic metrics chrF and BLEU are calculated, error analysis is performed, correlations are investigated.
Subtitling	Using text-to-speech captioning and MT subtitling - the trade-off between quality and time

solve any translation problems. Students are first introduced to the characteristics of conventional search engines and familiarized with the tools and strategies for querying the Internet as a macro-corpus. Afterwards, they are given guidance in using special concordance software for compiling and querying monolingual and bilingual corpora.

B. Machine translation and evaluation

Since MT is nowadays integrated in the majority of CAT tools, translators and post-editors must be aware of the capabilities of MT systems. Error analysis is a means to assess translations in qualitative terms. It refers to the identification and classification of individual errors in a translated text [23]. Students are given a detailed introduction into the human and automatic evaluation of machine translation and various taxonomies and tools are presented for performing evaluation and error analysis. By comparing different automatic error metrics scores with human judgements of the quality of MT output, the students develop ability to identify strengths and weaknesses of different approaches [11]. Two paths that can be followed during the lab session are presented in [24]. Students can either evaluate the same MT service on texts from different domains or evaluate the same text translations provided by different MT services.

C. Pre-editing

In line with the research in [17] and [25], we believe that translation programs should teach pre-editing as well. The author in [26] advocates pre-editing as one of the most exciting and effective ways of learning to use MT, learning to translate, and learning the language. An overview of different pre-editing guidelines can be found in [17]. Similarly to [11, 17, 18, 21], we ask trainee translators to input a foreign language sentence into an MT system, observe the errors in the translation, edit the source text by following a basic set of instructions or their intuition, and input it again in the hope of getting better output from the MT system.

D. Post-editing

PE, as [16] puts it, allows for discussion of the most abstract principles which underlie authoring and translation processes. On the other hand, it gives students their first experience of one of the most practical skills which trainee translators are expected to acquire. Students do rapid and full post-editing on the same text in order to see the difference more clearly, and bearing in mind how long a correction will take and whether a correction is necessary. A set of example cards illustrating guidelines is provided in order to make the training proper, as in [27]. A concise overview of guidelines and an actual exercise which provides students with hands-on experience on all the key elements of the controlled translation is presented in [17]. Another interesting exercise can be post-editing without source text [18].

E. Translation memories and terminology databases

Working with translation memories might appear cumbersome at the beginning because no immediate benefits are seen. After theoretical introduction to TMs and ethical considerations related to ownership and confidentiality, the learning process is somewhat similar to the model proposed in [28]. It is divided into several phases (Fig. 3). Similarly to [8], in this session we propose discussing the strengths and weaknesses of terminology management tools, dictionary coding for MT, and terminology exchange between tools using terminology exchange standards. Students also learn how to enable or disable machine translation, if the tool offers such support. The same applies to the publicly available translation memories. In order to complete the assignment, students have to upload the final translation, as well as the exported TM and TB.

Although there are free and open-source tools and services available, it is important that students get familiarized with at least one commercially available tool. We obtained a free academic license for one such tool. Since students do not know what tools they will have to use in their future work, the aim is to get them acquainted with as many tools as possible. The more tools and services they work with, the more they are accustomed to working with TMs in general, as the underlying processes do not differ much. The resources created with the first tool are migrated to a new tool as they move along, similarly to [20].

In order to experience different roles, when the tool or service allows it, students are asked to take up the role of the project manager and assign translations to translators.

We devote four sessions for this central part of the course. After each session, students are asked to reflect on the advantages and disadvantages of the introduced tool and to compare it to similar tools they have already worked with.

F. Subtitling

The author in [29] advocates subtitling in translators' training with the aim to fine-tune translation skills, develop critical thinking, learn to take distance from word per word translation, and concentrate on semantic units. There is a number of semi-professional tools on the Internet which can be used in classroom in order to enable students to meet the audiovisual translation and its particularities.

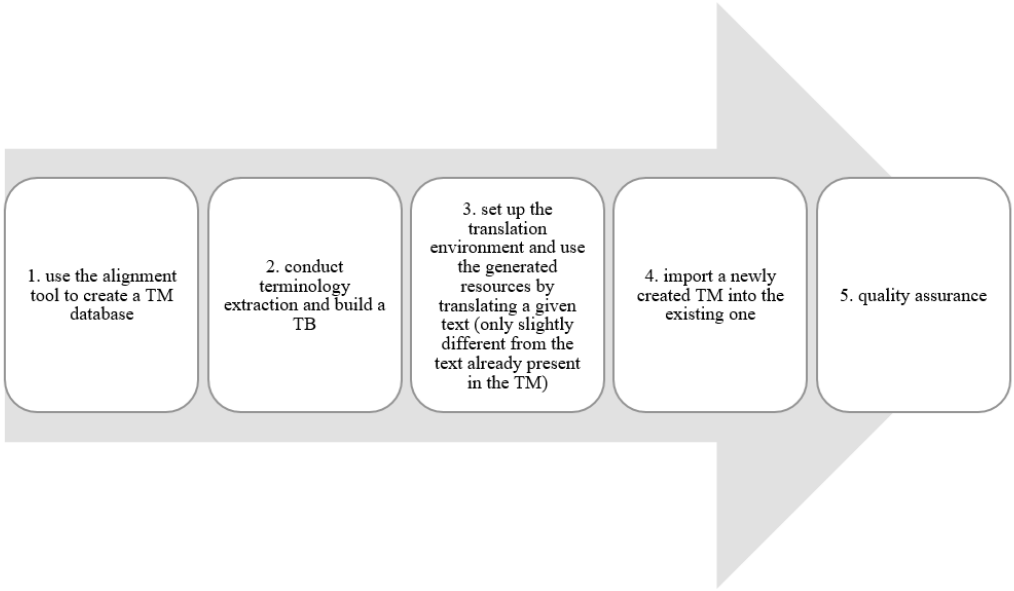

Figure 3. Translation memories and terminology databases

G. Localization

The author in [19] suggests using Crowdin as an introduction to the use of commercial CAT software. We, on the other hand, find appropriate introducing it only after free and commercial CAT tools have been introduced. We use it to localize applications developed by the students of Informatics. Furthermore, a cooperation has been initiated with the Raspberry Pi Foundation. The aim of this UK-based charity is to put the power of computing and digital making into the hands of people all over the world. These sorts of materials can also serve the purpose of introducing special vocabulary in the field of computer science, which is by far the fastest developing field, especially in terms of language.

V. EVALUATION

Since the course needs to be up-to-date, it will be continuously updated and improved. This is emphasized also in [11]. For that purpose we conduct different evaluations.

The workshop is evaluated with a questionnaire measuring the satisfaction with the organization of the workshop, topics covered, presentations, and labs. A general opinion on the usability of the workshop for future work is also tested. The average grades on a Likert 1-5 scale are 4.6 or above for all the questions, 5 being the dominant value per each question, with standard deviations below 0.17, and a total number of participants 10.

A questionnaire measuring the attitude of students toward MT and CAT tools is administered during the first and last week of the class, i.e. before and after taking the newly designed course. As in [24], students are oblivious to the fact that they will answer the same queries twice in order to make their responses in the second phase as spontaneous and as objective as possible. Due to the absence on a pre-test or a post-test, the test statistics consists of only 6 samples. The objective is to test multiple hypotheses:

a) A newly designed course positively affects students' attitudes toward MT.

b) A newly designed course positively affects students' attitudes toward TMs.

c) A newly designed course positively affects students' attitudes toward PE.

All three hypotheses are inspected in their general form, as well as with respect to time and quality dimensions. Although the test statistics is too small to draw any statistically significant conclusion, a change of opinion can be detected for the case of PE. It is also interesting to note that although the general attitude towards TMs is positive, as well as the attitude with respect to the time dimension, a fear for the final quality exists. It seems like the least affected attitude is the one towards MT. This can be attributed to the fact that MT is widely available and that students already use it on a daily basis.

VI. CONCLUSION

The paper gives a proposal of the course on computer-assisted translation. The course is envisaged as a hands-on experience and all the focus is put on practical work. Each theoretical component is followed by a practical one. During lab sessions, students are guided through exercises followed up by real-world homework assignments. The class is divided into eight assignments and a final exam. A special attention is paid so that as many of the non-exhaustive list of added value services are included in the course content.

The course has been constantly developed for three years to gain the form proposed here. Since the nature of the course does not allow it to be out-of-date, it will be

continuously updated and improved as the market dictates. In order to do this methodologically, different evaluations are conducted. However, the presence of different cohort each year provides a degree of uncertainty since the data may be skewed by inconsistencies between the cohorts, as acknowledged in [20]. Moreover, for students of humanities and social sciences technology may present a bigger challenge than to those in some other areas. In addition, providing students with materials specific to their own language pairs is not always feasible within the scope of the course. However, all the assignments require them to work from the foreign language or from English to their native.

The aim of the presented course is not to master all the tools with respect to the time dimension, but only to familiarize students with types of tools out on the market as the basic competence can be built on once the students begin to work as professional translators.

ACKNOWLEDGMENTS

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Young Entrepreneurs in Action

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Key competences for lifelong learning are the combination of knowledge, skills and attitudes that suit the context. They are especially needed for personal fulfillment, development and social inclusion of an active citizen. Key competencies are essential in the knowledge society, providing greater flexibility, enabling the individual to adapt more rapidly to constant changes in a connected world. They are also a major factor in innovation, productivity and competitiveness, and contribute to motivation and individual satisfaction and quality of work. Key competences need to acquire young people during their compulsory education and training, preparing for adult life, and adults throughout their life through the process of developing and updating skills. This paper presents the development of digital competences, enterpreneurship and financial literacy of students in elementary education, their parents and teachers as part of the international project and cooperation.

I. INTRODUCTION

Learning, working, creating and saving are the most important part of our life. If we look at our earlier generations' lifestyle, learning, working and savings were very closely associated with their daily life. They considered work and saving as the most important aspect of life and it helped them once they reached the old age. In modern times, learning and work are losing value. People often take over other people's solutions. They lost the motivation for research, the creation of their own products and services. With the modern economics and globalization, young generation is forced to spend more money on their daily life and it is difficult for people to control themselves in the environment that is promoting a lavish life. If you don't have good work and the habit of saving, then it will not help you in the later stage of your life. Anything you learn in childhood will stick with you forever. That is the reason why we should teach good habits at a young age.

II. IMPORTANCE OF FINANCIAL EDUCATION AND ENTREPRENEURSHIP

Financial discipline and independence is one of the most important lessons which this generation's parents have to teach their kids.

Including nancial education into the school curriculum in an on-going manner would hold the key to making our future generations nancially literate.[1]

The research shows that financial literacy is low even in the developed countries. A study by the FINRA Foundation estimated that nearly two-thirds of Americans couldn't pass a basic financial literacy test. According to the study, Americans have low levels of financial literacy and have difficulty applying financial decision-making skills to real-life situations.[2]

Children learn from examples. If you teach them something, you have to follow the process. Otherwise you are setting a bad example and your teaching won't be effective. If you follow what you are preaching, they will follow you without any hesitation. It is not only for the finance, they feel parents and teachers have to be an example in all other things as well. So our project includes education and workshops for parents, teachers and students.

Understanding the flow of "money in/money out" is a fundamental life skill that should begin as early as possible in life. Learning financial literacy early on can significantly impact young people's future as adults, when the ability to budget, save, spend and increase money determines a person's financial health and well-being. It's no exaggeration to say that today there is more encouragement – and opportunities - for young people to spend money than ever before. They are confronted with promotion and brand advertising on all fronts – online sites and blogs as well as traditional channels such as TV, radio and newspapers. Additionally, the increase in reality TV shows and heightened focus on celebrities and what they wear.

Entrepreneurship and financial literacy education is a process which must start in childhood. The knowledge of personal finance and money management acquired in this period plays an important role in defining person's life quality, happiness and well-being. In accordance with this, it is aimed to help children internalize the concepts like money, earning and spending money, making investment, risking, starting entrepreneurship and to prepare a substructure for the future with education in order to reflect these concepts in their daily lives. Early childhood and primary school period are the period in which the learning is the fastest and stimuli can be handled actively. So with this project, it will be aimed to support and improve their personal and social development, creativity, self-

confidence, mathematical and digital skills, logic and problem solving skills.

Project objectives:

- encourage students and teachers to actively approach the developing of the entrepreneurial spirit and the acquisition of entrepreneurial competences
- prepare teachers for the introduction of new working methods and teaching appropriate to adopt entrepreneurial, financial and digital skills, attitudes and competencies
- the introduction of systematic education for entrepreneurship and financial literacy in the education system
- encourage parents to actively cooperate with schools in order to plan and complete influence on their children
- the development of digital skills and the use of ICT as a fundamental literacy and fundamental tools for learning and personal development

Themes around which we organize project activities:

- What are the financial institutions? What is money?
- The money in the digital age: e-coins, transaction security
- What about saving? What is entrepreneurship?
- The development of ideas and the production of our own products/services
- How to develop a good business plan?
- ICT as a tool for learning, collaboration, creativity and innovations

III. INNOVATION AND IMPACTS OF ACTIVITIES

The impact our finances has throughout our lifetime on the way we live is immense, that is why it's never too early to start learning about money. Since the 2008 financial crisis, financial literacy programs have skyrocketed. Entrepreneurship and financial literacy are part of education in most of the developed countries. In most of the countries it is not yet introduced in the schools, but we can expect it in the very near future. Most of the countries are planning to formulate the entrepreneurship and financial literacy as part of the curriculum. The key characteristics of effective education programs for children are that they are taught early, they are developmentally appropriate, and taught with applied curriculum to develop decision making skills.

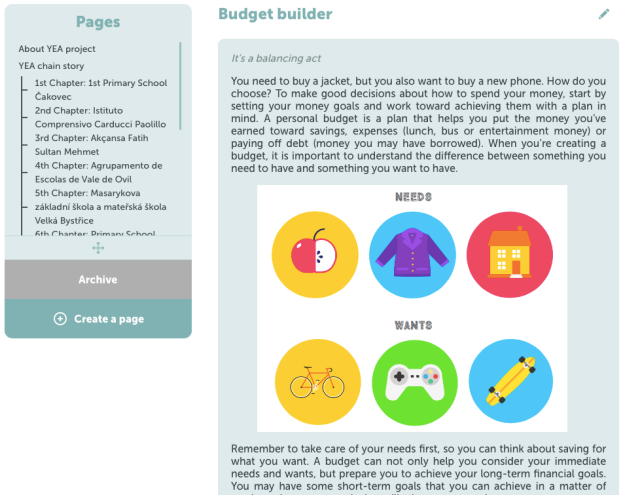
The research on financial literacy programs indicates that people learn financial concepts best when financial education is personalized and practical and when it can be applied to real-life situations. For example, financial learning is maximized when individuals are seeking to accomplish personal goals, such as when adults are planning to purchase a home or when they are saving for retirement. Delivering financial education in earlier grades helps to ensure that students who are at risk of dropping out and who may need financial education the most can receive it.

Financial literacy, or knowing how to spend and save money, is an important part of learning how to be a responsible adult. The sooner that you learn how to create a budget and save money, the more money you may have to spend on things that you want or items that you will need in the future. Printable worksheets and interactive tools can set you on the right path to budgeting, while making smart consumer choices and being practical with your money can help you save. We all want our children to grow up to become successful, capable adults who are able to earn a living, pay their own bills, and save for the future. These are skills that must be taught, in the same way as we teach our children table manners and how to get dressed. However, how often do we give our children the opportunity to learn those skills? We all need to start to teach financial literacy to our kids early, and continue to teach them as they grow older.

People often leave their families and go to work in distant places in order to ensure better opportunities for their families. Technology gives all of us the opportunity to "abolish national borders and reduce the distance". Each of us can work from home for any global company. Children should be properly taught how to use technology, and shown the opportunities to develop digital literacy with a special emphasis on creating new and fundamental values, new software, new services enabled by programming. Programming is the new literacy and programming language is a tool by which students will create their own world, their jobs in the future. The relationship between technology, entrepreneurship and finances is very strong and our children need to grow into open, satisfied and successful citizens.

The project activities are designed for students to create, with the support of teachers and parents, a complete story from observing the environment and seeking ideas for new products and services to making a profit and distributing the profit.

Students explore their strengths, specific to region in which they live and develop the idea of creating a new product or service. Products are traditional souvenirs, toys made of old stuff, decorative items from natural materials, products from plants of their homeland (tea, dried fruits, soaps), services: computer games, digital educational content, consulting services and assistance learning, drama, concert, etc.



Picute 1. Online course about financial literacy and entrepreneurship

After the selection of ideas, students explore ways to realize their idea: to develop a business plan, obtain the necessary materials, learn the procedures in the production process, making packaging for their product, devise marketing activities, develop a cash flow from the start of production to sales. Students prepare their product or service to be presented at fairs, exhibitions and other public events to their peers from school, neighboring schools and promoting partnership schools, parents, businesses and the wider community. Students sell their products for a symbolic price at public events too, and all the revenue collected and donated to the UNICEF.

Making profits and saving is not the main goal. Humans are primarily social beings whose task is to care for people around them. We encourage our students for social responsibility and sensitivity. Pupils share our products and services with the people that need them. Students volunteer with teachers at the hospital in the children's department, children will share the products they created.

Expected results:

- online course for the acquisition of knowledge and skills in the field of entrepreneurship, financial and digital literacy
- workshops for teachers, parents and student
- e-book, magazine, catalog, brochure, flyer
- e-portfolio
- keeping a diary in the online banking tool Bankaroo - a virtual bank for children available on any device connected to the Internet, enables children to learn about smart money management, revenue and expenditure management, setting savings targets, and rewarding various badges[3]
- good visibility of project activities and results on social networks
- being enriched in creative and innovative teaching methods
- improve school curiculums
- exchange experiences and best practices at the international level
- improve leadership skills and strengthen cooperation with the local community
- develop digital literacy (e-safety, collaboration, critical thinking and evaluation, curate information, proficient communicator, practical and functional skills)
- develop innovation and creativity
- develop entrepreneurial spirit and ideas
- learn to develop a business plan, a marketing campaign, monitor the flow of money, create new values
- the project web page with all results, activities: http://www.erasmus-yea.eu

More than 600 students are directly involved in the activities of six different schools with their teachers and family members. Hundreds of students have been given the opportunity to work and learn, to develop their own knowledge, skills and abilities in international teams of students and teachers during mobilities.

ICT is trying to be meaningful and purposeful in every project activity, developing the digital competence of students. Although digital technologies gradually cover all parts of everyday life, 60% of students never use digital equipment in their classroom. The full potential for improving education through ICT in Europe remains to be revealed, and that is why the European Commission is developing policy and supporting research to help students respond to life in the 21st century and work.[4]

Special attention has programming as literacy for the 21st century. Programming enhances creativity, teaches people to collaborate, work together regardless of physical limitations and geographical boundaries, it is a universal language that allows us to communicate. Technology is a part of our life, and programming connects and connects us.[5]



Picute 2. Project online magazine

IV. USED METHODOLOGY

Content and Language Integrated Learning (CLIL) which requires a teaching based on the awareness of the need to teach, in a foreign or second language, relatively complex content to people who do not speak that language as their mother tongue. The basic methodological principles are as follows:

- use, at various stages, of defined and limited lexical forms, structures and functions, at least at the initial levels;
- use of activities, materials, tools typical for foreign language teaching in content presentation, in practice, in testing and evaluation;
- ensure that listening and reading precede and exceed in quantity oral and written production;
- make frequent use of non-verbal media such as images, mind maps, photos and posters.

Critical and creative thinking inquiring (identifying, exploring and organizing information and ideas) in developing and acting with critical and creative thinking, students pose questions, identify and clarify information and ideas, organize and process information. Generating ideas, possibilities and actions element involves students creating ideas and actions, and considering and expanding on known actions and ideas. In developing and acting with critical and creative thinking, students imagine possibilities and connect ideas, consider alternatives, seek solutions and put ideas into action. Reflecting on thinking and processes involves students reflecting on, adjusting and explaining their thinking and identifying the thinking behind choices, strategies and actions taken. Students think about thinking (metacognition), reflect on actions and processes, and transfer knowledge into new contexts to create alternatives or open up possibilities. They apply knowledge gained in one context to clarify another. Analysing, synthesizing and evaluating reasoning and results involves students analysing, synthesizing and evaluating the reasoning and procedures used to find solutions, evaluate and justify results or inform courses of action. Students identify, consider and assess the logic and reasoning behind choices. They differentiate components of decisions made and actions taken and assess ideas, methods and outcomes against criteria. In developing and acting with critical and creative thinking, students apply logic and reasoning, draw conclusions and design a course of action, evaluate procedures and outcomes.

The Four Skills Activities (listening, speaking, reading, writing) has been specially designed to incorporate several language skills simultaneously (such as reading, writing, listening, and writing), they provide their students with situations that allow for well-rounded development and progress in all areas of language learning. Through activities, teachers provide learners with opportunities to develop each skill: students listen (to the teacher using the target language, to a song, to one another in a pair activity), speak (pronunciation practice, greetings, dialogue creation or recitation, songs, substitution drills, oral speed reading, role play), read (instructions, written grammar drills, cards for playing games, flashcards) and write (fill-in-the-blank sheets, sentences that describe a feeling, sight or experience, a dialogue script, a journal entry).



Picute 3. Project web page

The Six Thinking Hats is a tool that has been used by people in the business world and the educational community. This methodology of thinking was invented by Dr. Edward De Bono. He is considered an expert in the field of creative thinking and the direct teaching of thinking as a skill. Six Thinking Hats is a tool that can empower teachers of any grade and or subject matter to motivate students to use critical thinking and problem solving skills, while expressing inner creativity. We can teach the Six Hats to our students by focusing on a specific thinking skill. Students associate the colored hats with key words and questions that will direct or redirect their thinking resultingin a richer learning experience. By implementing the Six Hats to lesson, teachers can help students explore their own potential by taking an active role in their learning and enhance their creative thinking.

The methodology used in the project is based on active, collaborative learning and teaching of entrepreneurial and financial themes, on sharing experiences or ideas and on involving all participants in decision making based on consent to achieve best results as: improve pupils and teachers' language skills and to acquire new ones, develop applications and educational materials, acquire new skills and gain fresh perspectives about the application of new information and communication technologies in education, promote the European schools involved in the project development, strengthen confidence, develop social skills, improve our schools curiculums and develop innovations and creative enterprises.

V. CONCLUSION

As a Chinese proverb says, "I forget what I hear, I remember what I see and I understand what I do",our

partnership aims to encourage our pupils to learn and develop their knowledge and skills for real life. Children learn from examples. If you teach them something, you have to follow the process. Otherwise you will set a bad example for them, your teaching won't be effective. If you follow what you are preaching, they will follow you without any hesitation. It is not only for the finance, in all other things they feel parents and teachers have to be an example. So our project includes not only students but also teachers and parents.

Our objectives are develop linguistic competences, financial literacy, encourage the children to take the initiative, develop entrepreneurial spirit, strengthen self-confidence, develop IT competences in order to use ICT in a safe and responsible manner, as a tool for the creation of new values, learning and collaboration; allow the children to see how they can create new values, to learn the ways in which they can acquire their own work and earn a living; develop cooperating skills and the collaboration with European schools; encourage kids with special needs, those whose parents left abroad and low income kids to get involved in projects; promote the national identity, values and traditions, tolerance, cultural and social differences. Cooperation and collaboration, development of learning activities in schools with entrepreneurship and financialthemes and using modern techniques, as portfolios, activity diaries, map minding, brainstorming, learning through outdoor activities and research are the foundation for the development of an individual and society.

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Perceived Hedonic and Content Quality of Social Networking Sites

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***Abstract* - The implementation of social network sites (SNS) in the higher education curriculum is related to their adoption by students. The aim of the work presented in this paper was to examine hedonic and content quality of SNS as perceived by students. For that purpose, an empirical study was carried out in which students from two Croatian higher education institutions constituted a representative sample of users. Analysis of the collected data revealed the advantages and disadvantages of four SNS included in the study. Reported findings can be used as a backbone for future advances in the field of evaluating quality of SNS as well as improving their integration in educational ecosystem.**

***Keywords* – social networking sites; hedonic quality; content quality; questionnaire; empirical study**

I. INTRODUCTION

Social networking sites (SNS) are used for many activities in business and educational contexts, such as sending or receiving messages and sharing information, communicating, interacting, collaborating and "strengthening cooperation with different stakeholders across geographical boundaries using multiple modalities" (e.g. pictures, video, simple writing, voice or video chat and link sharing, etc.) [1]. On today's market, we can find a large number of SNS (e.g. Facebook, Twitter, YouTube, WhatsApp, Telegram, Pinterest, etc.).

Al-Rahmi et al. [2] emphasize that social media enhances learning. For example, Abrahim et al. [1] have found that students believe that Facebook can be used for learning foreign language and related online educational discussions. Moghavvemi et al. [3] discovered that apart from employing YouTube for entertainment and information seeking, this SNS can be used as a complementary tool in the educational process.

The results of an empirical study conducted by Bista [4] indicate that Twitter provides space and opportunities to engage students in educational activities as a new pedagogical tool (e.g. to receive immediate and frequent course information, to interact with the teacher, to update course assignments, and to share helpful information with both fellow classmates and the teacher).

Social networking sites, as an educational addition to online courses, have significantly contributed to students' motivation for learning [5]. Samad et al. [5] have found that SNS have a positive impact on social presence, students' social wellbeing, and their academic performance. The results of a quantitative analysis [5] uncovered that students use social media tools (e.g. Facebook, Twitter, Pinterest, and YouTube) as conversational facilitators.

Students' perceptions are important for examining the sustainability of the curriculum and establishing future SNS implementation with an objective to facilitate collaborative and interactive learning environments [2]. An important prerequisite for creating learning environments in higher education is a greater understanding of students' perceptions, familiarity with, and motives for using SNS as an effective pedagogical tool to enhance their educational experience [6].

In the human-computer interaction field, one of the most important factors influencing the broad acceptance of new technologies is their quality which consists of two concepts: usability and user experience [7]. While usability refers to the evaluation of pragmatic attributes, user experience consists of the application of subjective metrics (e.g. questionnaires) for the purpose of evaluating hedonic attributes [8].

The aim of this paper is to examine the extent of hedonic and content quality with respect to SNS as perceived by students.

The remainder of the paper is structured as follows. Brief theoretical foundation of our study is provided in the next section. Findings of an empirical study are presented and discussed in the third section. Concluding remarks and future work plans are offered in the last section.

II. RELATED WORK

According to the findings of the study conducted by Lee and Kim [9], flow experience and relationship quality while using SNS affect the continuance intentions related to the use of SNS; system quality, service quality, and hedonic value have an impact on flow experience, information quality and service quality; hedonic value affects the relationship quality of SNS.

Ali et al. [10] have found that usefulness and information quality significantly influence usage intention with respect to social media for learning and academic purposes whereas information quality has no impact on the actual behavior.

The results of an empirical study conducted by Moghavvemi et al. [11] indicate that outcome expectation

is the main factor affecting students' knowledge sharing, followed by perceived reciprocal benefit, and perceived enjoyment when using SNS. The same authors emphasize that knowledge sharing in a Facebook group can differ among students and contexts.

Wu and Chen [12] have discovered that social influence and information quality are critical and have a direct impact on users' continuous intention to use Facebook in learning, and that information quality has a mediating effect between social influence and usage intention related to Facebook.

Lim and Richardson [13] uncovered that intensity of social networking experience does not have a significant influence on students' perceived social presence but does have an impact on students' perceptions of using SNS for educational purposes.

The analysis of the aforementioned relevant literature suggests that students' experience and their perceived performance related to SNS can differ between different educational contexts. Therefore, the empirical study conducted for the purpose of this paper is considered justified.

III. Research Framework

In this study, quality of SNS was examined from two distinctive perspectives: content quality and hedonic quality.

Content quality (CNQ) refers to five attributes designed for measuring the degree to which the content that the social networking site provides is suitable for a specific goal in a defined context [14][15]. Accuracy (ACU) indicates the extent to which content offered by social networking site is correct, valid and free of errors. Credibility (CDB) denotes the degree to which content provided by social networking site is unbiased, trustworthy and verifiable. Coverage (CVG) implicates the extent to which content published on social networking site is appropriate, complete and compactly represented. Timeliness (TLS) represent the degree to which content offered by social networking site can be supplemented, modified, and updated. Added value (ADV) signifies the extent to which content published on social networking site is advantageous for users.

Hedonic quality (HDQ) refers to six attributes meant for measuring facets of user experience with respect to interaction with social networking site [8][16]. Aesthetics (AES) denotes the degree to which the social networking site has visually appealing user interface. Uniqueness (UNQ) signifies the extent to which the social networking site is distinctive among applications with the same purpose. Playfulness (PLY) represents the degree to which the interaction with the social networking site is focused and stimulates their curiosity. Pleasure (PLS) indicates the extent to which the employment of social networking site arouses users' emotional responses. Satisfaction (STF) denotes the degree to which users are content with using the social networking site. Loyalty (LOY) signifies the extent to which users have the intention to continue to use the social networking site and recommend it to others.

IV. Empirical Study

A. Procedure

The study was carried out in a controlled lab conditions and included evaluation of hedonic quality and content quality in the context of four SNS (Facebook, Instagram, Twitter, and YouTube). Upon arriving to the lab, the participants were welcomed and briefly informed about the evaluation study. After completing the questionnaire, study respondents were debriefed and thanked for their participation. The duration of the study was twenty minutes.

B. Apparatus

Data was collected by means of the questionnaire which was administrated online by means of the Google Forms questionnaire builder. The questionnaire consisted of 7 items related to participants' demography, 30 items meant for exploring hedonic quality and 16 items designed for examining content quality with respect to SNS. Responses to the questionnaire items were modulated on a five point Likert scale (1- strongly disagree, 5 – strongly agree). Each attribute was measured with between three and six items. Overall quality (OVQ) was examined directly by a six-point item (0 - cannot evaluate, 1 - insufficient, 5 - excellent). The internal consistency of quality attributes was tested with Cronbach's Alpha [17] coefficient values.

C. Participants

A total of 322 respondents took part in the study. They ranged in age from 18 to 49 years (M = 21.23, SD = 4.318). The sample was composed of 66.15% male and 33.85% female students. At the time when the study was conducted, 59.32% of study subjects were enrolled to one of the undergraduate study programs at Polytechnic of Rijeka (POLYRI) whereas remaining 40.68% were students at the Faculty of Informatics, Juraj Dobrila University of Pula (FIPU). Majority of respondents (85.09%) were full-time students whereas 63.98% of them were in their first year of study. They had been using regularly almost all SNS that were the subject of an evaluation. More specifically, 57.77% and 62.73% of study participants had used Facebook and Instagram, respectively, at least 4 hours a week, 9.93% of them had used Twitter at least up to one hour a week while 59.32% of respondents had used YouTube at least 11 hours a week. When the ofteness of employing those social networks was considered, it appeared that 52.17%, 57.45%, and 64.97% of students had used Facebook, Instagram, and YouTube, respectively, at least three times a day while 10.85% of them had used Twitter at least once a week. The aforementioned findings indicate that the most popular social network among students is YouTube followed by Instagram, Facebook, and Twitter.

D. Findings

The Cronbach's alpha values presented in Table 1 ranged from .639 (for attribute added value in the case of YouTube) to .955 (for attribute loyalty with respect to Instagram), thus indicating a high reliability of the scale in the context of exploratory study for all four evaluated SNS.

When content accuracy was considered, the analysis of data collected from study participants uncovered that 26.1%, 29.5%, 13.0%, and 45.3% of students agrees that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is valid (ACU1). It was also found that 23.3%, 27%, 12.4%, and 41.9% of study respondents believes that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is precise (ACU2). In addition, as much as 24.2%, 28.3%, 10.9%, and 37.9% of students perceives content published on Facebook, Instagram, Twitter, and YouTube, respectively, as correct (ACU3).

Study findings related to content credibility revealed that 18.9%, 22%, 10.2%, and 36.3% of study subjects is convinced that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is true (CDB1). It was also discovered that 20.5%, 21.7%, 9.3%, and 34.5% of students agree that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is trustworthy (CDB2). Moreover, 21.1%, 22%, 9.9%, and 39.1% of respondents believe that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is reliable (CDB3).

According to the outcomes of data analysis related to content coverage, 29.2%, 33.2%, 14%, and 45% of students thinks that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is complete (CVG1). It was also found that 64.3%, 63%, 27.6%, and 77.3% of study participants agree that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is clearly structured (CVG2). In addition, as much as 49.4%, 48.4%, 23%, and 63.4% of students believe that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is compactly represented (CVG3). Study findings also have shown that 30.4%, 32.9%, 16.8%, and 42.5% of respondents perceive content published on Facebook, Instagram, Twitter, and YouTube, respectively, as concise one (CVG4).

When content timeliness was tackled, the analysis of data revealed that 65.2%, 48.1%, 34.2%, and 48.1% of students believe that content published on Facebook, Instagram, Twitter, and YouTube, respectively, can be supplemented (TLS1). It was also discovered that 77%, 61.5%, 42.2%, and 62.4% of study participants agree that content published on Facebook, Instagram, Twitter, and YouTube, respectively, can be updated (TLS2). Moreover, 70.8%, 57.8%, 39.8%, and 57.5% of students think that content published on Facebook, Instagram, Twitter, and YouTube, respectively, can be modified (TLS3).

Study findings on content added value indicate that 44.4%, 35.4%, 19.6%, and 76.4% of participants agree that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is useful (ADV1). As much as 52.8%, 45.3%, 23.6%, and 81.1% of respondents perceive content published on Facebook, Instagram, Twitter, and YouTube, respectively, as usable (ADV2). It was also uncovered that 80.4%, 73.3%, 43.2%, and 86.6% of students thinks that content published on Facebook, Instagram, Twitter, and YouTube, respectively, is accessible (ADV3).

Regarding the aesthetics, 65.8%, 81.7%, 30.4%, and 89.8% of study participants believe that Facebook, Instagram, Twitter, and YouTube, respectively, have visually attractive interface (AES1). It was also found that 79.5%, 77.6%, 48.4%, and 85.7% of students agree that colors that predominate on interface of Facebook, Instagram, Twitter, and YouTube, respectively, are well-aligned (AES2). Furthermore, study findings uncovered that 73.3%, 73%, 45.3%, and 81.4% of respondents think that colors which dominate the interface of Facebook, Instagram, Twitter, and YouTube, respectively, are pleasing to the eye (AES3). As much as 60.6%, 73%, 36%, and 78.9% of students agree that Facebook, Instagram, Twitter, and YouTube, respectively, have an attractive interface (AES4). Finally, 67.7%, 79.8%, 41.3%, and 86.6% of study participants think that interface of Facebook, Instagram, Twitter, and YouTube, look nice (AES5).

When the extent of uniqueness was examined, it appeared that 63%, 65.5%, 32.6%, 86.3% of students believe that Facebook, Instagram, Twitter, and YouTube, respectively, has something that makes it different from other SNS (UNQ1). It was also discovered that 47.5%, 52.2%, 27.3%, and 73.9% of study participants agree that Facebook, Instagram, Twitter, and YouTube, respectively, is unique SNS (UNQ2). Furthermore, 44.7%, 52.2%, 23.6%, and 68.3% of respondents think that Facebook, Instagram, Twitter, and YouTube, respectively, is distinct SNS (UNQ3). Study findings also indicate that 59.3%, 57.1%, 32.9%, and 77.6% of participants agree that Facebook, Instagram, Twitter, and YouTube, respectively, is genuine SNS (UNQ4).

According to the results of data analysis related to playfulness, 51.2%, 60.6%, 10.6%, and 82.9% of students that using Facebook, Instagram, Twitter, and YouTube, respectively, successfully keeps their attention for a long time (PLY1). It was also found that 20.2%, 23%, 7.5%, and 35.1% of study participants reported they do not notice what is happening around them when using Facebook, Instagram, Twitter, and YouTube, respectively (PLY2). In addition, 46.6%, 51.6%, 13.4%, and 73.9% of respondents think they do not notice how fast the time passes when they are using Facebook, Instagram, Twitter, and YouTube, respectively (PLY3). As much as 29.2%, 38.2%, 9.9%, and 54.7% of students reported that interaction with Facebook, Instagram, Twitter, and YouTube, respectively, completely occupies them (PLY4). Study findings also indicate that 24.5%, 46.6%, 7.8%, and 72.7% of participants think that interaction with Facebook, Instagram, Twitter, and YouTube, respectively, encourages their creativity (PLY5). Finally, 25.2%, 45.3%, 8.4%, and 68.9% of students agree that using Facebook, Instagram, Twitter, and YouTube, respectively, stimulates their imagination (PLY6).

Study findings on pleasure are implying that 57.1%, 70.2%, 15.2%, and 93.2% of students think that using Facebook, Instagram, Twitter, and YouTube, respectively, is fun (PLS1). It was also discovered that 60.6%, 69.6%, 17.1%, and 92.9% of study participants think that interaction with Facebook, Instagram, Twitter, and YouTube, respectively, is interesting (PLS2). As much as 58.4%, 69.6%, 16.1%, and 89.1% of respondents believe that is pleasant to use Facebook, Instagram, Twitter, and

YouTube, respectively (PLS3). Finally, 64%, 72.7%, 17.4%, and 90.7% of students reported they like to use Facebook, Instagram, Twitter, and YouTube, respectively (PLS4).

When satisfaction was explored, 53.4%, 64.9%, 13%, and 87.6% of students believe that Facebook, Instagram, Twitter, and YouTube, respectively, has met their expectations (STF1). It was also discovered that 63%, 67.4%, 12.7%, and 93.2% of study participants is satisfied with using Facebook, Instagram, Twitter, and YouTube, respectively (STF2). In addition, 53.1%, 65.2%, 13%, and 87.9% of students reported that Facebook, Instagram, Twitter, and YouTube, respectively, left a good impression on them (STF3). As much as 38.5%, 51.6%, 10.2%, and 70.8% of study respondents agree that experience of using Facebook, Instagram, Twitter, and YouTube, respectively, was better than they expected (STF4). Study findings also indicate that 45%, 54.7%, 14%, and 69.3% of students believe that functionalities of Facebook, Instagram, Twitter, and YouTube, respectively, were better than they expected (STF5). Finally, 61.5%, 65.2%, 18.6%, and 78.9% of study participants agree that majority of their expectations related to Facebook, Instagram, Twitter, and YouTube, respectively, were confirmed (STF6).

Study outcomes related to loyalty indicate that 61.5%, 66.8%, 9.9%, and 91% of students agree they would employ Facebook, Instagram, Twitter, and YouTube, respectively, on a regular basis (LOY1). It was also found that 58.7%, 63%, 8.7%, and 88.5% of study respondents has the intention to use Facebook, Instagram, Twitter, and YouTube, respectively, frequently (LOY2). Furthermore, 52.5%, 59.3%, 14.9%, and 90.1% of students would recommend Facebook, Instagram, Twitter, and YouTube, respectively, to everyone (LOY3). According to study findings, 60.2%, 64.9%, 18%, and 87.9% of study participants would rather use Facebook, Instagram, Twitter, and YouTube, respectively, than any other SNS of the same purpose (LOY4). Finally, 73%, 70.5%, 13.4%, and 95.7% of students has the intention to continue to use Facebook, Instagram, Twitter, and YouTube, respectively.

When overall quality was taken into account, it appeared that YouTube (M = 4.609, SD = .5711) has the highest level of quality among examined SNS and is followed in that respect by Instagram (M = 3.696, SD = 1.5590), Facebook (M = 3.382, SD = .9953), and Twitter (M = 1.345, SD = 1.5715). All reported findings are summarized in Table 2.

V. CONLUSION

The aim of the work presented in this paper was to examine hedonic and content quality of social networking sites (SNS) as perceived by students. For that purpose, an empirical study was conducted in which data was collected by means of questionnaire. Reported findings indicate that majority of issues when all four examined SNS are considered are related to content accuracy and content credibility. On the other hand, three of four SNS have met all relevant facets of hedonic quality. Taking into account the overall quality, YouTube was perceived as the social networking site of the highest, and Twitter of the lowest quality. We believe that the aforementioned findings originate from the fact that sample of users in our study was composed of students who are using Twitter the least frequent among all four SNS which were involved in the study. Therefore, reported findings should be interpreted with caution. Our future would be devoted to examining the robustness of findings reported in this paper as well as evaluating the interplay of facets of both hedonic and content quality in the context of SNS.

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APPENDIX

TABLE I. INTERNAL RELIABILITY OF SCALE

Attributes	Number of items	Cronbach's α			
		Facebook	Instagram	Twitter	YouTube
Content quality					
Accuracy	3	.873	.886	.909	.880
Credibility	3	.901	.889	.921	.887
Coverage	4	.755	.783	.860	.764
Timeliness	3	.767	.789	.856	.755
Added value	3	.713	.750	.780	.639
Hedonic quality					
Aesthetics	5	.842	.903	.882	.786
Uniqueness	4	.827	.839	.820	.801
Playfulness	6	.837	.845	.906	.746
Pleasure	4	.913	.948	.951	.907
Satisfaction	6	.912	.929	.943	.800
Loyalty	5	.906	.955	.928	.830

TABLE II. SUMMARY OF STUDY FINDINGS

Items	Facebook		Instagram		Twitter		YouTube	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
ACU1	3.205	1.2106	3.329	1.2191	2.786	1.1496	3.727	1.2505
ACU2	3.068	1.2235	3.199	1.2447	2.742	1.1379	3.615	1.2706
ACU3	3.152	1.1965	3.289	1.2153	2.783	1.0718	3.571	1.2086
CDB1	2.935	1.1888	3.084	1.1902	2.717	1.0755	3.469	1.2828
CDB2	2.988	1.2074	3.099	1.1745	2.711	1.0504	3.453	1.2378
CDB3	2.960	1.2386	3.022	1.2341	2.671	1.0896	3.503	1.3261
CVG1	3.161	1.3132	3.289	1.3490	2.717	1.1988	3.640	1.3444
CVG2	4.115	1.2589	4.093	1.2644	3.143	1.3458	4.441	1.0871
CVG3	3.736	1.3262	3.733	1.3244	3.062	1.2712	4.109	1.2470
CVG4	3.373	1.1831	3.422	1.2159	2.969	1.1380	3.680	1.2229
TLS1	4.093	1.3056	3.643	1.4141	3.332	1.3597	3.596	1.4549
TLS2	4.391	1.1770	3.994	1.3672	3.556	1.3802	3.960	1.4257
TLS3	4.233	1.2648	3.901	1.3772	3.503	1.3563	3.811	1.4677
ADV1	3.634	1.3288	3.376	1.3203	2.944	1.2443	4.497	.9281
ADV2	3.854	1.3020	3.606	1.3841	3.056	1.2886	4.590	.8717
ADV3	4.525	1.0113	4.385	1.0740	3.615	1.3375	4.702	.7802
AES1	4.121	1.2804	4.562	.9720	3.227	1.3377	4.761	.7332
AES2	4.512	.9991	4.494	.9867	3.742	1.3368	4.665	.8534
AES3	4.348	1.1288	4.366	1.0948	3.674	1.3311	4.562	.9460
AES4	4.065	1.2121	4.376	1.0758	3.401	1.3457	4.519	.9674
AES5	4.189	1.2323	4.531	.9798	3.500	1.4059	4.705	.7713
UNQ1	4.068	1.2880	4.165	1.2257	3.286	1.3691	4.689	.8029
UNQ2	3.634	1.4018	3.755	1.3938	3.099	1.3475	4.339	1.1736
UNQ3	3.596	1.3598	3.801	1.3434	3.003	1.3125	4.239	1.1689

UNQ4	3.938	1.3680	3.894	1.3699	3.239	1.4060	4.432	1.1177
PLY1	3.602	1.5276	3.929	1.4267	2.224	1.2921	4.590	.9437
PLY2	2.540	1.4208	2.655	1.4690	2.025	1.1994	3.037	1.5841
PLY3	3.435	1.5818	3.596	1.5703	2.348	1.3615	4.267	1.2934
PLY4	2.922	1.5050	3.224	1.5527	2.205	1.2879	3.720	1.5089
PLY5	2.845	1.4079	3.484	1.5432	2.174	1.2000	4.317	1.1730
PLY6	2.854	1.4406	3.472	1.5308	2.205	1.2386	4.211	1.2476
PLS1	3.842	1.4349	4.199	1.3200	2.450	1.3872	4.823	.6902
PLS2	3.953	1.3923	4.186	1.3265	2.509	1.4191	4.845	.5753
PLS3	3.932	1.3632	4.211	1.2845	2.596	1.3621	4.761	.7117
PLS4	4.053	1.3512	4.267	1.2862	2.602	1.3843	4.776	.7318
STF1	3.770	1.4131	4.115	1.2955	2.463	1.3279	4.727	.7487
STF2	3.994	1.4054	4.149	1.3218	2.441	1.3106	4.845	.5966
STF3	3.761	1.4302	4.068	1.3813	2.407	1.3392	4.730	.7561
STF4	3.376	1.4247	3.770	1.3841	2.370	1.2518	4.348	1.0546
STF5	3.593	1.3872	3.851	1.3659	2.575	1.2955	4.286	1.1159
STF6	4.003	1.3477	4.121	1.2901	2.693	1.3814	4.525	.9543
LOY1	3.925	1.4514	4.000	1.5101	2.037	1.3013	4.783	.7208
LOY2	3.845	1.4770	3.898	1.5444	1.991	1.2715	4.739	.7532
LOY3	3.730	1.4463	3.888	1.4618	2.404	1.3870	4.780	.6866
LOY4	3.919	1.4360	4.037	1.4181	2.497	1.4560	4.717	.7997
LOY5	4.261	1.2875	4.112	1.4661	2.193	1.4077	4.898	.4980

The Exhaustive Search Algorithm in the Transport network optimization on the example of Urban Agglomeration Rijeka

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Abstract

The paper presents the use of Exhaustive Search Algorithm and model of Traveling Salesman Problem (TSP) in the transport network optimization, on the example of Urban Agglomeration Rijeka. The aim is optimal routing design between cities and municipalities of Urban Agglomeration Rijeka. In creating of Urban Agglomeration Rijeka has been defined the criteria of sustainability of transport and infrastructure systems covering the most important existing and planned economic zones, infrastructure buildings and traffic hubs (rail, highway, port, airport), located in cities and municipalities in the wider Rijeka area.The transport network of Urban Agglomeration Rijeka should provide optimal supply of cities, municipalities, and their distribution centers in the area of agglomeration. Choosing the relevant information technology and computer software to enable us to create optimal node connections (cities, distribution centres, ports, and terminals), and arrange the optimal transportation routes, is the key factor of transportation network modelling for an effective distribution of goods.

Visual and object-oriented methods of modelling and programming allows us to use and visualize the Exhaustive Search Algorithm in the transport network optimization, in the way to identify multiple optimal solutions with a clear interpretation of the results not only of the optimal value but also at approximately equal values and their deviations from the optimal value. Given that Urban Agglomeration Rijeka covers 10 cities and municipalities, Exhaustive Search Algorithm is suitable for designing the transport network. In making the program based on the Exhaustive Search Algorithm have been used Visual Basic for Application in Excel spreadsheet interface. The Exhaustive Search Algorithm, with the calculation of the optimal relation, also allows the calculation of suboptimal relations whose values within an acceptable deviation from the optimal value. The calculation and insight into the more optimum relationships can significantly support the reduction of transport costs, but also the creation of greater opportunities for the carrier with the more flexible design of the structure of goods flows and gaining more profit.

Key words: Transport network optimization, Travelling Salesman Problem, Urban Agglomeration Rijeka, Exhaustive Search Algorithm, optimal and suboptimal relationships

1. Introduction

Due to the large increases in the number of cities in the world, mobility between cities has become difficult because of there existing many dissimilar roads to reach the same city with different travelling cost [2], where there are several places that are all directly connected to each other by different long roads and the passenger wants to make the shortest trip. Some algorithms can be used to guide people using one of the transport or movement methods (walking, train, car, and bus) to reach their destination on the shortest route. [11].

The paper presents the use of Travelling Salesman Problem (TSP) model and a Exhaustive Search Algorithm on the example of the transport network of Urban agglomeration Rijeka The flexibility and adaptability of transport networks can be achieved by optimizing the routes of movement of vehicles between one of the sources and multiple destinations in transport network. [9]. The most important operational decision related to optimizing transport network of Urban aglomeration Rijeka can be set the analogy according to that the number of calculated suboptimal solution.

The basic criterion for selection of optimal transport relation is the distance between cities (trade-transport centres). In cases of the same or similar distance, there is a possibility of dynamic selection of multiple transport relations for different periods of time, so, from the perspective of other relevant criteria, there

can be one optimal relation for a certain period of time, and another optimal relation for other periods. The majority of existing software solutions allows calculation and insight into one optimal solution. Using visual and object methods in programming and modelling to form an algorithm of detailed search criteria can simulate models with more than one optimal solution for small scale patterns, with clear interpretation of the results, not only those in optimal value, but also those of approximately equal values and their deviation from the optimum. Finding a large number of optimal transport relations allows greater flexibility in making a multiobjecitive selection of optimal transport relation, especially over diferent periods of time [10].

Methodological frame of use of Visual Basic as a development tool in the visual modelling of Exhaustive Search Algorithm in VBA for Excel can serve as an incentive in creating new highly sophisticated algorithms, which will enable us to compute optimal and suboptimal solutions of transport network [10], [9].

Visual and object oriented methods of modeling and programming in the design of the exhaustive search algorithm in the spreadsheet interface, enables visualisation and interpretation of the transport network solution that can lead to insights into essential transport problem details that were previously not clearly recognizable and may indicate the possibilities for redefine the transport problem.

User oriented object modeling and programming in Excel spreadsheet interface can stimulate and affirm education and training of users (business oriented human resources – managers and workers) in choosing the best computing tools and programs for designing and optimizing the transport network and also education and training of professional informatics for translating mathematical models into computer algorithms and creating their own models and programs in the transport network optimization .

The paper is composed of seven parts.

In the first part of this paper **Introduction**, the features of this work are presented.

In the second part **Urban Agglomeration Rijeka**, the meaning of agglomeration is discussed and systematized commodity-transport centers as nodes in the agglomeration transport network.

In the third part **Traveling Salesman Problem and Exhaustive Search Algorithm,** there are considered theoratical background and determinants of Traveling Salesman Problem

In the fourth part **Exhaustive search algorithm and square pyramid model of transport network in generating multiple optimal and suboptimal solutions,** there are considered the usage and meaning of Exhaustive search algorithm in the calculating and visualisation of optimal and suboptimal solutions on the example of transport network in the form of two iinterconnected square pyramids.

In the fifth part **Transport Network Optimization of the Urban Agglomeration Rijeka**, Exhaustive Search Algorithm is considered in the Transport Network Optimization in the Excel spreadsheet interface and the optimal and suboptimal solutions are presented.

In the sixth part, **The imporetance of the suboptimal solution of the transport problem on the example of Urban Agglomeration Rijeka,** there are comparatively analyzed the similarities, differences, advantages and disadvantages of the optimal and suboptimal solution.

In the seventh part **Conclusion**, the synthesis of the whole work was presented and the most important results of the research were presented.

2. Rijeka Urban Agglomeration and transport network

The Development Strategy of the Urban Agglomeration Rijeka is based on strategic and territorial documents of all cities and communes included in the Urban Agglomeration Rijeka and is linked with all strategic higher order documents. Urban Agglomeration Rijeka Development Strategy was set up by a decision adopted on 21 September 2015 by the Ministry of Regional Development and EU Funds of the Republic of Croatia and it is formed of the following towns and cities, and municipalities: 1) City of Rijeka, 2) Town of Kastav, 3) Town of Kraljevica, 4) Town of Opatija, 5) Municipality of Čavle, 6) Municipality of Klana, 7) Municipality of Kostrena, 8) Municipality of Lovran, 9) Municipality of Mošćenička Draga and 10) Municipality of Viškovo.

Towards the end of 2014, the Government of the Republic of Croatia signed the Partnership Agreement which determines the towns and cities that may benefit from the ITI (Integrated Territorial Investment) mechanism. It relates to towns and cities having more than 100,000 inhabitants, which can form urban agglomerations as well as towns and cities with more than 50,000 inhabitants that can form urban areas. The ITI mechanism is a mechanism of the European Union for the period from 2014 to 2020 introduced with the aim of strengthening the roles of towns and cities as the promoters of economic development. The mechanism serves for implementing the activities of sustainable urban development that have an emphasized territorial dimension and for providing financial support for implementing integrated activities [4].

The activities related to the implementation of integrated territorial investments may be financed from three different European funds – the European Regional Development Fund, the Cohesion Fund and the European Social Fund, as well as within the Operational programme for Croatia for 2014-2020 entitled Competitiveness and Cohesion and the Operational programme for Croatia for 2014-2020 entitled Efficient Human Resources. The total funds that have been provided for the implementation of activities dedicated to sustainable urban development in major urban centers in the Republic of Croatia is EUR 345.35 million. The

Rijeka Urban Agglomeration project has been approved and will receive funding through the use of ITI instruments [4].

Following a public debate on the implementation of new legislation, during the period from 2013 to 2014, the City of Rijeka had made the necessary preparations for the announced changes to the regional development management system. In 2013, the City of Rijeka adopted the Development Strategy of the City of Rijeka 2014-2020 (hereinafter referred to as the Strategy), in line with the Europe 2020 Strategy, as the basic platform for the development of the Urban Development Strategy, where three strategic objectives are defined [13]:

- Strategic Objective 1: Global positioning of Rijeka with the development of the Rijeka Traffic Direction.
- Strategic Objective 2: Building a competitive economy on the foundations of a knowledge society and new technologies.
- Strategic Objective 3: Ensuring dignity for all the citizens by strengthening social inclusion and developing projects of common interest.

Global positioning of Rijeka with the development of the Rijeka Traffic Direction as the Strategic Objective 1 directly contributes to the strengthening of Rijeka's competitiveness on a global level, with its port as the greatest comparative advantage. The development of the Port of Rijeka involves a whole range of supporting services with a trend of enhancing the port logistics chains. This implies linking and aligning all entities within the transport sector. The purpose of such linking is to develop the Rijeka Traffic Direction as the unique economic offer on the global market [13].

Building a competitive economy on the foundations of a knowledge society and new technologies as the Strategic Goal 2 directly contributes to the development and application of new knowledge, with emphasis on the creation of a new economic structure in the Rijeka economy. Raising the competitiveness of the Rijeka economy through new knowledge and technology means contributing to the competitiveness of the Croatian economy, which is the EU's main objective.

By combining strategic objectives 1 and 2, a common interest of all local units that form part of Rijeka Urban Agglomeration is defined, where the synergy between these two strategic objectives directly contributes to certain aspects of competitiveness with a strong influence on the economy. A transportation network allows supplying of logistics centres of towns and cities, and municipalities, their subsystems and all logistics entities in Rijeka Urban Agglomeration. A key factor in designing an efficient transportation network to create an efficient system for goods distribution is the use of relevant IT technologies and computer applications to determine optimal routing between the nodes (towns, cities, municipalities, distribution centres, ports, terminals) as well as route planning.

Rijeka Urban Agglomeration is formed of 10 towns and cities, and municipalities that represent 10 distribution and transport centers (nodes) in the transportation network. In the advanced search algorithm used in this work, the maximum number of nodes is 9. Since the town of Lovran in situated along the Opatija - Mošćenička draga route, the transportation network could be reduced, for the purpose of finding a solution, to 9 nodes. The towns and cities, and municipalities shown in the table are nodes that represent distribution and transport centers, with the node numbers from 1 to 9, where 9A denotes the Lovran node whose routes are predetermined, and which is not included in the calculation.

Table 1 shows distances between towns and cities, and municipalities of Rijeka Urban Agglomeration, which had been determined by using Google Maps technology, a web mapping service developed by Google. It offers satellite imagery, route planning, searching and finding places, etc. Google Maps automatically displays a graphic representation of the selected route.

Table 1: Distances between towns and cities, and municipalities of Rijeka Urban Agglomeration

			1	2	3	4	5	6	7	8	9
No	**City**	**Acc**	**RI**	**KR**	**KO**	**OP**	**VI**	**KA**	**ČA**	**KL**	**MO**
1	Rijeka	**RI**	0	22	9	14	9	10	9	18	28
2	Kraljevica	**KR**	22	0	14	37	31	32	17	40	57
3	Kostrena	**KO**	9	14	0	22	23	24	12	32	43
4	Opatija	**OP**	14	37	22	0	12	7	22	20	14
5	Viškovo	**VI**	9	31	23	12	0	5	16	10	26
6	Kastav	**KA**	11	32	24	7	5	0	18	13	22
7	Čavle	**ČA**	9	17	12	22	16	18	0	22	37
8	Klana	**KL**	18	40	32	20	10	13	22	0	36
9	Mošćenićka Draga	**MO**	28	57	43	14	26	22	37	36	0

3. Traveling Salesman Problem and Exhaustive Search Algorithm

The Travelling Salesman Problem (TSP) is an optimization problem used to find the shortest path to travel through the given number of cities. Travelling salesman problem states that given a number of cities N and the distance between the cities, the traveler has to travel through all the given cities exactly once and return to the same city from where he started and also the length of the path is minimized [7]. .

The Travelling Salesman Problem (TSP) is one of the most studied problems in management science. Optimal approaches to solving Travelling Salesman Problems are based on mathematical programming. But in reality, most TSP problems are not solved optimally. When the problem is so large that an optimal solution is impossible to obtain, or when approximate solutions are good enough, heuristics are applied. Two commonly used heuristics for the Travelling Salesman Problem are the nearest neighbour procedure and the Clark and Wright savings heuristic [2].

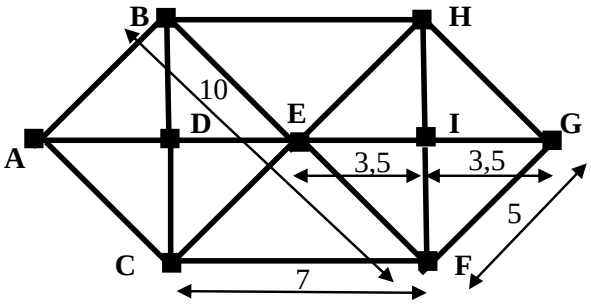
In terms of combinatorial optimization, the Travelling Salesman Problem (TSP) can be formulated in the following way: Given a list of *n* cities C and distance dij from city *i* to city *j*; TSP, is to find the best possible way of visiting all the cities by visiting each city only once finding minimum total travel distance. In analogy to the above definition, the following formulations are valid: 1) Travel distance or distance between cities is symmetric: $d_{ij} = d_{ji}$ (1) or asymmetric $d_{ij} \# d_{ji}$ (2); 2) Final list of cities is defined as incoming variable by the formula $C = (c_1 \ldots c_n)$, while distance matrix containing distance between city c_i and city c_j for each pair i,j is defined by $d(c_i,c_j)$; 3) Permutations or in other words all permuted relations that can be achieved for a given number of cities are computed as resulting variables. Permutations p(1), …, p(n) in the list 1, …, n are calculated and compared to give the minimum sum [1], [10].

Exhaustive search algorithm, also known as brute force seach, is a very general problem-solving technique. In the Travelling Salesman Problem (TSP), every tour corresponds to a permutation of the cities. In a permutation problem every freasible solution can be specified as a total ordering of an underlying ground set [3]. The Exhaustive Search Algorithm enumerating all possible candidates for the solution (permutations) and checking whether each candidate satisfies the problem's statement. It is considered as approach to apply and is useful for solving small–size instances of a problem.

4. Exhaustive search algorithm and square pyramid model of transport network in generating multiple optimal and suboptimal solutions

Choosing the relevant information technology and computer software to enable us to create optimal node connections (cities, distribution centres, ports, and terminals), and arrange the optimal transportation routes, is the key factor of the transportation network modeling and optimization. Object-oriented programming in spreadsheet interface allows us to design and visualize Exhaustive search algorithm to solve the Travelling Salesman Problem, and identify multiple optimal and suboptimal solutions in the transport network optimization.

Figure 1. Transport network in the form of two interconnected square pyramids



Model of transportation network that uses a base of a square pyramid allow us to demonstrate and analyze possibilities of generating a large number of optimal solutions that have equal or similar values. The base of a square pyramid [12] is a square having equal sides and equal angles. The base of a square pyramid is also made of diagonals that intersect at right-angles. The intersection of diagonals is the central node of the base that is equally distant from all other nodes.

Figure 1 shows a system of two interconnected square pyramids that represent the transport network. Nodes of transport networks representing cities and municipalities are marked by squares, and transport routes are marked by lines. Table 3 shows the input data and the solution in the Excel spreadsheet interface.

The cell range K1:S9 in the Table 3 contains transportation route lengths (lines) that correspond to the dimensions indicated in the square pyramid model in the Figure 1. The cell range J1:J40320 offers all possible solutions, which have been categorized from the lowest to the highest.

Table 3 shows that 36 optimal solutions were calculated resulting in equal minimum values of the total transport relation (J1:J36) and the corresponding structures of optimal transport routes (A1:I36). Considering the matrix from the cell range K1:S9 is symmetric, it follows that the model has generated 18 optimal solutions. Figure 2 is a graphical representation end example of two optimal solutions calculated in Row 1 and Row 3 in Table 3

Table 3. The input data and the solution in the Excel spreadsheet interface

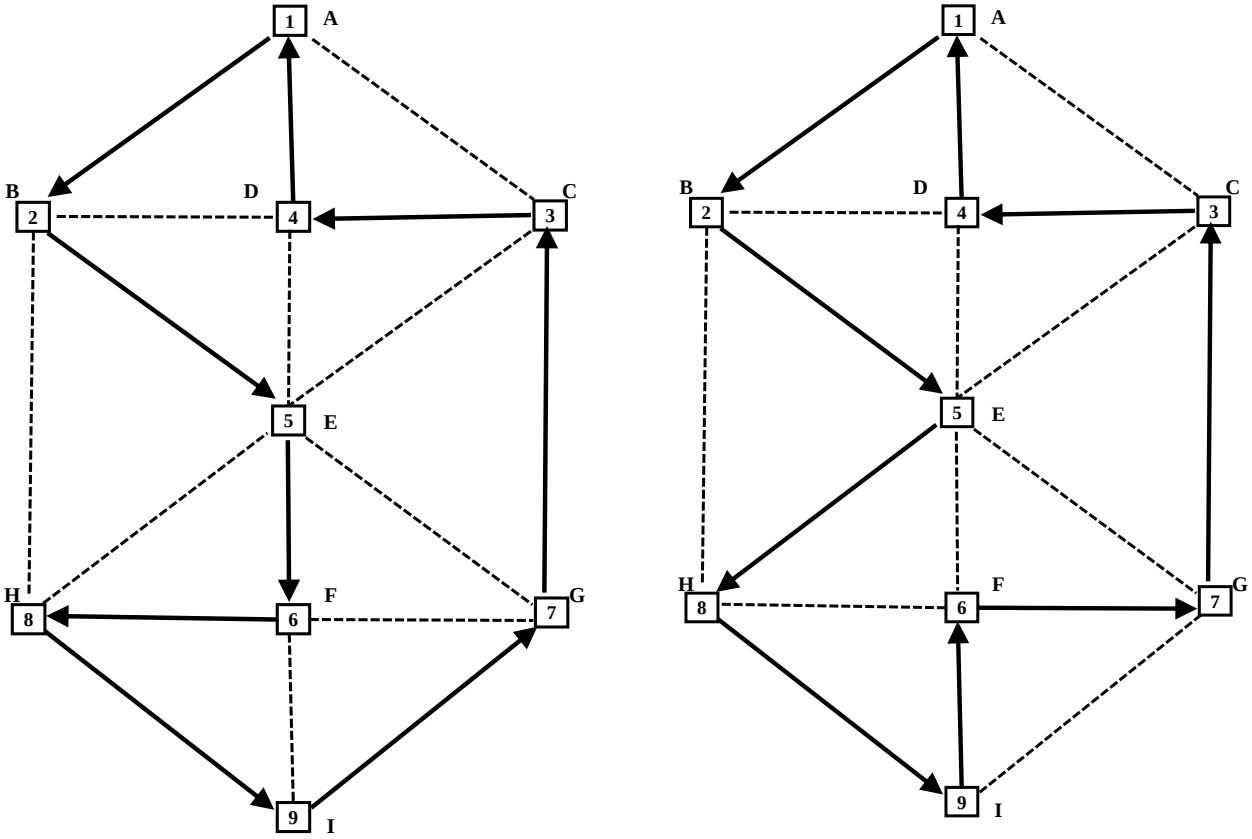
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	**1**	**2**	**5**	**6**	**8**	**9**	**7**	**3**	**4**	**41**	1,0	5,0	5,0	3,5	7,0	10,5	11,0	11,0	14,0	**1**	**A**
2	**1**	**2**	**5**	**8**	**6**	**9**	**7**	**3**	**4**	**41**	5,0	1,0	7,0	3,5	5,0	8,0	10,0	7,0	11,0	**2**	**B**
3	**1**	**2**	**5**	**8**	**9**	**6**	**7**	**3**	**4**	**41**	5,0	7,0	1,0	3,5	5,0	8,0	7,0	10,0	11,0	**3**	**C**
4	**1**	**2**	**8**	**9**	**7**	**6**	**5**	**3**	**4**	**41**	3,5	3,5	3,5	1,0	3,5	7,0	8,0	8,0	10,5	**4**	**D**
5	**1**	**2**	**8**	**9**	**6**	**7**	**5**	**3**	**4**	**41**	7,0	5,0	5,0	3,5	1,0	3,5	5,0	5,0	7,0	**5**	**E**
6	**1**	**2**	**8**	**6**	**9**	**7**	**5**	**3**	**4**	**41**	10,5	8,0	8,0	7,0	3,5	1,0	3,5	3,5	3,5	**6**	**F**
7	**1**	**2**	**8**	**6**	**9**	**7**	**5**	**4**	**3**	**41**	11,0	10,0	7,0	8,0	5,0	3,5	1,0	7,0	5,0	**7**	**G**
8	**1**	**2**	**8**	**9**	**6**	**7**	**5**	**4**	**3**	**41**	11,0	7,0	10,0	8,0	5,0	3,5	7,0	1,0	5,0	**8**	**H**
9	**1**	**2**	**8**	**9**	**7**	**6**	**5**	**4**	**3**	**41**	14,0	11,0	11,0	10,5	7,0	3,5	5,0	5,0	1,0	**9**	**I**
10	**1**	**2**	**4**	**5**	**6**	**8**	**9**	**7**	**3**	**41**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
11	**1**	**2**	**4**	**5**	**8**	**9**	**6**	**7**	**3**	**41**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**		
35	**1**	**3**	**5**	**7**	**9**	**6**	**8**	**2**	**4**	**41**											
36	**1**	**3**	**5**	**6**	**7**	**9**	**8**	**2**	**4**	**41**											
37	**1**	**2**	**8**	**6**	**9**	**7**	**3**	**5**	**4**	**43**											
38	**1**	**2**	**8**	**9**	**6**	**7**	**3**	**5**	**4**	**43**											
40319	**1**	**9**	**4**	**8**	**3**	**5**	**7**	**2**	**6**	**81**											
40320	**1**	**6**	**3**	**8**	**5**	**2**	**7**	**4**	**9**	**81**											

Source: Authors

Figure 2. Graphical display of optimal solutions calculated in Table 3

Optimal solution calculated in Row 1
1 – 2 – 5 – 6 – 8 – 9 – 7 – 3 – 4 – 1

Optimal solution calculated in Row 3
1 – 2 – 5 – 8 – 9 – 6 – 7 – 3 – 4 - 1



Source: Authors

5. Transport network optimization of Urban Agglomeration Rijeka

In the transport network optimization of Urban Agglomeration Rijeka, Exhaustive Search Algorithm built in Visual Basic has been used. Object-oriented programming in Visual Basic has been used to build and visualize Exhaustive Search Algorithm to calculate one or multiple optimal transportation routes. Table 4 contains travelling salesman problem (TSP) results.

Table 4. Solution of transport network in program Visual Basic for Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	**1**	**9**	**4**	**6**	**5**	**8**	**7**	**2**	**3**	**126**	0	22	9	14	9	10	9	18	28	**1**	**RI**	Rijeka
2	**1**	**3**	**2**	**7**	**8**	**5**	**6**	**4**	**9**	**126**	23	0	14	37	31	32	17	40	54	**2**	**KR**	Kraljevica
3	**1**	**4**	**9**	**6**	**5**	**8**	**7**	**2**	**3**	**127**	9	14	0	22	23	24	12	32	49	**3**	**KO**	Kostrena
4	**1**	**3**	**2**	**7**	**8**	**5**	**6**	**9**	**4**	**127**	14	37	22	0	12	7	22	20	14	**4**	**OP**	Opatija
5	**1**	**9**	**4**	**6**	**8**	**5**	**7**	**2**	**3**	**128**	9	31	23	12	0	5	16	10	26	**5**	**VI**	Viškovo
6	**1**	**3**	**2**	**7**	**5**	**8**	**6**	**4**	**9**	**128**	11	32	24	7	5	0	18	13	22	**6**	**KA**	Kastav
7	**1**	**4**	**9**	**6**	**8**	**5**	**7**	**2**	**3**	**129**	9	17	12	22	16	18	0	22	37	**7**	**ČA**	Čavle
8	**1**	**6**	**4**	**9**	**5**	**8**	**7**	**2**	**3**	**129**	18	40	32	20	10	13	22	0	36	**8**	**KL**	Klana
9	**1**	**3**	**2**	**7**	**5**	**8**	**6**	**9**	**4**	**129**	28	58	50	14	26	22	37	36	0	**9**	**MO**	Moščenička Draga
10	**1**	**7**	**2**	**3**	**4**	**9**	**6**	**8**	**5**	**130**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
11	**1**	**6**	**9**	**4**	**5**	**8**	**7**	**2**	**3**	**130**	**RI**	**KR**	**KO**	**OP**	**VI**	**KA**	**ČA**	**KL**	**MO**			
12	**1**	**5**	**8**	**6**	**9**	**4**	**7**	**2**	**3**	**130**												
13	**1**	**5**	**8**	**6**	**4**	**9**	**7**	**2**	**3**	**130**		**Provjera rezultata**										
14	**1**	**5**	**8**	**6**	**9**	**4**	**3**	**2**	**7**	**130**												
15	**1**	**3**	**2**	**7**	**8**	**5**	**9**	**4**	**6**	**130**		**Ri - Mo - Op - Ka - Vi - Kl - Ča - Kr - Ko - Ri**										
16	**1**	**3**	**2**	**7**	**4**	**9**	**6**	**8**	**5**	**130**		**1**	**9**	**4**	**6**	**5**	**8**	**7**	**2**	**3**	**1**	
17	**1**	**3**	**2**	**7**	**9**	**4**	**6**	**8**	**5**	**130**		=28 + 14 + 7 + 5 + 10 +22 +17 +14 + 9										
18	**1**	**7**	**2**	**3**	**4**	**9**	**6**	**5**	**8**	**131**		**126**										
19	**1**	**8**	**5**	**6**	**4**	**9**	**7**	**2**	**3**	**131**												
20	**1**	**8**	**5**	**6**	**9**	**4**	**7**	**2**	**3**	**131**												
40319	**1**	**8**	**3**	**9**	**2**	**5**	**4**	**7**	**6**	**251**												
40320	**1**	**8**	**3**	**9**	**2**	**4**	**5**	**7**	**6**	**251**												

Source: Authors

Table 5. Optimal and suboptimal transport routes within acceptable tolerance

No	Optimal and suboptimal transport routes										Length	Tol.
1	1	9	4	6	5	8	7	2	3	1	**126**	**0,0%**
	RI	MO	OP	KA	VI	KL	ČA	KR	KO	RI		
1	1	3	2	7	8	5	6	4	9	1	**126**	**0,0%**
	RI	KO	KR	ČA	KL	VI	KA	OP	MO	RI		
2	1	4	9	6	5	8	7	2	3	1	**127**	**0,8%**
	RI	OP	MO	KA	VI	KL	ČA	KR	KO	RI		
2	1	3	2	7	8	5	6	9	4	1	**127**	**0,8%**
	RI	KO	KR	ČA	KL	VI	KA	MO	OP	RI		
3	1	9	4	6	8	5	7	2	3	1	**128**	**1,6%**
	RI	MO	OP	KA	KL	VI	ČA	KR	KO	RI		
3	1	3	2	7	5	8	6	4	9	1	**128**	**1,6%**
	RI	KO	KR	ČA	KL	VI	KA	OP	MO	RI		
4	1	4	9	6	8	5	7	2	3	1	**129**	**2,4%**
	RI	OP	MO	KA	KL	VI	ČA	KR	KO	RI		
4	1	6	4	9	5	8	7	2	3	1	**129**	**2,4%**
	RI	KA	OP	MO	VI	KL	ČA	KR	KO	RI		
5	1	3	2	7	5	8	6	9	4	1	**129**	**2,4%**
	RI	KO	KR	ČA	VI	KL	KA	MO	OP	RI		
6	1	7	2	3	4	9	6	8	5	1	**130**	**3,2%**
	RI	ČA	KR	KO	OP	MO	KA	KL	VI	RI		

Source: Authors

In the transport network optimization, Exhaustive Search Algorithm built in Visual Basic has been used. Object-oriented programming in VBA for Excel has been used to build and visualize Exhaustive search algorithm in order to compute one or multiple optimal transportation routes. It can be seen from the Table 4, that 40,320 possible transport routes (permutations) have been computed with the minimum route length having 126 km. The results have been calculated by program Visual Basic in Excel spreadsheet interface (VBA for Excel), created by the authors of this work.

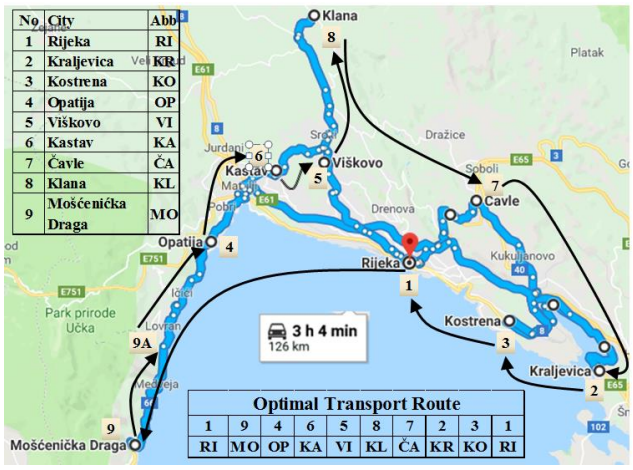
Table 5 reveals optimal transportation routes having values within an acceptable tolerance of 3% as compared to the best optimal value, or minimum route length as calculated. In Table 5 in the column No the same ordinal numbers indicate the relations that are symmetrical. From the table it is seen that the relation No 1 is optimal, and relations from No 2 to No 6 are suboptimal relations.

In the described example of the transport network optimization of Urban agglomeration Rijeka, the criterion (factor) of optimization is the minimum length of the transport relation. Considering the more optimal solutions within a given deviation interval, it is possible to parse and analyze the synergy of all relevant factors that determine the best (optimal) or set of best solutions.

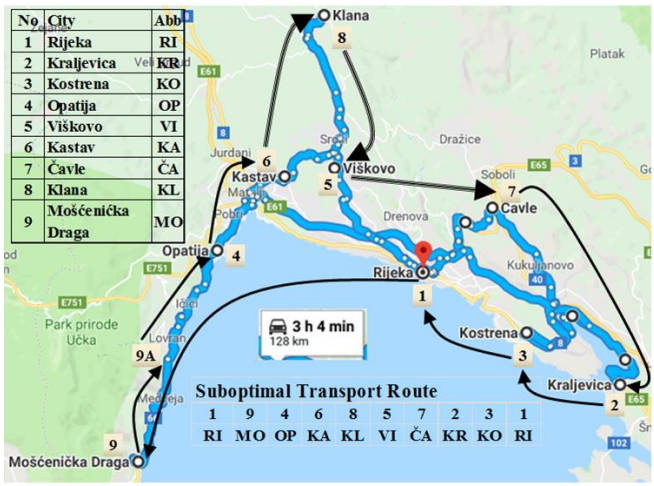
Map 1 is the graphical display of the optimal transportation route (No1 in Table 5) having the minimal length. The map shows ordinal numbers of cities and optimal transport route, names of cities and their ordinal numbers and abbreviations are indicated in the left part of the figure, while the optimal transport route is shown in down part of the figure.

Map 2 is the graphical display of the suboptimal transportation route No. 3 in Table 4 of Urban agglomeration Rijeka. The suboptimal solution to Map 2 corresponds to the solution under No. 3 shown in Table 5. By comparing the optimum solution to map 1 and the suboptimal solution to the map 2. where is a difference in the transport relation segment Kastav (6) – Viškovo (5) – Klana (8) – Čavle (7) can be seen the change of order of nodes in the tranport network. On the map, the 2-bold arrows indicate the segment of the transport network that has been changed. The changed order of nodes of the suboptimal transport network solution is Kastav (6) - Viškovo (5) - Klana (8) - Viškovo (5) - Čavle (7).

Map 1 Optimal transport route



Map 2. Suboptimal transportation route of Urban Agglomeration rijeka



6. Significance of suboptimal solutions of the transportation problem illustrated by the example of Urban Agglomeration Rijeka

In the described example of the transport network optimization of Urban agglomeration Rijeka, the criterion (factor) of optimization is the minimum length of the transport relation. Considering the more optimal solutions within a given deviation interval, it is possible to parse and analyze the synergy of all relevant factors that determine the best (optimal) or set of best solutions (transport cost and time, choosing the alternative route in case of traffic jams, the greater utilization of transport capacity [8].The Traveling Salesman Problem (TSP) is a problem which requires an optimal solution, especially if the route is to be used several times. In general, if the solution is to be applied only once, a suboptimal solution will be adequate and a very close to optimal solution may be even more desirable than the optimal solution [5].

Sequential insertion with possible requests for variable quotes to all trucks and to all routes potentially produces suboptimal solutions [6]. Significance of suboptimal solutions to the transportation problem of Rijeka Urban Agglomeration is illustrated by a hypothetical example as shown in Table 6.

Table 6. Comparison of two transportation routes and suboptimal solution on the example of Urban agglomeration Rijeka

	Route1	Route 2	
	Destination1	Origin	Destination2
	Viškovo ←	Kastav →	Klana
TTC	1000	1000	1000
RTC	700	500	900
FTC	300	500	100
LCU	70%		90%
Input1	200		200
Input2	0		200
Input	200		400

Source: Authors

The example shows the following parameters: Total Transport Capacity (TTC), Reserved Transport Capacity (RTC), Free Transport Capacity (FTC), Loading Cargo Units (Inputs), Fixed Quote of Loading

(Input1), Variable Quote of Loading (Input2) and Load Capacity Utilization (LCU).
The following formulas are used:
Input = Input1 + Input2
RTC = RTC + Input
FTC = TTC – RTC
LCU = RTC/TTC*100
With the following limit:
FTC > 0

The table shows a comparison of the two transportation routes: Route 1 (Kastav - Viškovo) and Route 2 (Kastav - Klana). Map 1 reveals that Route 1 is the optimal solution of the total transportation route of Rijeka Urban Agglomeration, while Map 2 suggests that Route 2 is a suboptimal solution.

In the example, as shown in Table 6, Load Capacity Utilization (LCU) is analyzed. The origin is Kastav, and potential destinations are Viškovo (Route 1) and Klana (Route 2). The data in the origin column (Kastav) are values for TTC, RTC, and FTC, whereas the data in the destination columns (1 and 2) are values of the fixed and variable quotes of loadings, transported along Route 1 and Route 2. The table reveals that the fixed quotes of loadings (Input1) that are loaded at the origin (Klana) are equal for both routes. The variable quotes are different, with the quote for Route 1 (Kastav - Viškovo) being equal to 0, and the quote for Route 2 (Kastav - Klana) is 200. Choosing Route 2 increases the load capacity utilization. The table shows that the value of LTC on Route 1 equals 70%, and LTC on Route 2 is equal to 90%.

7. Conclusions

In the optimization of the transportation network of Urban agglomeration Rijeka, the Exhaustive search algorithm was developed and written in the Visual Basic programming language. Object Modeling and Programming in the Spreadsheet Interface (VBA for Excel) is considered in the design and visualization of a detailed search algorithm for calculating one or more optimal transport relationships. The scientific contribution of this paper is reflected in the fact that most of today's software solutions enable calculation and insight into one optimum solution and consideration of the significance of using suboptimal solutions to the transport problem on the example of Urban agglomeration Rijeka. In the paper, it has been proven that visual and objective programming and modeling methods in designing the exhaustive search algorithm can generate models with more suboptimal solutions for smaller samples (up to 10 merchandise transport centers) with clear interpretation of results not only for the same optimum values but also about the same values and with the definition of allowed deviations from the optimal values.

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Learning of Color in Croatian Primary Schools

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***Abstract* - In this article the learning of color will be described by presenting concrete illustrations of art problems, which pupils are solving by reproductions of art masterpieces. The reproductions are examples from the teaching program for the subject visual art in primary schools from the 5th to 8th grade. After the theoretical part of the learning of color, the use of a database of art reproductions for pupils and teachers will be elaborated as an useful application in practice. For this purpose examples of paintings are stored in an original computer program previously developed by the authors.**

***Keywords* – learning, color, primary schools, visual art, computer program**

I. INTRODUCTION

The education of color from the 5th to the 8th grade in elementary school is defined by the Curriculum for the subject Visual arts. [6]

This is an obligatory program for Visual arts education in all Croatian primary schools, so all pupils are included in this research about Learning of Color.

Since the learning of color should be accessible (adapted) to children, teachers in daily practice, i.e. in art classes encourage interest in the visual arts area and motivation for learning, by showing artworks of art painters (.ppt(x) presentation). Artistic artworks are one of the main initiators of the learning and teaching activity of the subject Visual Arts. It has been proved that by an enlarged presentation on a screen, i.e. by a slide or video projector, the visual attention and motivation of the children increases.

For each lesson teachers plan different tasks for children to motivate and encourage them for active learning: observation of reproduction, exploration of visual artworks, acquaintance of visual arts, interpretation of paintings, preparation of questions related to the image, discussion and critical judgment and evaluation.

Such learning by concrete examples of the paintings, i.e. by establishing a communication between children and artworks, pupils learn better and more about art. It stimulates the visual experience and develops perception among pupils. The children learn the names of painters, basic information about the authors paintings, places and periods in which they are painted, painting techniques, art motives, characteristic style of the painter, ways of composing color, action and symbolism of color and other issues. [3] In the handbook for visual art teachers is written: "Into the language of art, communication with artworks and visual exploration and the creation of art techniques, it is necessary to enter gradually, as one gradually enters into writing and creation of music". [4]

The main instrument of this learning mode is research and analysis of the painting. Through the painting pupils build their own world and their visual experience helps them in the processing of this information. By analysis of these paintings, the visual speech and the development of all degrees of divergent thinking in the field of visual art education is enhanced. [6].

Twelve mandatory and elective color themes are defined in the Curriculum or Teaching Plan and Program. These are:

1) Pure colors, contrast warm-cold
2) Complementary contrast
3) Light values of pure colors
4) Local color, tone gradation
5) Optical color mixing
6) Symbolic and associative role of color
7) Tone modeling
8) Color modulation
9) Color perspective
10) Expression of color
11) Spatial effect of color
12) Shape and color.

Each lesson contains key concepts, educational achievements and examples of artworks.

The key concepts defined by the Curriculum are the following: spectral color scheme, warm and cold colors, chromatic intensity, color dynamics, daltonism, complementary contrast, artistic elements, chromatic scale, color brightness, pure color, local color, harmony (color harmony), tone gradation, mechanical and optical color mixing, mimicry, camouflage colors, symbolism, association, light, tone, tonic modeling, appearance of roundness, color modulation, expressiveness (expression), figurative art composition, coloristic perspectives, color dynamics and space plans. [6]

Below, artworks will be presented as examples for these color explanations, stored in a special computer program, that was also used as a database, (PaintArt 2.0) developed by the authors in previous years and presented at the Conventions of Mipro 2013 (PaintArt) and 2014 (PaintArt 2.0).

It is interesting to explain how it came to the development of these computer programs, because despite a lot of improvements and innovations in education systems worldwide, the use of computers and software in learning and teaching Visual Arts on the primary school level, was not common and widespread, not only in Croatia but also in Europe.

Taking into account that only a minority of teachers in Croatian primary schools implement modern teaching methods and activities to motivate their pupils learning and even a smaller part of them is using computers as an aid in learning and teaching Visual Arts, especially from 5th to 8th classes, the authors explored in earlier research recommended software that would be most appropriate for learning and teaching Visual Arts in Croatia and abroad. According to this research authors have come to the conclusion, that beside already existing software, it would be useful to develop a simple and portable computer program in graphic mode together with an art database to be suitable for teaching Visual Arts in school and appropriate for interactive learning at home. [8]

They also have taken into consideration the fact that in a significant number of schools only older and less powerful computers are available to teachers and pupils and even at home pupils do not always have the newest and fastest computers. Because of that, simpler software, not so demanding in terms of hardware requirements, but also running in graphic mode, would be an appropriate solution in both cases. [1]

There are of course a lot of excellent free paint programs existing in the market like Microsoft Paint being part of MS Windows, Paint.Net or GIMP even for Linux operating systems, but these computer programs are so sophisticated that they very often distract pupils, meaning that they are not enough focused on the main issue, i.e. learning about Visual Arts or like in the case of this article Color, but would rather explore the numerous possibilities of the paint programs by "playing" with them.

For this reason the authors developed a simple computer program called PaintArt with an art database included, programmed in MS Visual Basic for Windows. With this computer software which includes a paint program (in graphic format) and forms in bitmap format, it is possible not only to write text bur also to draw lines, boxes, circles etc., interactive learning gets a new dimension. From now on it is possible not only to ask questions in the form of yes/no, multiple choice or demand answers in so called full-text, but really to apply the solutions. [8]

In the second version of this computer program called PaintArt 2.0 enhancements are provided on two levels. On the first or technical level the program has now full freehand drawing possibilities, the delete function is enhanced and the windows can be resized in a more flexible way. Secondly, this computer program now includes four different forms in bitmap format, where it is not only possible to ask questions in the form yes/no, multiple choice, ordinary questions demanding answers in full-text but also where real applications are required such as drawing of the solution. If the lesson is about Color, the teacher could show a painting of a well known artist and ask to which movement of painting it belongs and what color concept it implies. By presenting this software in class and by sharing it, pupils can take it home and by comparing own answers with the provided solutions in the software they can verify their knowledge of the topics discussed at school. [9]

More about these articles, as well as computer programs in general, can be found in the following literature. [8] [9] [1]

II. Color Analysis of Artworks

The analysis of artworks (stored in the computer program PaintArt 2.0) is presented below for the color concept from the 5th to the 8th grade of primary school by different sources of literature. [5] [7] [2] [10]

Paul Gauguin, Woman with Flowers, oil on canvas, 1891
- a powerful and free choice of colors
- expressing feelings and thoughts
- the color is clean and applied in wide areas
- expressive simplicity and power of the composition
- the role of the color is decorative
- chromatic intensity of color
- large areas of blue, red and yellow colors with orange, green and purple
- with a warm and cold contrast, an unusual and expressive color was achieved
- dynamics is achieved by pure spectral colors (from the chromatic circle of colors)
- separation from naturalism

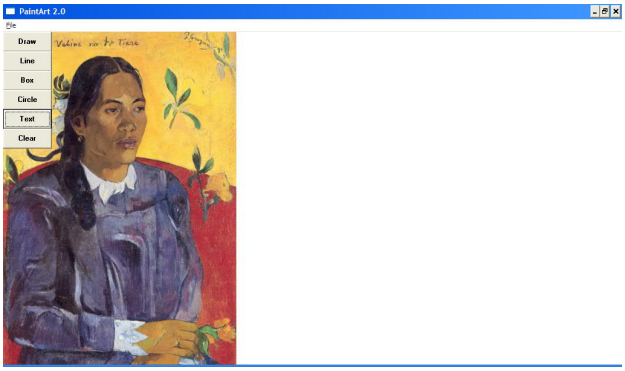

Figure 1. Painting titled Woman with Flowers in PaintArt 2.0

Henri Matisse, Portrait of Madame Matisse, oil on canvas, 1905
- strong color, vibrant colors
- no descriptiveness, the color is already in the function of modulation
- colors work by complementing one another (they support themselves when standing next to each other)
- contoured and simplified contours
- the color is harmonious but unnatural lively
- the description of reality is missing reality

- flatness - a two-dimensional composition
- color separation
- the power of the tones does not diminish with the fictitious green line that runs from the forehead to the chin

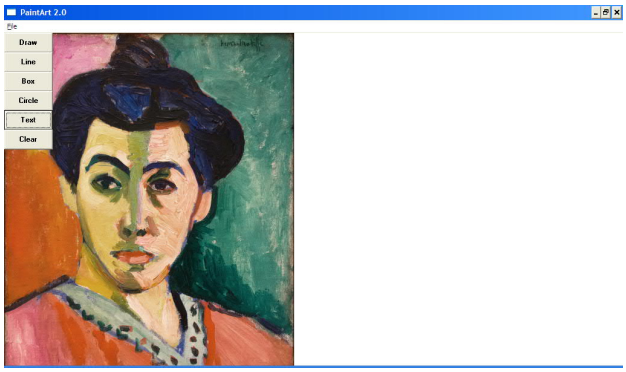

Figure 2. Painting titled Portrait of Madame Matisse in PaintArt 2.0

Jan Vermeer, The Milkmaid, oil on canvas, 1660
- clean colors have their light value
- chromatic scale
- light has the power and accurate representation of the new scene of apparent immobility with the help of light
- the yellow and blue colors create the dynamics and clarity of the composition

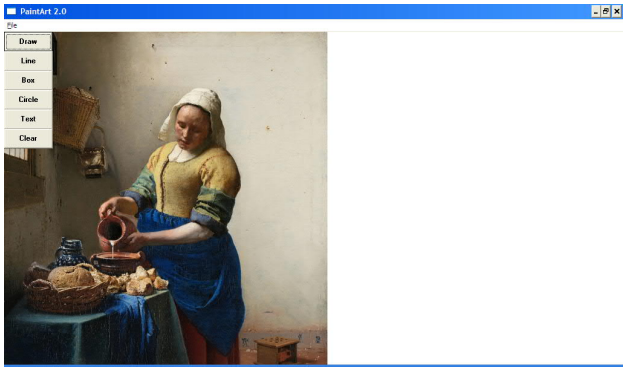

Figure 3. Painting titled The Milkmaid in PaintArt 2.0

Victor Vasarely, LA-MI, serigraph, 1973
- optical art - Op-Art art
- application of geometric canons
- harmony (harmony of colors)
- tone gradation
- a proper mesh of colored surfaces in the form of squares
- a motion experience in several opposing streams
- opposing two perspectives
- achieving the architectural meaning of the work
- pure abstraction

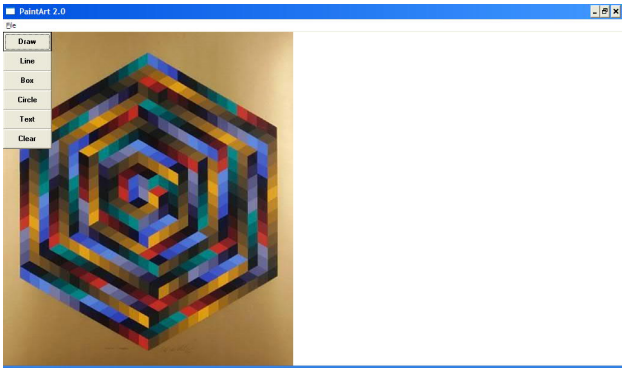

Figure 4. Painting titled LA-MI in PaintArt 2.0

Georges Seurat, Circus, oil on canvas, 1890
- elaborated technique of pointillism
- the purity of the shape, the rigidity of the unity with the subtlety
- light shimmering without the color of the paint on the palette
- placement of colors in isolated, separated and correct spots of pure color (replacement for pigment mixing)
- optical color mixing (merging complementary colors) in the observer's eye at a certain distance from the image
- strict geometry and stylization
- clarity of the image construction
- color separation technique

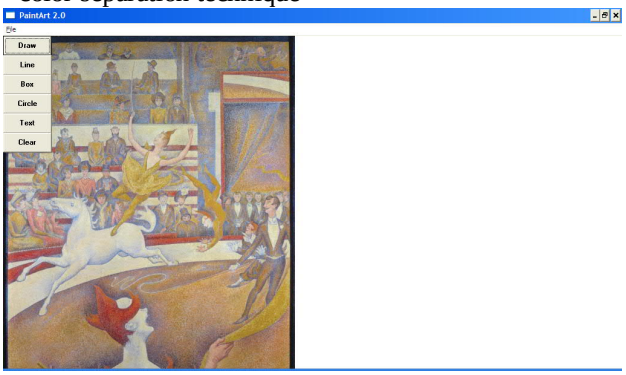

Figure 5. Painting titled Circus in PaintArt 2.0

Joan Miro, People and Dog in the Sun, tempera on canvas, 1949
- an unusual combination of shapes
- surrealism (beyond dimension of reality)
- abstract consonance (harmony) of pure colors
- association - hidden color richness
- undetermined figures (indicated by the unusual similarity of different creatures)
- the color is caused by the sensation of stimulating and overwhelming
- the color is multidimensional and can be interpreted in different ways
- distortion of realistic (irrational, unconventional)
- color symbolism

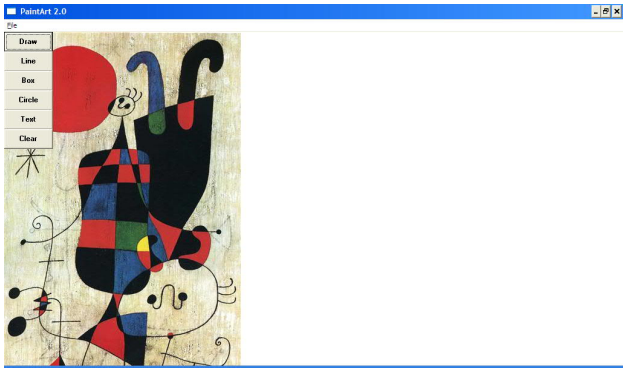

Figure 6. Painting titled People and Dog in the Sun in PaintArt 2.0

Josip Račić, Mother with Child, oil on canvas, 1920
- tonic painting
- a simple palette enriched with gray tones
- the presence of different tonal values
- application of valence, i.e. tonal gradation (grading)
- achievement of the perception of the roundabout
- dominions of black and gray
- clarity of volume
- a realistic display of the portrait
- narrow color range
- solid modeling

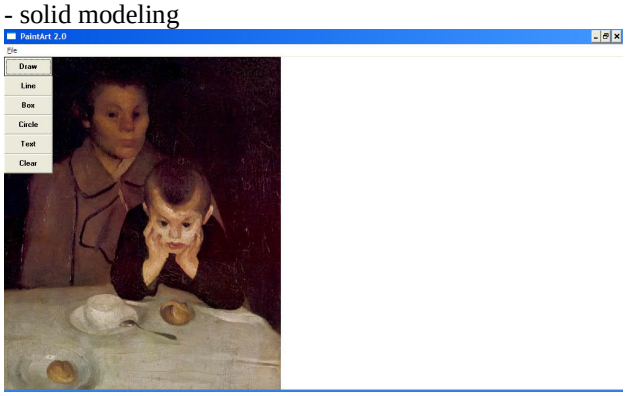

Figure 7. Painting titled Mother with Child in PaintArt 2.0

Marino Tartaglia, Self Portrait, oil on canvas, 1917
- color modulation achieved volume illusion
- expression and color expressiveness
- flat layout of the chromatographic surfaces
- rich but suppressed color
- warm colors appear closer and cold appear visually
- warm colors prevail
- the painter's handwritten notes
- the expressive subjective state of the artist
- the distance from the real view (close to abstraction)
- unconventional form of expression

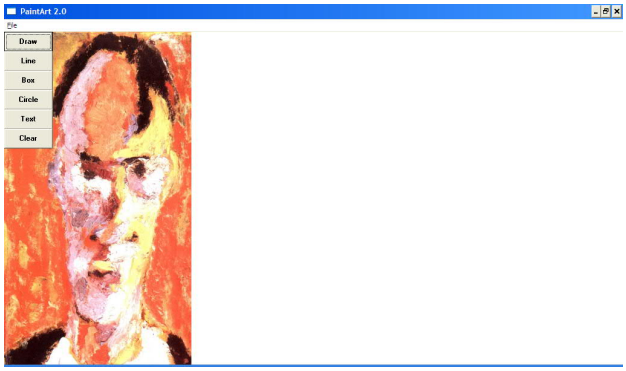

Figure 8. Painting titled Self Portrait in PaintArt 2.0

Maurice de Vlaminck, Bougival, oil on canvas, 1905
- coloristic perspective - warm and cold colors
- the paint is painted with wide brush strokes
- the surface of the paint is framed with painted drawings
- color dynamics
- the volume is expressed in color contrast
- the composition is made of strong, pure and mixed colors
- the colors act aggressively and wildly
- impulsive painter (flameproof)
- the painting acts aggressively, fiercely, wildly

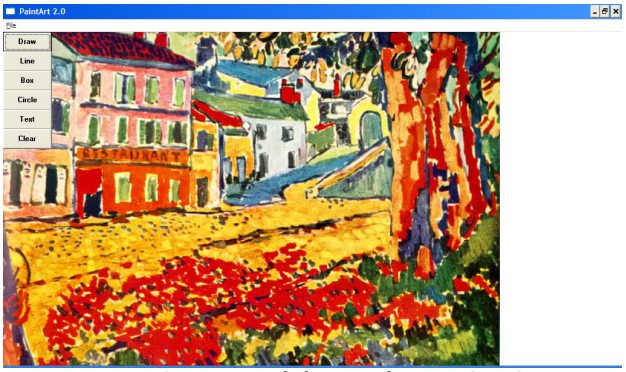

Figure 9. Painting titled Bougival in PaintArt 2.0

Vincent van Gogh, The Night Cafe, oil on canvas, 1888
- color has an expressive function
- color is flattered in expression and passion (excitement, anxiety, ...)
- strong and saturated tones
- brush action can be monitored (focused and emphasized)
- color is not a function of describing reality but of the environment experience
- color is expressive and the idea is represented by chromatic values (yellow, orange, ...)
- a personal vision of the world
- thick color plaques (visible script - impasto)
- the color contains symbolic value

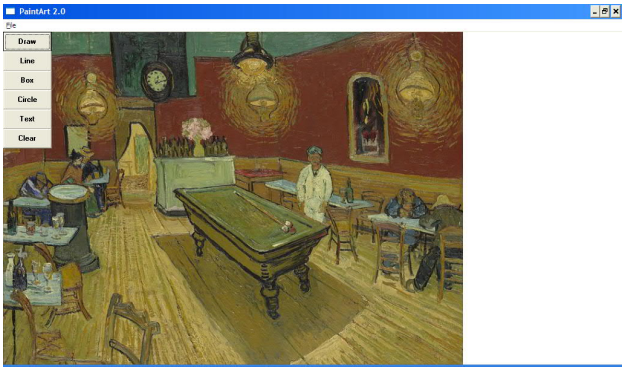

Figure 10. Painting titled The Night Cafe in PaintArt 2.0

Piet Mondrian, Composition, oil on canvas, 1925
- abstract image
- color reflects liveliness, mobility and strength
- the color dynamics were realized in a psychological way
- subjective experience - general impression
- pure colors are rotated by a raster of vertical and horizontal lines
- artistic purity, strong action of basic colors
- color balance and spatial proportions
- ultimate simplicity and purity based on geometric shapes and pure colors

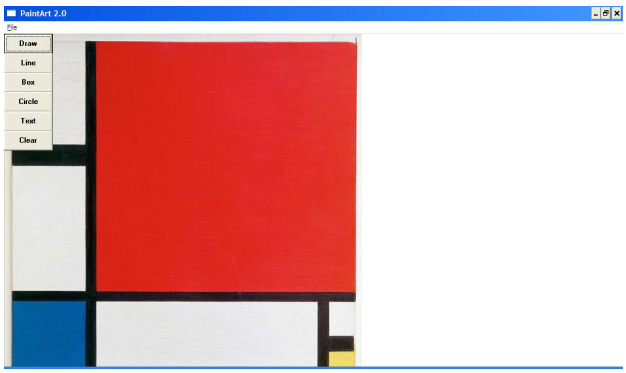

Figure 11. Painting titled Composition in PaintArt 2.0

Gerrit Rietveld, Red and Blue Chair, wood, 1917
- the color and shape are in function of the design of the chair
- pure, dynamic colors
- flat, smooth surfaces
- red, blue, yellow and black support the construction

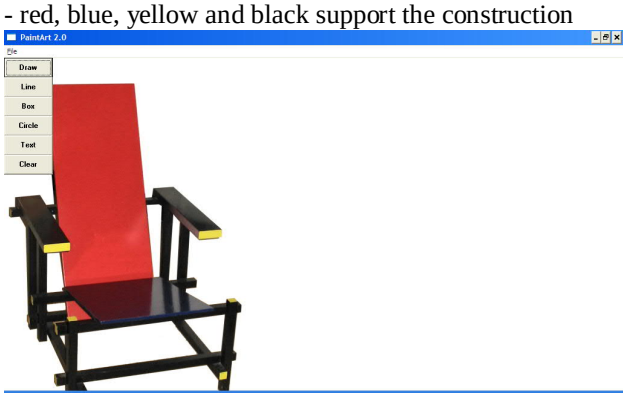

Figure 12. Furniture titled Red and Blue Chair in PaintArt 2.0

To sum up, as it can be clearly seen from 12 Figures containing screenshots of various paintings and one chair stored in PaintArt 2.0, it is evident that it really makes the analysis of these (and all desired) artworks, by teachers and for pupils, easy and effective since questions in different forms can be added and correct answers provided.

III. Conclusion

To explore color and its actions through artworks (paintings), the selected and presented examples, should be accessible and interesting for the children. By preparing and defining tasks, the teacher creates a process that should be motivating for pupils and focused on learning about color. The curriculum for four years teaching the subject of Visual Arts offers a list of artistic artworks and the teacher can choose and use them in the teaching process. By well prepared presentation and creating a situation in which children explore art concepts and solve artistic tasks related to the topic color and communicate with the image as a visual stimulus, the teacher can achieve the goals of teaching visual arts such as artistic literacy, visual perception, and artistic creativity and children's learning. For this purpose special computer programs both in graphic mode, called PainArt and PaintArt 2.0, with a well prepared database were developed and presented.

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C T S

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PAPERS

INTERNET OF THINGS

Highlighting the Key Factors of an IoT Platform

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***Abstract* - The Internet of Things (IoT) is a hot topic in the engineering and technology community, and IoT-enabled devices are becoming increasingly common due to advancements in technology. IoT platforms provide valuable and specific services for IoT applications, and the number of platforms used by IoT applications is growing rapidly commensurate with the increasing number of IoT devices. However, fierce competition between IoT platforms is making it difficult for companies to select a suitable type of IoT platform for their business needs. This paper attempts to identify the important factors of IoT platforms that can be consider before selecting an IoT platform. In this paper, Twenty-one important IoT platform factors are identified from the literature and these factors were then verified by the Delphi method and categorized. This paper aims to help companies choose an appropriate IoT platform from the huge number and variety of IoT platforms available in the market.**

Keywords - IoT, IoT platforms, IoT components, key-factors, Protocols

I. INTRODUCTION

The term "Internet of Things", abbreviated "IoT", was introduced by British technology entrepreneur Kevin Ashton in 1999 as the title of a presentation at Procter & Gamble (P&G) and can be defined as small and complex systems that allow businesses, governments and citizens to adopt and interconnect physical objects and virtual objects based on existing and evolving interoperable information and communication technologies [1]–[4]. An IoT platform enables IoT device and endpoint management, connectivity and network management, processing and analysis, data management, application development, access control, security, monitoring, event processing and interfacing [5]. Recent growth in mobile devices, embedded technologies, cloud computing and data analytics has resulted in a boom in IoT utilization, for both personal and organizational use, to conduct information exchange in order to facilitate recognition, monitoring, tracing, positioning and administration [5],[6]. For example, Williams [8] stated that in 2015 the number of IoT platforms was almost 260, which grew to 360 platforms in 2016, and exceeded 450 platforms in 2017. Requirements for IoT platforms, which provide important services and features for IoT applications, change as new IoT devices emerge [9]. Lee [10] identified 4 types of IoT platforms namely end-to-end, connectivity management, cloud and data. This complexity in the context of rapid change poses challenges for businesses, governments and citizens, who often have little experience of the infrastructure of IoT and little knowledge of how to select an IoT platform that can meet their current and future needs.

This paper aims to help companies or organizations address key factors in IoT platform selection and thus enable them to find and choose a suitable IoT platform for their business.

The rest of the paper is organized as follows. Section II discusses building blocks of IoT and important factors of an IoT platform, section III discusses research methods and data collection, section IV presents Delphi study results, and section V discusses the findings and concludes the paper.

II. RELATED RESEARCH

IoT application needs a platform to run smoothly and provide the data so that the companies take some future decisions based on the data received from the IoT platform [11]. Hundreds of IoT platforms are available and finding the most suitable IoT platform for a specific IoT application is becoming increasingly difficult. The problem is compounded by a lack of experience and knowledge, and in some cases, a company may select a platform without adequate requirements analysis, which later leads to problems [9].

The question thus arises: "what important factors should be considered before selecting an IoT platform?"

The literature review structure is similar to [13] and the literature review had two main objectives:

- To identify the building blocks of IoT.
- To identify key factors of IoT platforms.

A. IoT Building Blocks

In order to understand the functionality and significance of IoT, it is essential to understand its building blocks. Building blocks are the components of IoT, that work together to deliver the functionality of IoT. There are six IoT building blocks that work together and provide functionality [12], as shown in Fig 1.

Identification block: The identification method is used to identify devices in the network. Devices are identified with the Object ID, which is the name of the device, and the object address, which provides the address of the device in the communication network [14]. The main addressing methods of IoT objects are IPv6 and IPv4 [12].

Sensing block: Sensors are used for collecting the data of objects in the communication network and sending the

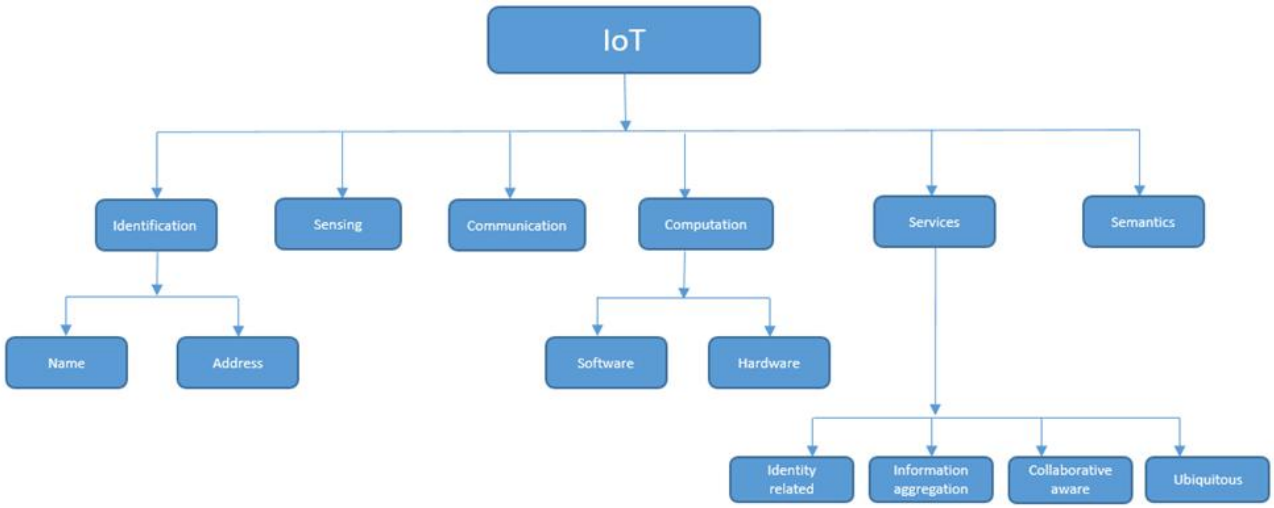

Figure 1. IoT building blocks, idea from [12]

collected data to the destination database or to the cloud. The data collected is analyzed in the cloud . Actuators, i.e. hardware mechanical devices such as switches, are also used in IoT platforms and operate in the opposite way of a sensor [12], [15], [16].

Communication block: This block contains many heterogeneous objects that exchange data and various services with each other and with the IoT platform. The communication block contains IoT communication protocols like MQTT and CoAP to connect to the objects that are connected in the IoT and to send data to the management system. The sensors and other devices are connected to the Internet by communication technologies like ZigBee, NFC, UWB, Wi-Fi, SigFox, and BLE [9], [12].

Computation block: The computation block consists of two parts, hardware and software. Many hardware platforms have been built to run IoT applications, for example, Intel Galileo, Raspberry PI, Gadgeteer, UDOO, and Arduino. Similarly, there are many software platforms that are used to perform the functionalities of IoT. The main software platform is the operating system that runs throughout almost the whole activation time of the device. The cloud platform is also a computational component of the IoT; it enable small objects to send data to the cloud, it facilitates big data processing in real time and helps the end user to obtain knowledge extracted from the big data [9], [12].

Services block: IoT services aid IoT application developers by providing a starting point for development. When developers know the services available, they mainly focus on building the application rather than designing the service and architecture for supporting the IoT application. IoT services are divided into four Categories. *Identity related* services can be divided into two categories, active and passive. Services that broadcast information and have a constant power or take power from the battery are active identity related services. Active identity related services can transmit or send information to another device. Passive identity related services have no power source and need some external device or mechanism to transmit its identity. Passive identity related services can only read information from devices. *Information aggregation* services refer to the actions of collecting data from sensors, processing that data, and transferring it to the IoT application for processing. *Collaborative aware* services use the data provided by the information aggregation services to make decisions and react accordingly. *Ubiquitous* services provide collaborative aware services anytime to anyone who needs it anywhere [15], [17], [18].

Semantic Block: IoT provides different services, for which it needs knowledge, and in order to get that knowledge in a smart way, IoT uses different machines. Knowledge extraction can include finding and using resources, modeling information, and recognizing and analyzing data to reach some decision and provide the correct service. So, it can be justifiably claimed that the semantic block is the brain of the IoT [9], [12], [15].

B. *Key Factors Of IoT Platforms*

An IoT platform is the main part of an IoT solution. There are hundreds of IoT platform vendors in the market, and finding and selecting a suitable IoT platform that is reliable and scalable is difficult. However, consideration of some key factors prior to making a platform selection decision can enable companies find and select an appropriate IoT platform for their business. The platform requirements are context-specific and it is not necessary that a platform include all the factors discussed below.

Stability: There are hundreds of IoT platforms in the market and it might be the case that not all platforms will work perfectly. Some platforms might fail to deliver services to clients. Thus, a platform should be chosen that has high chances of survival in the market. Information about the platform can be obtained from previous customers using the same platform [9].

Scalability and flexibility: Initially, a company might be small and operate in a small business area but, ideally, over time, the business will expand and with this growth, the business area will also expand. Thus, to ensure that the IoT platform can support the business throughout its development, the platform should be scalable to business needs [9]. Similarly, the platform should be flexible as regards to the technology, since modern technology and market demands change rapidly.

The pricing model and business case: Some platform providers offer a low price for a period at the start of a contract agreement, after which the price increases greatly. Additionally, some providers offer a low price to attract customers, but the contract includes limited features and additional features have a significant cost if included. Thus, a platform should be selected that offers full features for the business at a cost that suits the company's budget [9], [19].

Security: Security is an important aspect of IoT and all platforms providing IoT services should have high quality security. The security may be a device to implement cloud network security, data encryption, application authentication, secure session initiation, application authentication, cloud security, and device security (authentication and up-to-date certification) [20].

Time-to-market: When selecting an IoT platform, the questions of time-to-market and how the platform provider will support the business during the journey from product conception to sale should be considered. Some IoT platform providers offer quick-start packages for new customers, which can speed up product development, reduce time-to-market and offer better solutions [20].

Data analytics and visualization tools: Before selecting an IoT platform, prospective IoT platform users should establish which platform offers the best capabilities to aggregate, analyze and visualize data. In particular, users should consider how the IoT platform integrates leading analytics toolsets and uses them to replace built-in functionality. Data analysis and information visualization requirements should be identified before selecting an IoT platform [17].

Data ownership: A complicated issue with IoT data is ownership of the data. Different jurisdictions have different laws and legal interpretations. For example, the European union (EU) has different rules and regulations regarding data ownership than the United States (US) [21]. Therefore, it is important to have knowledge of data rights and the territorial scope of data protection for the IoT platform provider.

Ownership of cloud infrastructure: The hardware infrastructure layer is very expensive and some smaller IoT platform providers only provide the software layer. Some IoT platforms providers certify their platform on single or multiple leading public cloud providers and mostly run their services on a single leading platform. Thus, the compatibility of the broader enterprise cloud strategy with the IoT platform provider should be checked [22].

Extent of legacy architecture: The connectivity in an existing IoT is often unknown, and IoT devices are designed to work with a variety of infrastructure systems. Thus, when selecting an IoT platform, businesses should ascertain how new generations of technology can interlock with older technology [23].

Protocol: The important protocols supported by IoT platforms are MQTT, HTTP, AMQP, and CoAP. Due to its binary nature, MQTT is extremely lightweight and has much lower overheads. As a result of development in technology, new devices are coming onto the market. The selected IoT platform should support new protocols and enable easy upgrade of these protocols [27], [28].

System performance: In an IoT platform, when an event happens, a rule based trigger is invoked automatically. Since IoT platforms support rule-based triggers, as larger numbers of devices connect to the IoT platform the average time to analyze and handle each event increases. Prior to selection of an IoT platform, it should be noted what steps the provider has taken to maintain high IoT platform performance [29].

Interoperability: The IoT platform solution is a middleware. The data collected will be used by many applications and may not be available on the platform itself. Consequently, the selected IoT platform should support integration with open source ecosystems. Interoperability will enable the organization to gain higher productivity [30], [31].

Redundancy and disaster recovery: Problems sometimes occur in the IT infrastructure, either natural or man-made, and IoT platform providers should have dedicated infrastructure to handle data during such occurrences. Issues that require consideration include the data backup plan schedule and whether the IoT platform has failover cluster provision [27].

Attractive interface: The interface provided by the IoT platform should be simple, attractive and user friendly, so that it is easy for customers to use its functionalities. All the services offered to the customers should be easy to access.

Application environment: Three aspects of the application environment should be considered before selecting an IoT platform: which applications are available out of the box, what are the characteristics of the application development environment, and what are the common application interfaces [22].

Hybrid cloud: Some IoT platforms can fit with existing

IT systems hosted on company premises. In such situations, a hybrid cloud is very useful as mission critical or business sensitive processes can be handled locally, while public and less critical operations can be managed by the IoT platform [27].

Platform migration: Over time, and as the company grows, the IoT platform may be unable to meet all the company's requirements. Thus, a bigger IoT platform provider may be needed. Consequently, companies should ensure that the selected IoT platform provider provides clearly documented interfaces, schema, and API for any possible future migration to other IoT platforms [9], [27].

Previous experience: Prior to selection, a company should check whether the IoT platform provider has some experience of work similar to that of the company application. Successful working experience in the same area can be considered a good sign [20].

Bandwidth: For efficient movement of information and communication between the processing components, the IoT platform needs low latency and high bandwidth networking. Thus, it should be ascertained that a potential IoT platform provider has a large data pipe and that there is sufficient room to grow [26], [27].

Edge intelligence and control: IoT platforms are advancing at a fast rate due to high competition in technology and business markets. The future of IoT platforms is moving towards distributed, offline and edge intelligence [24]. Devices become more powerful when they are able to make decisions based on local data instead of waiting for every decision from the cloud. Thus, it should be ensured that the IoT platform has the capacity to support new topologies and utilize edge intelligence [25].

III. RESEARCH METHOD & DATA COLLECTION

A pre-study was conducted prior to the research presented in this paper to gain background information about IoT and IoT platforms. The aim of the current research is to identify key factors of IoT platforms that require consideration before IoT platform selection. The work began with a literature survey of research articles and publications related to IoT and IoT platforms published in journals, conferences and books. Twenty-six out of 200 articles were selected for study. The databases used in this research are IEEE, ACM and SCOPUS. Google Scholar is also used for some topics and some selected websites reviewed and referenced.

The Delphi method is used in the main part of this study. In this work, 15 professionals participated in the Delphi study, which was conducted in two rounds. In the first round, a questionnaire comprising twenty-one questions was sent to the participants by email through a survey link. A 5-point rating scale was used: 1) totally disagree, 2) disagree, 3) neutral, 4) agree, and 5) totally agree. Fourteen participants responded in the first round. One reply was removed because it included no information about the respondent. The results of the first round were calculated, and based on the first round results, the second round questionnaire was constructed and sent to individual participants. Twenty-one (21) important factors were identified from the literature. These factors were then verified by the Delphi method and categorized.

IV. DELPHI STUDY

The Delphi method is an accepted and widely used method for canvassing opinions from a limited number of experts or professionals, from 10 to 18, operating in the same field [32], [33]. Delphi method is an iterative process, there are series of rounds and each round has some output, the output of one round is the input of the next round until the result is obtained. Two rounds of Delphi process are preferred when extensive literature is available and the aim is to get experts' opinions about the subject [34].

Delphi methods, as shown in Fig 2 is used in this research consists of two rounds. During the first round, fifteen IoT experts from three different universities were recruited, based on their experience in IoT field. A questionnaire comprising twenty-one (21) questions was sent by email to the experts through a link. Fourteen experts replied, giving a response rate of 93% . The experts' opinions of the first round of Delphi study are shown in Fig 3. Most of the experts opinions were in favor of first round questions. The experts' opinions in the first round of the Delphi study were noted. Based on the first round opinions, individual questionnaires on the second round of the Delphi study were designed and sent to the concerned experts along with the summary of experts' opinions of first round results either by email or on paper.

In the second round of the Delphi study, some experts changed their opinions about some questions based on the summary of experts' opinions of the first round. The second round opinions are shown in Fig 4. The final results of both rounds are shown in Fig 5.

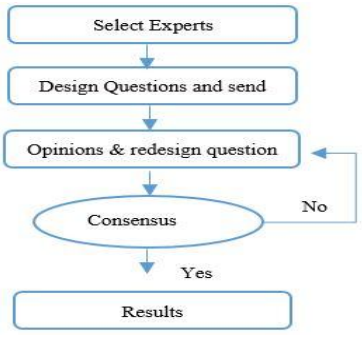

Figure 2. Delphi method.

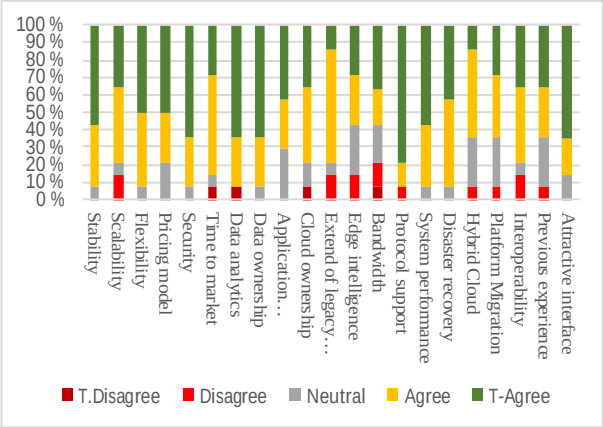

Figure 3. Expert opinion in the first round.

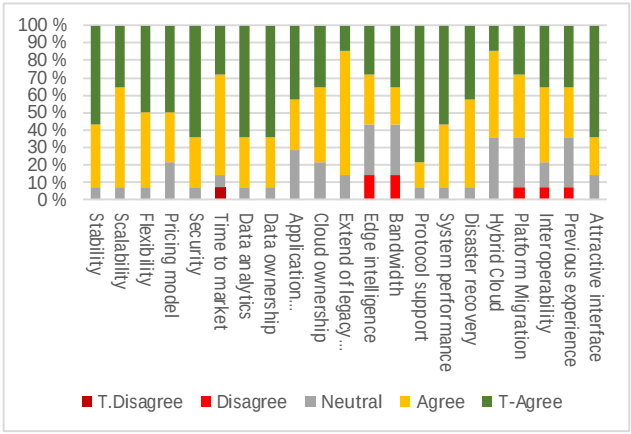

Figure 4. Expert opinion in the second round.

		Round 1					Final Round				
Sno	Topic	Mean	Median	Dis agree %	Neutral %	Agree %	Mean	Median	Dis agree %	Neutral %	Agree %
1	Scalability	4	4	14 %	7 %	79 %	4	4	0 %	7 %	93 %
2	Flexibility	4	4,5	0 %	7 %	93 %	4	4,5	0 %	7 %	93 %
3	Data analytics	4	5	7 %	0 %	93 %	5	5	0 %	7 %	93 %
4	Disaster recovery	4	4	0 %	7 %	93 %	4	4	0 %	7 %	93 %
5	Stability	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
6	Security	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
7	Data ownership	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
8	Protocol support	5	5	7 %	0 %	93 %	5	5	0 %	7 %	93 %
9	System performance	5	5	0 %	7 %	93 %	5	5	0 %	7 %	93 %
10	Time to market	4	4	7 %	7 %	86 %	4	4	7 %	7 %	86 %
11	Extend of legacy architecture	4	4	14 %	7 %	79 %	4	4	0 %	14 %	86 %
12	Attractive interface	5	5	0 %	14 %	86 %	5	5	0 %	14 %	86 %
13	Pricing model	4	4,5	0 %	21 %	79 %	4	4,5	0 %	21 %	79 %
14	Cloud ownership	4	4	7 %	14 %	79 %	4	4	0 %	21 %	79 %
15	Interoperability	4	4	14 %	7 %	79 %	4	4	7 %	14 %	79 %
16	Application environment	4	4	0 %	29 %	71 %	4	4	0 %	29 %	71 %
17	Hybrid Cloud	4	4	7 %	29 %	64 %	4	4	0 %	36 %	64 %
18	Platform Migration	4	4	7 %	29 %	64 %	4	4	7 %	29 %	64 %
19	Previous experience	4	4	7 %	29 %	64 %	4	4	7 %	29 %	64 %
20	Edge intelligence	4	4	14 %	29 %	57 %	4	4	14 %	29 %	57 %
21	Bandwidth	4	4	21 %	21 %	57 %	4	4	14 %	29 %	57 %
	Percentage			**6 %**	**14 %**	**80 %**			**4 %**	**15 %**	**81 %**

Figure 5. Results of the Delphi study

In the first round, agreed percentage is 80%, disagree percentage is 6% and neutral percentage is 14%. In the second round, agreed percentage increased to 81%, disagree percentage dropped down to 4% and neutral percentage increased to 15%. The importance of all the twenty-one factors of IoT platform are categorize into three categories in the light of experts' opinions. Factors with agreed percentage up-to 79% and above are considered very important, factors with agreed percentage between 78% and 64% are considered somehow important, and factors with agree percentage less than 60 % are considered as less important. According to experts opinions factors i.e. *stability, security, protocol support, system performance, disaster recovery, data analytics, scalability, flexibility, data ownership, extend of legacy* architecture, pricing model, *interoperability, attractive interface, cloud ownership, time to market* were considered as the most important factors and according to the experts opinions four factors i.e. *application environment, hybrid cloud, platform migration, previous experience* were considered as somehow important and two factors i.e. *edge intelligence and bandwidth* were considered as less important.

V. DISCUSSION & CONCLUSION

The aim of this study was to identify important factors of an IoT platform from the literature and facilitate companies in selection of suitable platform that can solve the needs of IoT application. We identified twenty-one IoT platform factors from literature, Delphi method was used to verify those factors through the expert's opinions. Fifteen experts from three universities were selected based on experience in IoT field. The identified twenty-one IoT platform factors were divided into three categories based on expert's opinions.

In this study, we have identified and explained most of IoT platform important factors that should be considered before selection of an IoT platform for IoT application. Comparing this study with recent studies in literature, we have noticed that similar study has been done by [9] in which the authors have mentioned few IoT platform factors like stability, scalability and flexibility and pricing model of the business case. Another study [35] highlighted the importance of data security. During another study [36] the authors claim that IoT platform should support integration with open source ecosystem and considered interoperability as important factor for IoT platform. The selected recent studies in literature have targeted few specific important factors about IoT platforms. The current study mainly focused to identify most of the important IoT platform factors and verify those factors, based on expert's opinions using Delphi method. Based on the expert's opinions using the Delphi method, we believe there are many important IoT

platform factors that should be considered before selecting a suitable IoT platform for IoT application.

The challenges the companies are facing in selection of IoT platform, are quite common due to advancements in technology. We believe company can select an appropriate IoT platform for their IoT application, if they first analyze their business requirements, and start selection of the IoT platform with clear business requirements and have the knowledge of key factors of IoT platforms.

This study highlighted important key factors of IoT platform. Those key factors may cover some of the current requirements of the companies and can help ensure that future needs of the business are meet. It will facilitate the companies to select a suitable IoT platform for their business needs.

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Cloud Connected Smart Birdhouse for Environmental Parameter Monitoring

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Abstract – **The Internet of Things (IoT) is an emerging technology that is changing our world by making it a smarter and a better place to live in. The idea to build a smart and connected world cannot be imagined without the IoT. Many modern houses and buildings are equipped with different sensors, which are constantly monitoring specific parameters and are reporting them to the owners or to the residents. However, we are not the only inhabitants of this planet and as dominant species, we have the obligation to take care and look after the wildlife and the natural resources of Earth. According to a recent study, which was carried out by the National Center for Scientific Research of France (CNRS), the population of farmland birds has rapidly decreased by more than 30% in the last 17 years. This trend is presenting a significant problem for the bird populations, the ecosystems and the biodiversity as whole. Finding nutrition and water is quite daunting task for some bird species, especially during cold weather or in the winter. This is one of the many situations, where the IoT technology can be utilized. With the help of the modern information and communication technologies, we are planning to build smart cloud connected birdhouses, which could help protect the endangered bird species.**

Keywords - Cloud birdhouse, IoT, wildlife preservation

I. INTRODUCTION

The population of the world has increased tremendously during the past few decades. According to several studies, the human population is growing at a rate of around 1.1% annually [1]. This expanding has a negative effect on the nature and puts a lot of pressure on the wildlife. Because of this, the list of extinct species is constantly growing and many new species are being enlisted as endangered. As endangered species, we consider all species of organisms that face the risk of partial or full extinction within the geographical ranges of their habitats. There are several widely recognized organizations, which are focused on the wildlife protection. Some of them are the World Wildlife Fund (WWF), the Wildlife Conservation Society (WCS), the International Union for Conservation of Nature (IUCN) and Greenpeace [2, 3, 4 and 5]. In Bulgaria, all endangered species are enlisted in the Red Data Book [6], which is published in three volumes – Plants and Fungi, Animals and Natural Habitats. A well-known nature park in the northeast part of Bulgaria, called Rusenski Lom [7], is focused on the preservation of many of the species, which are found in the Red Data Book. The nature park is a real paradise for many birds, which caused the region Lomovete, located around the park, to be approved as ornithological site of significant value. There are around 110 species of birds, which are nesting in the park area, but the total number of bird species exceeds 190. One of these bird species is the Stock Dove (Fig. 1). With less than 400 breeding pairs left [8], the Stock Dove is considered as one of the endangered species on the territory of Bulgaria. In the past, the population of this dove was spread over the whole territory of the country. In the last decade, the deforestation processes have caused the destruction of natural biotopes of the Stock Dove and its population was significantly reduced.

In this paper, we are going to present the impact, which the modern information and communications technologies could have on the wildlife. Our focus is specifically on bird populations and we will show some of the steps for the creation of cloud-connected smart birdhouses.

Birdhouses are widely used to help the birds find suitable places to live during their breeding session. A major drawback of the regular birdhouses is the fact that they cannot provide any information if the house is being used or not. Additional details, including the number of birds, which are visiting or living in the birdhouse, their type, species, etc., are also impossible to get, unless an onsite visits for inspection and cleaning of the birdhouse is performed. In order to resolve this issue, we are proposing to build a cloud connected smart birdhouse. This house will have all of the necessities of the regular birdhouses, but will also have additional smart features. In this way, we will have the opportunity to collect information about the birds, which are visiting the house, as well as to perform measurements on the environmental parameters of the surrounding area, including temperature, atmospheric pressure, humidity, gases, etc. All of the collected environmental parameters will be used to analyze the behavior of the birds and will guarantee that the deployed birdhouses are still habitable.



Figure 1. Drawing of the Stock Dove (Columba oenas) [9]

Section II of the paper is devoted to the design of the birdhouse, including the design of the electrical schemes. The design phase is an important one, as the components, which are providing the smart capabilities to the birdhouse, do not have to obstruct the natural life or endanger the birds. Most birdhouses are placed in areas where the internet connectivity or any wireless connectivity is not available, except for the (3G or 4G) cellular networks. In Section III, we are going to make an analysis on several wireless technologies and evaluate their advantages and disadvantages. We will then select the most suitable technology for our case. Section IV will cover the application layer of the smart birdhouse and more specifically everything related to the collection, storage and visualization of information. Section V will conclude the paper and we will make some final remarks.

II. DESIGN OF THE BIRDHOUSE AND THE ELECTRICAL SCHEMATICS

As already stated in the previous section, this part of the paper will be devoted entirely to the design of the birdhouse and will show the electrical schemes, which were used to describe the links between the components that are providing the smart capabilities to the birdhouse.

There is abundance of commercially available designs of wooden birdhouses, but most of them do not meet our requirements. The design of the house, as already stated in the previous section, does not have to obstruct the natural life of the birds. Due to this reason, we have decided to build our own prototype of the birdhouse.

The first stage of the birdhouse design process is to hide and protect all of the electronic components, so that the birds cannot reach them. For that reason, we have decided to create a hidden compartment underneath the house, which will house all electronic components. Another important aspect of the birdhouse design process is to provide the possibility to detect the presence or absence of birds. This will be achieved using an infrared (IR) sensor, which is going to be placed inside the house.

The second part of the design process is planning and choosing electronic components, which are going to provide the smart capabilities to the house. The most important step in this phase is the selection of suitable microcontroller. The most renowned and most widely used in similar applications microcontrollers are probably the Arduino family of microcontrollers. The Arduino boards come in variety of shapes, models and capabilities. Our main requirement for the microcontroller is to be relatively small, but at the same time powerful enough, so that it can power all other electronic components, which will be used. Another important requirement for the microcontroller is its power consumption. As we are planning to deploy the birdhouses in a remote location, where electricity is not available, we have to power all electronic components with batteries. In order to maximize the lifetime of the whole system, we are also planning to install a solar panel on the rooftop of the house. The microcontroller that meets the aforementioned requirements is the Arduino Nano microcontroller board and more specifically its 3.3V version.

The measurements of the environmental parameters will be made using a BME680 sensor board, which can measure temperature, humidity and barometric pressure. In addition to these parameters, the BME680 contains also a small metal-oxide (MOX) sensor. The heated metal-oxide changes resistance based on the volatile organic compounds (VOC) in the air, so it can be used to detect gasses & alcohols such as ethanol, alcohol and carbon monoxide. The VOC detection capabilities of the sensor will provide us with the ability to collect information about the forming of gasses, which is a sign that the birdhouse is contaminated and requires on-site visit for cleaning. The BME680 sensor is has both I^2C and SPI interfaces, which makes it suitable not only for Arduino boards, but also for other microcontrollers.

Additional sensors and electronic components will also be included in the birdhouse. An infrared sensor will allow us to sense the presence or absence of birds in the house. We will also use a solar panel, which will maximize the lifetime of the system. Li-Po batteries will be used to power the whole system and last, but not least, a LoRa transceiver will provide wireless capabilities to the smart birdhouse and connect it to the cloud. The electrical diagram for the birdhouse components is shown in Fig. 2.

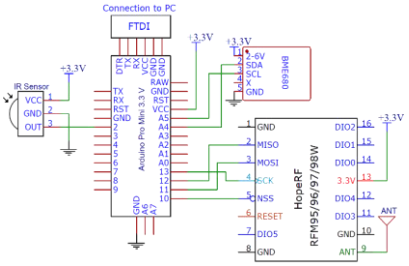

Figure 2. Logical representation and links between the electrical components of the smart birdhouse

The electrical schematic, shown in Fig. 2, is a logical representation of the electrical components and the connections between them. Each of the components is connected to the microcontroller through a specific communication interface. The BME680 sensor utilizes the I^2C interface, while the LoRa transceiver (RFM 95/96/97/98W) uses the SPI communication protocol. The IR sensor on the other hand is a simple device with a single output pin that could be easily connected to any of the digital input pins on the microcontroller. Another part of the electrical design process is the development of the battery management system BMS. The BMS includes a solar panel, constant current (CC) and constant voltage (CV) linear charger and a Li-Po battery (Fig. 3).

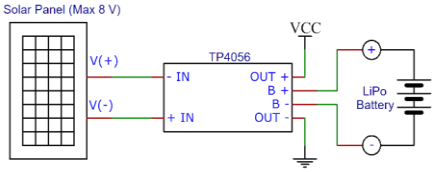

Figure 3. Electrical diagram of the smart birdhouse battery management system

The output of the solar panel is fed to the input of the constant current/voltage linear charger. The typical input voltage in the 4-8 V range. The output of the charger is used to power the electronics of the smart birdhouse. A Li-Po battery pack is used as redundant power source during nighttime or in bad weather. The typical output voltage of the charger is around 4.2 V.

III. COMPARATIVE ANALYSIS OF THE AVAILABLE WIRELESS TECHNOLOGIES

There are plethora of wireless standards and technologies that exists nowadays. Each of these technologies is characterized with a trade-off between power consumption, processing capabilities, coverage and bandwidth [10]. Many of the available technologies use the TCP/IP protocol suit and provide reliable data delivery. Other technologies are simpler and are characterized with low power consumption and longer range. The Internet of Things, as technology, has different aspects and depending on the application, the appropriate wireless technology needs to be selected.

The wireless communication protocols from the IEEE 802.15 family, including Bluetooth, UWB (Ultra-wide band) and ZigBee, are renowned for their low power, but short communications range. Bluetooth is a wireless standard, typically used for communication between devices that are in close range. To meet the needs of IoT, Bluetooth has evolved to a new version called BLE (Bluetooth Low Energy) [11]. BLE has approximately the same communications range as its predecessors, but is a reduced power consumption standard. BLE is widely used for IoT and can be found mainly in portable medical, healthcare and lifestyle devices.

ZigBee is another low power consumption standard that, in contrast to Bluetooth, was specially designed for communication purposes at longer distances. However, this is achieved as a trade-off for the lower data rates [12, 13]. ZigBee uses the carrier sense multiple access with collision avoidance (CSMA-CA) technique, which specifies how multiple devices can access the same channel using different time slots and without any interference. The devices in the ZigBee networks are connected either in a point-to-point or in a star topology. The combination of these two topologies forms a ZigBee mesh network. The mesh topology is commonly used to extend the coverage of the short-range networks. The ability for the signal to travel using multiple paths provides flexibility in the case of a failing node, but the multi-hop communication in the mesh networks can cause huge delays and leads to additional power consumption. The lower power consumption in the star networks makes them suitable for nodes with built-in batteries, which, in some cases, are not intended to be replaceable. The Wi-Fi family of standards can also be used for the Internet of Things. Compared to the other standards, Wi-Fi provides significant data rates and robustness, but usually the communication range of the standards in the family is limited to no more than 100 meters. To fix this issue, the IEEE 802.11 family of standards was extended with another addition. The improved communications range of the IEEE 802.11ah (also known as HaLow) is achieved by the lowering of the transmission frequency to 900 MHz [14]. The use of this lower frequency is not only beneficial in terms of the improved range, but also guarantees lower power consumption.

Another promising communications solution for the Internet of things is the LoRaWAN standard [15]. This multilayer standard includes the LoRa protocol at the physical layer and the LoRaWAN protocol at the data-link layer where it is used for the media access control (MAC). The main advantage of LoRaWAN, over the aforementioned standards, is the lower power consumption, especially during the transmission and the sleep cycles. Our initial experiments with the birdhouse prototype have shown power consumptions of 100 to 150 mA and around 6 μA, correspondingly in the transmission and in the sleep mode. Besides the lower power consumption, the LoRa technology has a higher communications range, compared to the other wireless technologies. That is another key advantage, because our plan is to deploy the birdhouses in remote locations in the forests of the nature park. The higher range and the lower power consumption comes at a price – the standard has lower data rates of around 50 kbps and the maximum Time-On-Air (TOA) per device per day is 30 seconds [16], which is more than insufficient for applications with demands for higher data rates.

A thorough analysis of the available wireless networking technologies showed that the LoRaWAN technology could cover our requirements and would be a perfect fit for the project. The lower power consumption of the technology will provide us with the possibility to power the birdhouse with a relatively small, but enough powerful Li-Po battery, which will last for several months in conjunction with the solar panel. In addition to that, the information for the environmental parameters, which we will measure, is just several kilobytes and we will probably never reach the maximum threshold of the LoRaWAN technology.

IV. APPLICATION LAYER AND FUNCTIONALITY OF THE CLOUD CONNECTED SMART BIRDHOUSE

This section is entirely devoted to the application layer of the cloud connected smart birdhouse. The smart capabilities of the birdhouse provide us with the ability to collect, store and analyze information about the presence or absence of birds in the living compartment of the birdhouse, as well as information about several environmental parameters, such as temperature, humidity and barometric pressure. Additionally, we will also collect information about any indoor gases, which could be a potential sign of contamination of the living compartment. Since the sampling rate for the environmental parameters does not have to be very high, we can use the LoRaWAN technology for our communication purposes. The LoRaWAN technology is a preferred choice when it comes down to applications that require low data rates, high range and low power consumption.

The functionality of the application layer of the system is divided into several specific stages. The first stage is related to the programming of the microcontroller and guarantees that the connection to the nearest

LoRaWAN gateway is established. The second stage encompasses everything related to the transport of the data to the TCP/IP network. Since the nodes broadcast LoRaWAN messages over the LoRa radio protocol, these messages are not compatible with the TCP/IP networks. This issue is resolved at the network gateway (controller). The main job of this gateway is to encapsulate the LoRaWAN messages in TCP/IP packets and to route these packets to the corresponding network server. When the data has reached the network server, we can move on to the third stage, which includes the storage and visualization of the data. This stage depends entirely on the application requirements and is strictly individual for each case.

A. *Functionality within the nodes*

There are two functional sub-stages for each node – data gathering from the sensors and encapsulation of the sensed data in LoRaWAN message. The BME680 sensor comes with a pre-build library for the Arduino boards that could be used to pull the data from the sensors. The second sub-stage is related to the encapsulation of the data and its transmission via the network gateway to the cloud. Fig. 4. Presents a code snippet that shows this functionality.

```
#include <Wire.h>
#include <SPI.h>
#include <Adafruit_Sensor.h>
#include <lmic.h>
#include <hal/hal.h>
#include "Adafruit_BME680.h"

static const u1_t DEVKEY[16] = { 0x01, ... ,0xC4 };
static const u1_t ARTKEY[16] = { 0x0F, ... ,0x01 };
static const u4_t DEVADDR = 0x12345678;

bme.setTemperatureOversampling(BME680_OS_8X);
bme.setHumidityOversampling(BME680_OS_2X);
bme.setPressureOversampling(BME680_OS_4X);
bme.setIIRFilterSize(BME680_FILTER_SIZE_3);
bme.setGasHeater(320, 150); // 320*C for 150 ms

float Temp = bme.temperature
float Pressure = bme.pressure / 100.0
float Humidity = bme.humidity
float Gas = bme.gas_resistance / 1000.0
uint16_t mydata[] = {Temp, Pressure, Humidity, Gas};

void do_send(osjob_t* j){
  LMIC_setTxData2(1, mydata, sizeof(mydata), 0);
  os_setTimedCallback(j, os_getTime()+sec2osticks(25), do_send);
}

void setup() {
  LMIC_reset();
  LMIC_setSession (0x1, DEVADDR, (uint8_t*)DEVKEY, (uint8_t*)ARTKEY);
  LMIC_setAdrMode(0);
  LMIC_setLinkCheckMode(0);
  LMIC_disableTracking ();
  LMIC_stopPingable();
  LMIC_setDrTxpow(DR_SF(7-12),14);
}

void loop() {
  do_send(&sendjob);
}
```

Figure 4. Code snippet of the cloud connected smart bird application

B. *The network gateway*

The network gateway, a.k.a. LoRaWAN concentrator, plays an important role – it takes care for the routing of the LoRaWAN messages to the TCP/IP network. Most network gateways are constructed using single-board microcomputers from the Raspberry Pi family. Fig. 5 presents the architecture of a typical LoRaWAN concentrator.

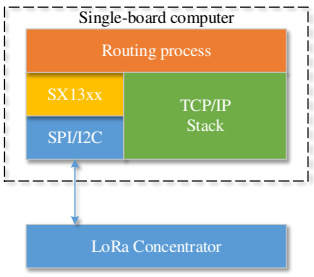

Figure 5. Architecture of a typical LoRaWAN network gateway

The LoRaWAN concentrator is a wireless network device, compatible with the LoRa standard, which listens for the LoRaWAN messages transmitted by the nodes. If any messages are received, they are encapsulated and sent over the TCP/IP network to a particular network server, which is pre-configured on the device.

There are plethora of commercial gateways [17] currently available on the market. Our objective for this research was to find a gateway that supports multiple channels (up to 8) and is yet cheap enough, so that we do not exceed our budget. Table I. summarizes some of the commercially available gateways for the European market (868 MHz).

TABLE I. COMMERCIALLY AVAILABLE LORAWAN GATEWAYS

#	Name	Devices[1]/ Channels[2]	Range, km LOS	Price, $
1	MultiConnect Conduit [18]	1K[1] / 8[2]	15	740
2	Laird Sentrius RG1 [19]	8[2]	16	260
3	IMST Lite Gateway [20]	10K[1] / 8[2]	15	220
4	LG01N / OLG01N [21]	50-300[1] / 1[2]	5-10	70
5	IC880A [22]+RP3 [23]	10K[1] / 8[2]	15	180
6	Pycom LoPy [24]	100[1] / 1[2]	22	40

There are few gateways, which cover our requirements, but we have chosen to work with the IC880A concentrator (number five in the table). At a relatively lower price, compared to some of the other gateways, this device supports up to 8 parallel channel and up to 10000 nodes, which makes the IC880A concentrator a promising solution. We have paired the concentrator with a Raspberry Pi 3 model B+ [23].

C. *Publishing of the data to the cloud*

Publishing the collected data to the cloud is the third and final stage of the process. "The cloud" is a very broad term that can encompass many things and cannot be reviewed or explained in a single paper. For the purpose of the current work, we will briefly explain only how we plan to store and visualize the data using the web and a smartphone application.

The basic flow of information is depicted in Fig. 6. As already mentioned in the previous sections, the collected data from the birdhouse is sent to a network gateway via the LoRaWAN wireless technology. This data is then routed to the public cloud servers of The Things Network (TTN) [25]. The TTN cloud and network servers only process and store the data for a short period.

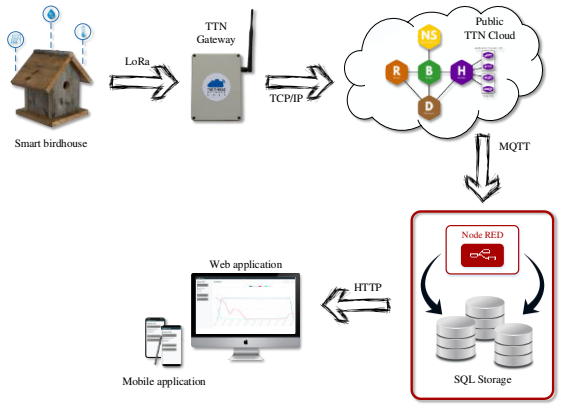

Figure 6. Information flow of the proposed system

Because our main objective is to locally store and further visualize the collected information, we have to use one of the SDKs (Software Development Kits) that is freely available. These SDKs (Go, Java, Node.js, Python, Node-RED) are comprised of two APIs (Application Programming Interfaces) – data API and application API. The Data API, in which we are mainly interested, uses the MQTT [26] (Machine-to-Machine) connectivity protocol to publish the collected information. The Application API, on the other hand, provides a way to manage all applications and devices, which are registered on the TTN platform. Since we are only interested in the information that the sensors are providing, we are going to use only the Data API. From the publically available SDKs, we have chosen to work with the Node-Red platform [27]. Node-Red is a programming tool for connecting and wiring hardware devices, APIs and online services in a quick and easy fashion, by using the provided browser-based editor. Since Node-Red is built on Node.js, we can take full advantage of its event-driven and non-blocking model, which makes it ideal to run on low-cost hardware, such as the Raspberry Pi as well as in the cloud. Fig. 7 shows how a typical node connected to the TTN network looks like and how we can quickly download and store the information on a local SQL (Structured Query Language) server.

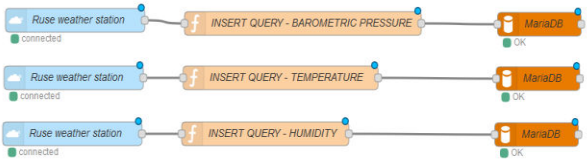

Figure 7. Typical Node-Red flows for collecting and storing information on a local SQL server

The flows depicted in Fig. 7 are composed of three parts. The first one (in blue) is representing the node that is connected to the backend of the TTN platform and guarantees that the connection to the application and its particular device is established. The node itself takes as input the information about the server, where the data has to be stored, and of course, an access key that is giving permissions to the application to register with the TTN platform (Fig. 8). The second part of the flow (colored in light orange) is representing the SQL queries, which are mapping the appropriate fields from the received messages and is encoding and sending them to a SQL server. In our case, the server is the MariaDB (dark orange node) server. From this point forward, the encoded information is stored on the local server for further processing and analysis.

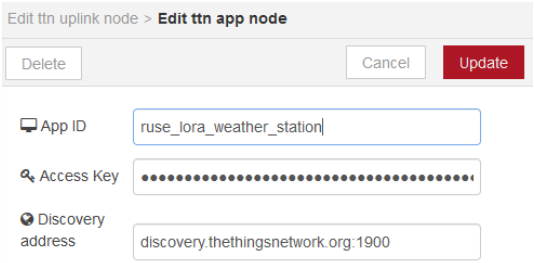

Figure 8. Configuration of an uplink TTN node in Node-Red

The visualization of the information is the last and final stage of the publishing of the available information that was collected from the smart birdhouse. Node-Red has a built-in functionality that could be utilized for this purpose. The issue with the built-in functionalities is that sometimes they do not meet the requirements of the application. Our application is intended to show relevant graphs about the measurements of the environmental parameters around the birdhouse, as well as its condition and location. Fig. 9 presents the environmental parameters measured by the smart birdhouse.

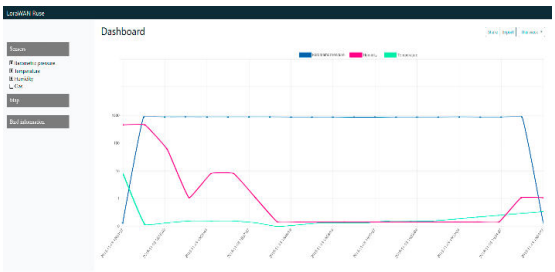

Figure 9. Graphical representation of the environmental parameters, which were measured by the smart birdhouse

The web application is hosted on our own web servers. It provides access to three sections – for the sensor data, for the map and for the birds. The first section is designed to plot the information received from the sensors for a specific interval of time. If no time interval is specified, the graphics display the available information in real-time.

The second section of the application provides basic information about the birdhouse and its location. Since the smart birdhouse will be in a known remote location, we can obtain its GPS coordinates, encode them into the web application and plot them on Google Maps (Fig. 10). Future revisions of the system might also include a GPS sensor, which will report the GPS coordinates of the smart birdhouse. The third section of the web application shows information about the number of birds visiting the house, as well as some additional functionalities that are going to be implemented in the near future. These

functionalities include the measurements of the food and water supplies available in the birdhouse, as shown in Fig. 11.

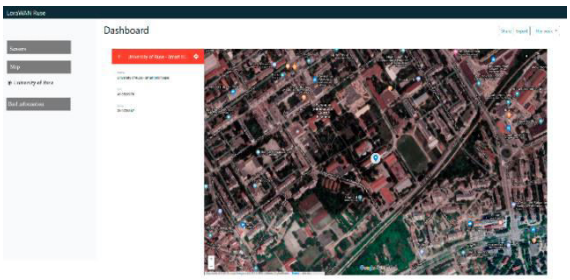

Figure 10. Map information about the smart birdhouse



Figure 11. Measurements of number of birds visiting the house and other functionalities

V. CONLUSIONS

The population of the world has grown significantly in the last several decades. This has put a lot of pressure and has caused severe negative effects on the wildlife and their habitats. Because of that, many animal species went extinct, while others are being enlisted as endangered species. The Stock Dove (*Columba oenas*), which is found in the norther parts of Bulgaria, is one of these endangered species. The rapid deforestation and the contamination of the natural habitats of these doves has led to their inclusion in the Red Data Book for endangered species of Bulgaria.

In the paper, we have proposed a workflow for the creation of smart birdhouses. These birdhouses will be deployed in different locations and they will potentially help the endangered birds in their search for suitable living places, especially during the breading season. Several dozen regular birdhouses are already installed in different places, but they are not having any smart functions. In this way, they cannot record or transmit any information if the houses are actually being used by any birds. For this reason, we have proposed to introduce smart capabilities to the birdhouses. The smart functions of the birdhouses and the collected information will help ornithologists in their observation and analyses on the behavior of the birds and will potentially help in the preservation of the endangered species.

The ability of the smart birdhouses to track the presence or the absence of the birds and the possibility to monitor the environmental parameters will help for the better utilization of the birdhouses and will provide adequate information for the proper and timely maintenance of the living compartments within them.

ACKNOWLEDGMENTS

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Assessing compression algorithms on IoT sensor nodes

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***Abstract* - With the ever-growing presence of IoT devices in everyday applications, the sheer volume of data exchanged is increasing rapidly. Communication channels' bandwidth used in these applications often presents a bottleneck and limits the frequency at which data can be exchanged, making application of compression beforehand a viable approach.**

In this paper, we analyze some of the well known lossless compression algorithms capable of seamless integration as software modules on embedded devices used in (near) real-time applications. Low processing and memory resources available on them as well as unsteadiness of aforementioned communication channels were taken into consideration in algorithm selection.

Attained compression ratio is evaluated on data harvested from smart meters, whilst time and energy consumed during processing were analyzed within a measurement framework purposefully built for this research. We show that considerable gains can be attained in the volume of data that can be sent from devices based on commonly used microcontrollers, with only a modest toll on time and overall energy used.

Keywords* - *compression algorithms, stream of data, real-time systems, sensor nodes, internet of things, smart meters

I. INTRODUCTION

Emergence of Internet of Things (IoT) connecting not only people, but vast number of ubiquitous objects that harvest environmental information and act on their surroundings, proved as the next evolutionary step of the Internet [1]. Smart metering applications present a significant and fast-growing segment of the IoT universe, being the enabler technology for smart grids and smart cities [2-4]. Those devices are characterized by a relatively small amount of data periodically collected from a single end-device, but resulting in a high volume traffic due to the large number of employed end-devices possibly spread over sizeable physical space and sharing the same communication channels.

Requirements for different smart metering applications can exhibit a significant variance in many important aspects such as amount and frequency of collected data, communication costs, and energy consumption. Data collection strategies can vary from just a few bytes a day delivered from end-device on a best-effort basis, to frequent and reliable data collection over a wireless channel in dense and interference-prone environments [5]. Limitations of wireless communication channel capacity can present a significant challenge for such applications where frequent and regular data collection is required in densely populated areas [6].

Employing different data compression techniques on exchanged data can significantly decrease its length, resulting in shortening on-air time of individual end-devices, reducing individual device's energy spent on communication, reducing the cost of exchanged data and allowing the increased frequency of data exchange over shared wireless communication channels.

To assess the usability of different lossless data compression algorithms on IoT sensor nodes, with particular focus on smart metering applications using wireless communication channels, we selected several algorithms - representative of the major lossless data compression methods - and tested their performance from two major aspects: compression ratio efficiency and resource consumption on embedded devices. Compression ratio efficiency was evaluated on utility consumption measurement data sets originating from publicly available data repositories. On the other hand, purposefully built test environment was used to measure the energy consumption of tested algorithms on embedded devices, among other performance measures such as memory and processing power used, the time required to process the exchanged data packet, etc.

Section II of this paper briefly describes the main data compression algorithms and defines algorithm selection criteria. Section III details on the test environment used to assess the suitability of a particular compression method to the studied application context, including performance measures, test datasets, compression method parameters, and execution platforms. Section IV presents the test results and discussion, and Section V concludes the paper.

II. COMPRESSION ALGORTIHMS

In IoT sensor nodes, especially when delta (difference) encoding preprocessing is applied, smaller valued readings can be expected to be more frequent. Compression algorithms used in this paper were selected for their excellent performance on compression of a stream of such data, where its value probability distribution is not known beforehand. In addition to good compression ratio, they provide a lossless encoding process that is friendly for use in embedded devices as algorithms are computationally simple with low space and time complexity.

Some of the assessed algorithms are static, with their symbol to codewords distribution model staying unchanged during the whole encoding process, others are adaptive and change the codewords distribution according to the incoming symbols. Although adaptive algorithms generally have better compression efficiency, static algorithms are more robust in unreliable communication channels as a single wrongly received package can create a discrepancy between adaptive coder and decoder.

A. Elias gamma (γ) and delta codes (δ)

Peter Elias introduced gamma and delta codes in his work on universal codes [7]. Universal codes are prefix codes of codeword length within a constant factor of distance to that of the optimal code if the probability distribution of symbols is monotonically decreasing for ascending integers.

The idea behind Elias codes is to prefix the positive integer being encoded with a representation of an order of its magnitude M, so that $2^M \leq n < 2^{M+1}$. For every n, we can denote n as $n = 2^M + L$, where offset L is a positive integer as well. In γ code, the magnitude part, M is represented in unary code, followed by offset L displayed in its M-bit binary representation. In δ encoding, the magnitude part is represented in γ code instead of unary.

B. Golomb-Rice code

Unlike Elias codes that do not have an external parameter and have a fixed codewords-symbols distribution, codewords of Golomb codes [8] are parameterized by the value m (modulo). Coded symbols are grouped into same length sets (m codewords in one set), where latter sets map bigger integers and have longer codewords. Resulting codeword of integer n consists of quotient $q(n) = \lfloor n/M \rfloor$ and remainder $(n) = n \bmod M$, where q(n) is represented in unary and r(n) in $\lfloor \log_2 M \rfloor$ -bit and $\lceil \log_2 M \rceil$-bit binary codes.

The particular case when m is a power of 2 ($m = 2^k$) is interesting as it allows simplified computation of codewords by using shift operations. Golomb code in this form is widely known as Golomb-Rice [9]. Golomb-Rice code with k=0 is identical to unary code.

Golomb codes are interesting because they are optimal for geometric distribution of symbols, which is similar to some values of natural phenomena sensors are measuring.

C. Adaptive Golomb-Rice code

JPEG2000 [10] specification defines Adaptive Golomb-Rice code algorithm that changes the amount of parameter k using the accumulator of the last encoded values. With estimated value in the accumulator being E [X], k is selected as $k = \max\left\{0, \left\lfloor \log_2\left(\frac{1}{2} E[X]\right)\right\rfloor\right\}$.

D. Exponential-Golomb code

In the Exponential Golomb Code (Exp-Golomb), introduced by Teuhola in [11], sizes of codeword sets grow exponentially, which introduces robustness of code efficiency when the symbol distribution deviates from optimal geometric distribution.

Exp-Golomb code of integer n (of order k=0) is identical to Elias-Gamma code of n+1. Further generalization for higher orders is attained by encoding $n+2^{k-1}$ in Exp-Golomb (k=0) and removing k leading zero bits.

E. Adaptive Exponential-Golomb code

The algorithm for the adaptive Exp-Golomb code was suggested in [12], stating that codeword length using optimal parameter value k is always within interval $[k + 2.8, k + 3.8]$. The adaptive step decreases the value k if the average codeword length in the accumulator of previous values is below the lower limit of that interval or increases the parameter k if it is above the upper limit.

F. Variable byte code

Variable byte codes use a different number of bytes to represent integers. Usually, these algorithms form bytes in a way where every byte has a descriptor bit, and 7 payload bits, descriptor bit carries the information whether the received byte is the last. One of the commonly used algorithms with this form is known as LEB128 (Little-Endian Base 128). A slight deviation from this form is used in varint30, another variable byte algorithm, that carries two descriptor bits in the first byte, with any additional bytes carrying only payload bits.

III. ASSESMENT METHODS

In the first part of our assessment, we analyzed compression efficiency and the processing time of algorithms described in Section II. Using UMass Smart* Dataset-2017, a dataset on electricity consumption containing the total electricity consumption for 114 family apartments during a three year period 2014-2016 [13]. The data were sampled every 15 minutes and saved using the differential code (recording only differences between previous and current consumption readings).

Values in the dataset are stored with a precision up to the tenth decimal, but since practical usage of these sensor values in smart metering often doesn't require precision higher than second decimal, values were normalized to integer values by multiplying with 100 before compression. The distribution of frequencies of normalized values resembles geometrical distribution with a few spikes, visible in Figure 1. The entropy of normalized dataset is 5.3135 b, which presents a theoretical minimal codeword length without any loss of information.

Algorithms were implemented using Python v3.7 and assessed on Windows 10 OS(build 17134.407) PC with Core i5-7300HQ@2.5Ghz CPU. Before evaluating the complete dataset, preliminary evaluation was conducted on 10% of the dataset and interesting parameter space for k value in Golomb-Rice and Exp-Golomb algorithm was found to be k=0-8, as compression efficiency started to deteriorate for values of k bigger than 6.

Customizations were done on the payload size of LEB128 variable byte algorithm and evaluations were conducted for payload sizes 5 and 6 bits. Payload sizes

bigger than 7 and smaller than 4 bits gave worse results in preliminary evaluation.

Adaptive Exp-Golomb and Adaptive Golomb-Rice had counter N initialized at 0, with adaptive parameters refreshment done together with accumulator and counter normalization on every 100th iteration. Accumulator and counter normalizations were done by having their values halved.

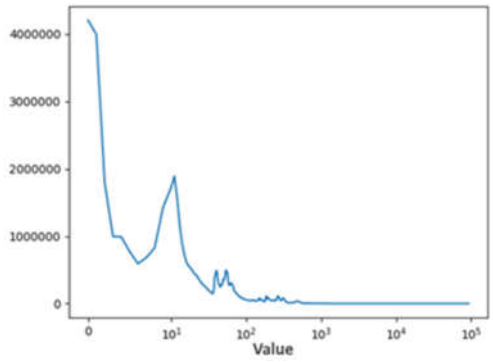

Figure 1. The frequency of values for UMass Smart* Dataset-2017 apartments readings normalized by multiplying with 100

For the second part of our assessment, we selected some of the algorithms analyzed in the first part which appeared suited for use on an embedded device that sends the compressed data over unreliable communication channels. Selected algorithms were rewritten in C++ with $\log_2$ and 2^x operations speed up using bit-shifts and lookup tables. After we implemented selected algorithms on the ESP32-WROOM32 embedded device, processing time along with power consumption of the device during compression was analyzed. It should be noted that although ESP32 is a low powered device, it is quite powerful for an embedded device due to its Xtensa 240Mhz CPU.

Since the test dataset is quite large and it cannot completely fit in ESP32 memory, a special test environment was built which sends chunks of the dataset in predefined batch sizes over serial communication. When the complete batch was received and parsed into the buffer of values a two-way readiness handshake was done (by setting ENCODING_STATUS and ENCODING_ACK pins high) between ESP device and test environment, marking their readiness to start the compression and measuring. When compression of the whole batch finishes, pins used in the handshake are set low, and the next iteration starts.

Code which controls the complete process was developed in Python v3.7 and uses GPIO interrupts and processing time and power consumption measuring was separated into two threads, this allowed for minimum influence communication within different devices had on the overall results. The whole measuring process is visible on the state diagram in Figure 2.

Power consumption was measured using INA219 sensor which relies on the I2C interface to communicate with the test environment. RaspberryPi device has both enough memory needed to store the whole test dataset and all of the needed communication interfaces (serial communication interface, I2C interface, and digital input and output pins for readiness handshake) and proved to be a natural choice for the core of the test environment.

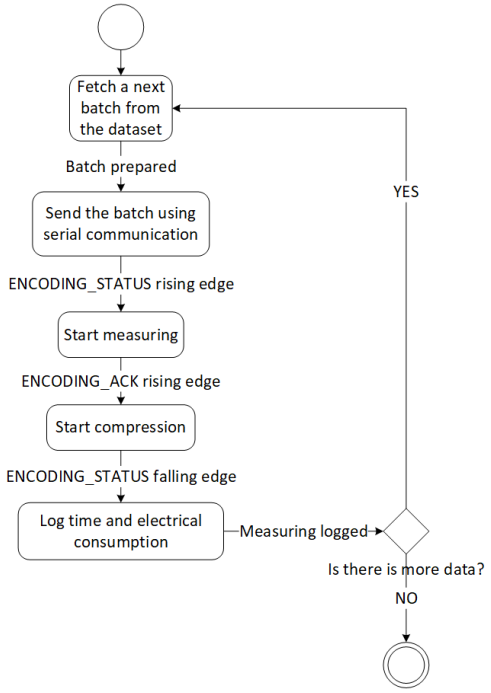

Figure 2. State diagram of the measurement process

IV. ASSESMENT RESULTS

Results from the first part of the assessment described in Section III are visible in Table I. Compression efficiency and processing time are evaluated on the complete UMass Smart-2017 dataset.

TABLE I. COMPRESSION EFFICIENCY AND TOTAL PROCESSING TIME

Algorithm	Compression efficiency	Time[s]
Elias γ	0.5189	220.86
Elias δ	0.5509	326.28
Golomb-Rice(k=6)	0.6333	216.45
Exp-Golomb(k=6)	0.6375	322.62
Adaptive Golomb-Rice	0.6466	418.94
Adaptive Exp-Golomb	0.5293	521.96
LEB128	0.5178	115.86
Varint30	0.4832	183.01

It is interesting to note from these results that Exponential-Golomb (k=6) code has the highest compression efficiency out of all of the static algorithms, Adaptive Golomb-Rice has the best compression efficiency, and LEB128 has the shortest processing time out of all the analyzed algorithms.

On Figure 3 we can observe how selected algorithms compare to the entropy of the UMass apartments dataset. Mean codewords lengths are mostly under the two times

TABLE II. CODEWORD LENGTHS

Algorithm	Mean length	Median length	Percentil-25 length	Percentil-75 length	Minimal length	Maximal length
Elias γ	10.23	11	7	15	1	33
Elias δ	9.64	10	8	14	1	25
Golomb-Rice(k=6)	8.39	7	7	9	7	1456
Exp-Golomb(k=6)	8.34	7	7	9	7	27
Adaptive Golomb-Rice	8.22	8	7	9	1	530
Adaptive Exp-Golomb	10.04	10	10	10	1	25
LEB128	10.26	8	8	16	8	24
Varint30	11.0	8	8	16	8	24

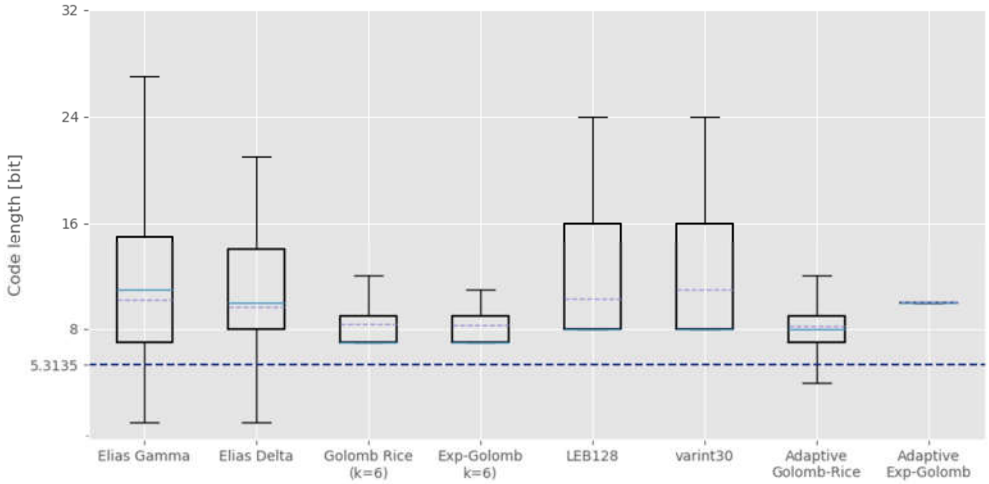

Figure 3. Codeword lengths compared to the dataset entropy (dashed line)

the entropy size, and well under the common 16-bit and 32-bit integer sizes.

Table II displays mean, median, minimal, maximal, 25th percentile and 75th percentile codewords lengths for assessed algorithms. It is interesting to note that Adaptive Golomb-Rice method gave the best result in terms of smallest mean codewords length, but both static and adaptive Golomb-Rice methods have extremely big maximal values, rendering them very troublesome for practical use with the UMass apartments dataset.

A. Customizations to LEB128 code

Adjusting payload size of LEB128 code can improve its compression efficiency, referenced in this paper as varint6p and varint5p, variable byte codes with payload sizes of 6 and 5 bits have compression efficiency comparable to other algorithms while maintaining the short computation time. Codeword lengths of these customizations along with that of the original version can be seen in Figure 4. Both varint6p and varitn5p dropped mean codeword lengths to 9.621 and 9.2 respectively, with varint6p having a lowest maximal value of 21 bits. Interestingly lowering payload size to 5 bits increased maximal value to 24 bits.

Good results with the payload size customizations encourage further assessment of practical usage, with emphasis on decompression, as a possible drawback to these customizations could be the lack of SIMD instructions enhanced decompression that the original LEB128 has, as data is no longer byte-rounded.

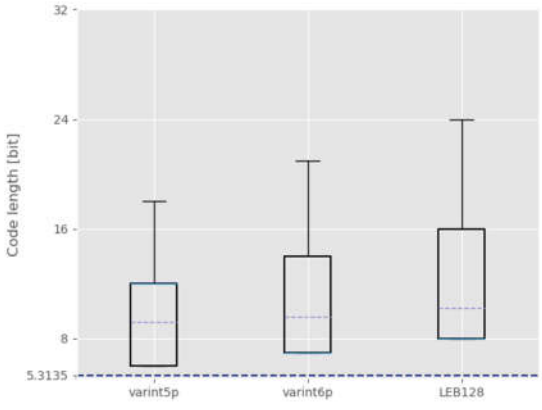

Figure 4. Codeword lengths compared to the dataset entropy (dashed line) – customizations to LEB128

B. Influence of k- parameter in Golomb-Rice and Exp-Golomb algortithms

It is interesting to see how codeword lengths change with different values of parameter *k* in both Golomb-Rice and Exp-Golomb compression algorithms. With bigger *k*-

values, extremes deviate less from the mean value and increasing value *k* from 0 to 6 improves compression efficiency. Enlarging parameter *k* further doesn't improve compression efficiency and introduces a longer processing times. Compression efficiency and total processing time for both algorithms for values k=0-8 are displayed on Table III.

TABLE III. COMPRESSION EFFICIENCY AND TOTAL PROCESSING TIME FOR DIFFERENT K-PARAMETER VALUES IN GOLOMB-RICE AND EXP-GOLOMB ALGORITHMS

Algorithm	Compression efficiency	Time[s]
Golomb-Rice (k=0)	0.0474	179.05
Exp-Golomb (k=0)	0.5189	220.86
Golomb-Rice (k=1)	0.0927	165.39
Exp-Golomb (k=1)	0.5598	287.27
Golomb-Rice (k=2)	0.1746	165.85
Exp-Golomb (k=2)	0.5955	291.44
Golomb-Rice (k=3)	0.3035	167.63
Exp-Golomb (k=3)	0.5569	302.32
Golomb-Rice (k=4)	0.4609	178.70
Exp-Golomb (k=4)	0.5762	309.62
Golomb-Rice (k=5)	0.5800	198.06
Exp-Golomb (k=5)	0.5790	316.80
Golomb-Rice (k=6)	0.6333	216.45
Exp-Golomb (k=6)	0.6375	322.62
Golomb-Rice (k=7)	0.6186	235.55
Exp-Golomb (k=7)	0.6091	329.43
Golomb-Rice (k=8)	0.5767	245.69
Exp-Golomb (k=8)	0.5675	341.77

Both Golomb-Rice and Exp-Golomb algorithms gave best results for $k = 6$, with Exp-Golomb code having bigger mean codeword length values, but much smaller maximal extremes. Golomb-Rice ($k = 0$) has a towering maximal value of 92759 bits, and although small in comparison maximal value is still very big 371 bits even at parameter $k = 8$. Meanwhile, Exp-Golomb algorithm has a maximal value of 33 bits at $k = 0$, down to 25 bits at $k = 8$. Golomb-Rice and Exp-Golomb codeword lengths for different k-parameter values can be seen in Figures 5 and 6 respectively.

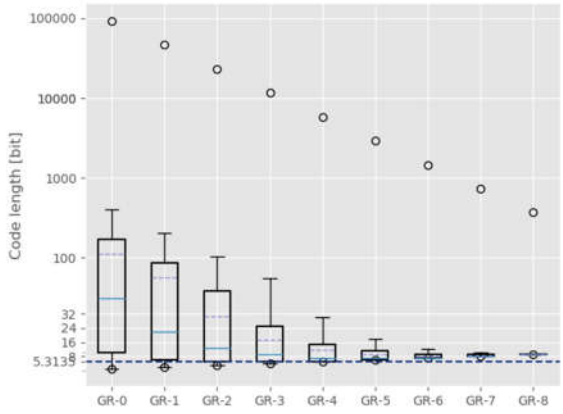

Figure 5. Codeword lengths compared to the dataset entropy (dashed line) – for different *k*-parameter values in Golomb-Rice

These results display the robustness that exponentially growing set sizes introduce in Exp-Golomb algorithm and although Golomb-Rice algorithm has better compression efficiency, spikes in the dataset values distribution that deviate from geometrical distribution make them virtually unusable because of the high maximal values. In practical use one could add a descriptor bit to the compressed payload which would indicate whether the value was compressed or sent in an original form if the compressed value exceeds a set threshold.

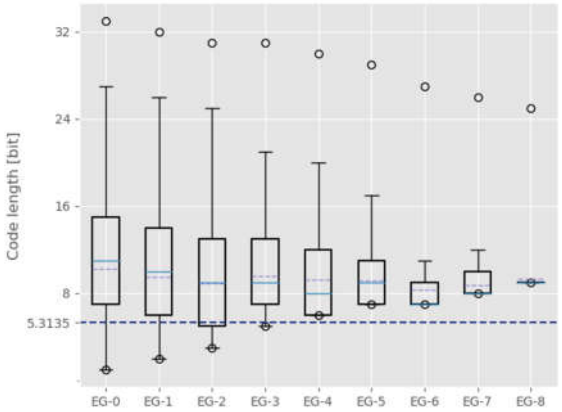

Figure 6. Codeword lengths compared to the dataset entropy (dashed line) – for different *k*-parameter values in Exp-Golomb

C. *Evaluation of selected algorithms on embedded device system ESP32*

In the second part of the assessment, to simulate a real-world scenario where these compression algorithms could be used, compression was evaluated on an embedded device system described in Section III.

Processing time and energy consumption were again assessed on the complete dataset, to minimize any influence measuring process described in Section III had on the overall result, batches of 1000 values were used, and every value was compressed 1000 times.

Overall results are even better than those from the first part of the assessment which was run on a much more powerful PC, this due to speedup attained by optimizing log2 and 2x operations with bit-shifts and lookup tables. Compression efficiency and total processing time for selected algorithms on ESP32 are displayed on Table IV.

TABLE IV. COMPRESSION EFFICIENCY AND TOTAL PROCESSING TIME ON ESP32

Algorithm	Time [s]	Energy [J]
Elias γ	28.25	5.72
Elias δ	45.62	8.13
Golomb-Rice(k=6)	16.719	3.59
Exp-Golomb(k=6)	46.84	10.06
LEB128	5.884	1.25

Although adaptive algorithms had the best compression efficiency in the first part of the assessment, the fact that one lost package can create inconsistency

between coder and decoder, resulting in incorrectly communicated sensor readings is why they are regarded too unreliable for usage in communication channels where package loss is a regular occurrence. Therefore, for further evaluation on sensor nodes following static algorithms were selected because of their excellent compression efficiency and short computation time: Elias γ, Elias δ, Golomb-Rice(k=6), Exp-Golomb(k=6) and LEB128.

Similarly to results in previous assessments, LEB128 was the algorithm that took the shortest processing time. It is interesting to note the energy consumption of ESP32 device during compression, as it could be a reference for energy savings in IoT sensors communication. For a difference in compression efficiency of 15.43%, Exp-Golomb algorithm took around 41 seconds more to compress UMass apartments dataset and while doing that spent 8.81 J of energy more.

V. CONLUSION

Assessment of commonly used variable length code algorithms in a real-world scenario of compressing smart meter readings on an embedded device empirically asserted some theoretical foundations known from before.

Results show how Exp-Golomb code introduces robustness to Golomb codes and that overall compression efficiency is heavily dependent on properly selecting the k parameter. Another assertion was that adaptive compression algorithms can have better compression efficiency than static counterparts as they change the k parameter according to the previously encoded values.

An interesting revelation from the assessments was the plausible usage variable byte algorithms might have in IoT sensor nodes as they introduce little loss in compression efficiency to a large gain in processing time and energy consumption. Results of processing time and total energy spent during compression on an embedded device could be used as a reference to the future evaluation of potential energy savings compression could introduce before sending packages over wireless communication channels.

Results show how optimizing common mathematical operations in compression algorithms shorten their processing time, which in combination with the fact that embedded devices nowadays often come with modestly strong CPU-s makes data transfer from IoT sensor nodes unhindered even if compression is used.

Future work might include assessing decompression algorithms on servers that aggregate data from sensor nodes, with emphasis on SIMD enhanced LEB128 decompression. Another area of research that might induce some positive findings could be self- recovery of adaptive compression methods in unreliable communication channels.

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Project Houseleek - A Case Study of Applied Object Recognition Models in Internet of Things

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***Abstract* - Nowadays, the gap between academic work and practical application of that work is rapidly diminishing. This fact can be backed by several factors: the increase in availability of the research results, as well as research artifacts; the rise in the level of education in general; the availability of broadband networks and the more affordable prices of the technology used for research. Also, due to the pervasion of the technology in all spheres of society, there is an emergence of new possibilities of applying disruptive technologies at all levels, including homes or workplaces of individual users.**

This paper presents Project Houseleek: a multilayer system that utilizes disruptive technologies to enhance and facilitate access to individual premises in smart areas. On the authentication layer, the system uses disruptive deep learning technologies to identify or learn itself a person in a real-world environment from an image grabbed in relatively rough conditions, while at the authorization layer it learns at runtime the access rights to specific parts of the smart area for that person. The testing system is implemented at the Department of Control and Computer Engineering, Faculty of Electrical Engineering and Computing where it exceeded the expectations of the users on both authentication and authorization layers.

Keywords - deep learning, smart home, internet of things, face recognition

I. INTRODUCTION

Automation is the technology by which a process or procedure is performed without human assistance [1]. Although the term "automation" has mostly been used in the context of industrial automation, recently it is used to describe home automation as well. Home automation is, therefore, an automatic centralized control also known as building automation for a home, shortly the smart home or the smart house. The potential uses of the Internet of Things (IoT) in home automation are endless. Every home device connected to the Internet can be programmed to automate something that was usually carried out manually. IoT can be implemented to control lighting, climate, appliances, and numerous other processes. Home security is one of such applications of large importance and with the ability to be improved by employing the concepts from IoT. Most relevant to home security is the process of access control and alarm systems [15].

Machine learning is sub-branch of artificial intelligence, representing a group of methods of data analysis that are used to automate analytical model building in a way that computers can learn and improve without being explicitly programmed. The basic idea of machine learning is to develop the computer programs that can access the data, identify patterns and make decisions or predictions with minimal human intervention and adjust actions accordingly [2]. Particularly, machine learning algorithms can be used to achieve higher levels of efficiency while being applied to the IoT, therefore saving time, energy, and money.

Project Houseleek is designed to create a specific home IoT environment that would carry out users' authentication and authorization in smart environments by detecting the movement in front of the door and identify persons triggering the movement sensors. The aim is to establish a connection for each one of the IoT modules with the centralized server, on which face recognition algorithm will be run. Furthermore, the goal is to keep the hardware price of the designed IoT module relatively low (under 10$).

The rest of the paper is organized as follows: Section II. describes the implementation in detail including technical details, communication protocols, object detection, and face recognition algorithms. Section III. concludes the paper including future work.

II. IMPLEMENTATION

A. Overview

The first objective of the Houseleek project is to set up the home IoT environment that detects movement at the front door, captures a picture with the camera and decides if there is a person on the captured image. A centralized solution called openHAB [14] is used to establish a connection between the server and remote modules. OpenHAB has predefined rules of communication with Houseleek server that has face recognition and object detection algorithms. For example, if movement happens at the front door, openHAB will request Houseleek server for a face recognition algorithm. If the server has successfully identified the person as a familiar person, for example, a homeowner or a family member, a warm welcome message to greet the person at the front door will be played. In the opposite case, when that person is a stranger, home IoT

system should send a notification message to the homeowner's mobile phone and alert homeowner of the possible threat.

Hardware parts used to meet these requirements are ESP32 microcontroller [3], a motion detector (PIR sensor), OV2640 camera, and stereo speaker. Rules correspond to different actions and represent a specific reaction. Therefore, all rules defined for several possible actions that our home system should observe were employed within the home IoT system. Any action observed by home IoT system is sent to open source centralized solution openHAB from where the rule for the upcoming reaction is determined. For example, when the homeowner appears at the front door, the system would observe his appearance as an action, and a predefined rule to that action would be playing the welcome message.

Houseleek implementation consists of the following actions:

- detect movement
- alert about the movement
- acquire a picture from the camera
- send the picture to the face recognition API.

If a person is found on the picture, the picture is then forwarded to face recognition API

- if face recognition API recognizes a familiar person, play the welcome message with their name on the home stereo speakers
- if face recognition API does not recognize a familiar person, send a warning message to homeowner's mobile phone.

Basic implementation of the described system is shown in Figure 1.

B. *Communication*

Communication between openHAB server and face recognition algorithm is done using Hypertext Transfer Protocol (HTTP), while IoT devices communicate with openHAB using Message Queuing Telemetry Transport protocol (MQTT protocol). Therefore, to connect software with openHAB, face recognition and object detection need to be available over HTTP request/response method. HTTP request contains an image for the analysis, and an HTTP response sent from Django server to openHAB contains data with information about recognized objects from the image. openHAB then reads the response and acts

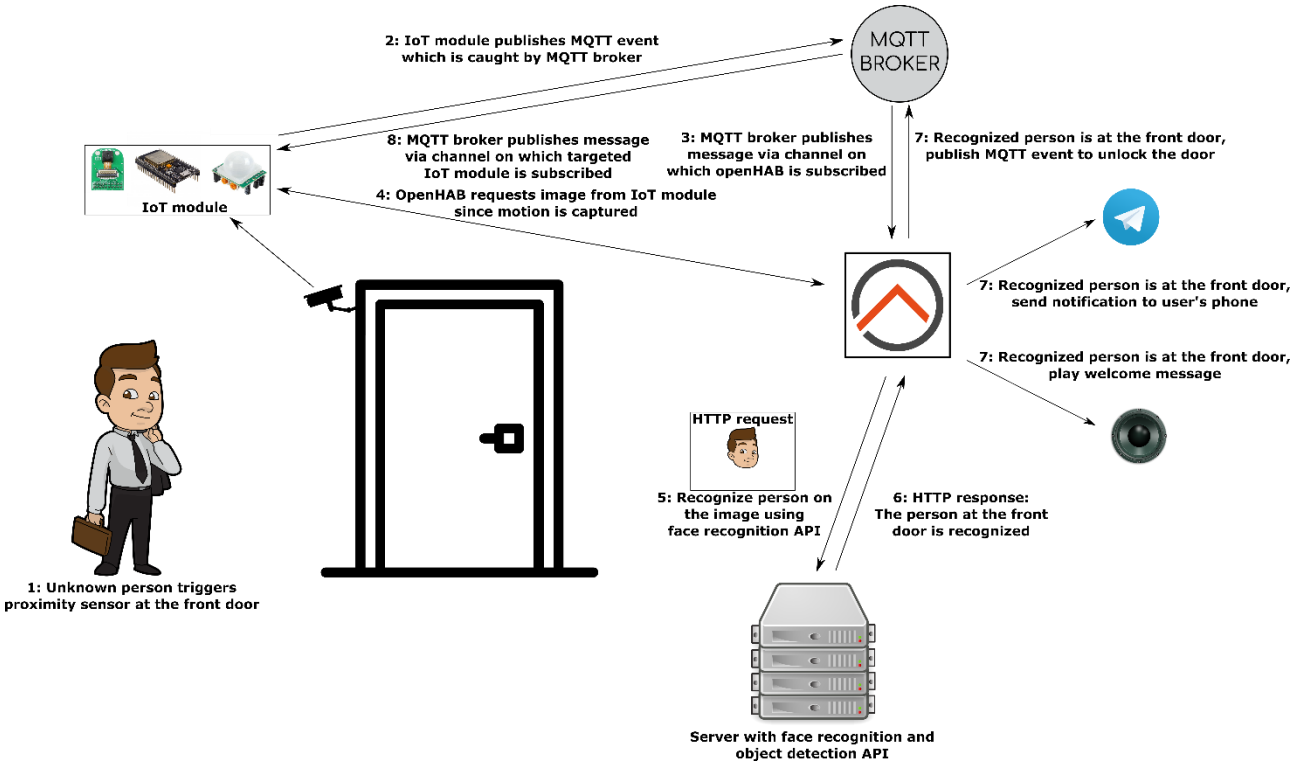

Figure 1. System components with communication scheme

Based on those actions, openHAB has following rules set up, which define what will be executed when the corresponding action is detected:

- if a movement is detected, send a picture from the camera to object detection API
- Object detection, using methods described in paragraph C, is run on the picture from the camera.

according to the predefined rule.

MQTT is a protocol often used in IoT, where network bandwidth may be extremely limited, and is therefore designed to be extremely lightweight. The MQTT protocol works on top of TCP/IP, where both the client and the broker need to have a TCP/IP stack. The client can be represented with any device that aims to publish or subscribe to the predefined topics, and in houseleek project that would be the ESP32 microcontroller. The broker side

of the protocol is responsible for handling all the announcements and subscriptions. The concept of MQTT protocol is different than HTTP as the client does not have to pull the information, but the broker pushes one to the client in case of a new event, as shown in Figure 2. To establish that, each client has a permanently opened connection to the broker. If such a connection is interrupted by any means, the broker can buffer all messages and send them to the client when it becomes available again. Microcontrollers in this project act as Houseleek nodes that are publishing and subscribing to topics. Of all the defined topics, the most important are those for motion detection and camera. The topic associated with the motion sensor has a route named */iot/motion/id*, where *id* is the identifier of the sensor. Mounted test sensor has a route named */iot/motion/1*. The ESP32 microcontroller reads the data from the motion sensor and if a case of movement, it publishes the event to the topic with the message "*TRUE*". Any device in the network that

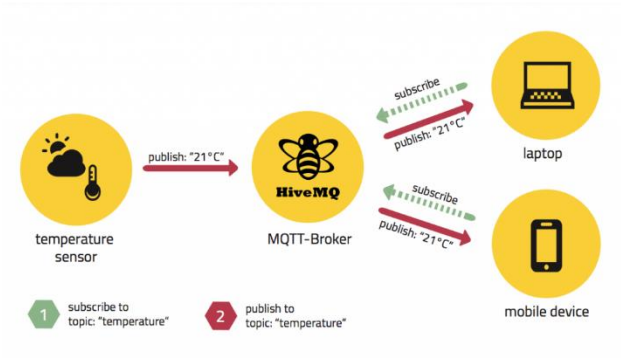

Figure 2. Illustration of MQTT protocol scheme for weather temperature [17]

is subscribed to that topic will automatically know that movement has been observed because they are waiting for the message with payload "*TRUE*". The broker part of the MQTT protocol is installed on Houseleek server node. As a main part of the publish-subscribe protocol, it enables a communication channel by which all the messages are broadcast. It attends all subscriptions, publishes events, and serves as a central hub that is highly scalable and is easy to monitor. When a new message needs to be published, the broker automatically sends it to subscribers, *i.e.* nodes subscribed to the corresponding topic.

MQTT allows authentication and authorization which is an important addition to any IoT system. Username and password are set within the MQTT broker part and are required to be sent together with the data payload each time an event for publish or subscribe action occurs. Therefore, Secure Sockets Layer certificate was installed to protect the username and password as it is not safe to send them as a plain text through the opened network. In that way, username and password are sent encrypted through the network channel.

C. Object detection

The TensorFlow [4] framework is used to fulfill project objectives established for object detection. It is an open source machine learning framework, developed for internal use by Google, but released under the Apache 2.0 open source license on November 9, 2015. TensorFlow object detection API includes construction, training, and deployment of object detection models. It accounts for the structuring of various necessary elements for object detection while giving the user an ability to quickly explore different configurations using TensorFlow backend. TensorFlow can be paired with collections of pre-trained detection models; COCO dataset [5], Kitti dataset [6], and Open Images dataset [7]. Those datasets are large-scale object detection, segmentation, and captioning datasets. All of them include models such as people, cars, animals, and various other groups of objects. As this project requires to detect people, those models will be extremely useful to fulfill all the project objectives. We have chosen to use COCO dataset since it contains the vast variety of pre-trained models with easy to compare specifications. Of many models for object detection available within TensorFlow API, most common ones are Single Shot Multibox Detector (SSD) developed and published by Google in 2016 [8], and Faster R-CNN developed by Microsoft [9].

Single Shot Multibox Detector (SSD) is an object detection model which uses a single deep neural network combining regional proposals and feature extraction. Various sets of boxes, defined with different aspect ratios and scales, are employed to the feature maps. The feature extraction for the bounding boxes can be extracted within the single pass of the image through an image classification network when all maps are computed. Scores are generated for each object category in every of the default bounding boxes, and for better fitting of the ground truth boxes, adjustment offsets are calculated for each box [8]. For image classification within SSD object detection model, one can choose various classification networks. Depending on project needs, each classification network brings certain benefits. Inceptionv3 network [10] is trained to detect objects at different scales, ResNet [11] achieves very high accuracy overall, where Mobilenet network [12] is trained to minimize the required computational resources. The performance data of the COCO-trained models for those classification networks of SSD architecture was evaluated using Nvidia GeForce GTX TITAN X card. In this project we focused on achieving the best precision in reasonable time, meaning that the use of SSD model architecture would bring faster detection, but it would also reflect on lower detection precision. On the other hand, Faster R-CNN typically outperforms SSD, but it requires significantly more computational power. Faster R-CNN models should be used if the project demands better precision, and the total execution time is not relevant. For this project, speed was of more essence compared to precision, which resulted with the decision to employ SSD model architecture for our system, since we only need to distinguish a person from other objects on the picture.

Object detection API is needed to connect the chosen pre-trained model with the utilized server that will communicate via HTTP protocol. HTTP request should contain an image that is needed to be analyzed, and HTTP response should inform if something is recognized on the image. For HTTP server, Django is chosen, a high-level Python Web framework. OpenHAB communicates with Django web server via HTTP requests. When Houseleek node (ESP32 microcontroller, camera and motion sensor)

detects a movement, openHAB makes a request which contains JPEG image that needs to be processed with Django view function. View function takes a JPEG image and runs it through TensorFlow object detection API, which uses SSD model architecture with Mobilenet network. When TensorFlow processes the image, view function takes as the input all detected classes with corresponding scores, which are probabilities that the object is on the image (percentage 0-100%) and returns them as an HTTP response to openHAB.

D. Face recognition

In paragraph C, TensorFlow object detection API which is implemented in our system was described, which can easily detect humans at the front door (images), but it is not able to recognize them. Without face recognition API, TensorFlow object detection would act as a smart proximity sensor which can then trigger a relay and allow entrance only if persons are found in the picture. To recognize persons on the picture, trained model over the images of people who the homeowner wants to be recognized needs to be established. This process would require months of image gathering of people at the front door. Such images would need to be labeled so that the model knows who is on which image. As that job is tedious and does not guarantee success, other options were explored using deep learning algorithms. Recognizing a person on an image is not a simple assignment. To overcome such task, several sub-assignments need to be addressed accordingly:

- Look at the image and detect all faces.
- Focus on each face and recognize the person even if the face is u turned in a different direction or has bad lighting.
- Pick out unique features of the face to set it apart from other people - e.g. distance between the eyes, size of a nose, eye color, face length, etc.
- Determine the person's name by comparing such unique features to all already known people from the database

These problems have already been solved and are incorporated into a single Python library for face recognition [16]. The algorithm used in this project uses the Histograms of Oriented Gradients (HOG) method to detect faces [19]. It converts the image to black and white and compares each pixel with surrounding ones. The main point of such comparison is to create a vector, pointing in the direction where the image is getting darker. The process is repeated for every pixel in the image, where each pixel is replaced with such an arrow. Those arrows are gradients and indicate the light flow from bright to the dark part of the image. Since the image has many pixels, the algorithm breaks the image into small squares of 16x16 pixels and saves only one gradient per square. The gradient that would be saved is one repeating the most within the corresponding 16x16 box. The result is shown in Figure 3.

Second face recognition problem is to recognize the same face turned into different directions. The problem is solved by warping each picture so that a person's eyes and lips are always at the same place. To find eyes and lips, the library uses the algorithm by Kazemi and Sullivan [13]. Fundamental idea is that the face has 68 specific points called landmarks. For example, the top of the chin, the inner edge of each eyebrow, top of the nose, etc. The machine learning model is trained to find these 68 specific points on any face. This way the image is prepared for the next step of face encoding where specific features of the face will be extracted.



Figure 3. Image before and after applying a face detection algorithm [18]

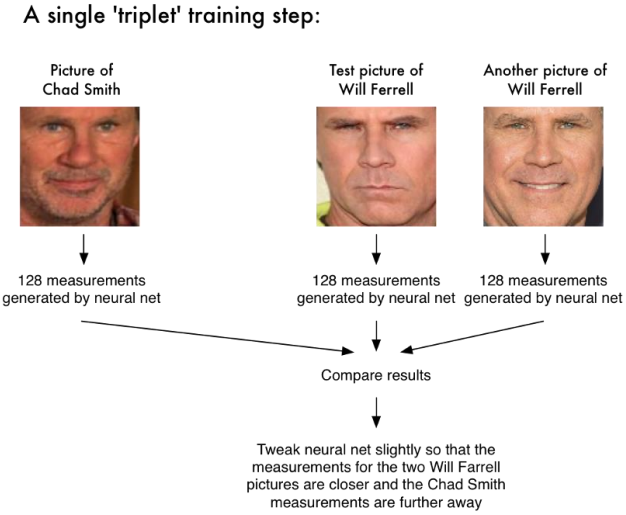

Figure 4. Deep learning one training step [18]

Face encoding is a process which converts a person's face to quantifiable metrics. The typical approach would be to apply some mathematical and computer vision algorithms that calculate the distance between specific face landmarks, but lately, deep learning techniques are being exploited. Deep learning has a greater possibility of learning which parts of the face are more important to measure. This Python library for face recognition applied a deep learning technique by training the network to generate measurements for each face. Training process requires three faces at a time. The base of this algorithm is the triplet training method, shown in Figure 4 [20]. First two images are the face of a known person, while the third picture is the

face of an unknown, random person. The algorithm looks at the measurements it is currently generating for each of those three images. It then tweaks the neural network slightly so that it makes sure the measurements it generates for pictures of known person are slightly closer while making sure the measurements generated for the unknown person are slightly further apart. After repeating this step millions of times for millions of images of thousands of different people, the neural network learns to reliably generate measurements for each person. Once the network has been trained it can generate measurements for any face, even ones that were not in the training dataset. Getting the face encoding is a useful feature for this project because project stores face encoding for familiar persons in one file that contains the name of the familiar person and face encoding. The face recognition API opens that file and compares the face encoding of unfamiliar persons to familiar face encoding from the stored file.

III. CONCLUSION

Home automation is coming into average homes faster than expected. To demonstrate the potential capabilities of next-generation IoT systems, a test system with a motion detector and an inexpensive camera was developed. On the other side, Deep learning methods were exploited to demonstrate the accessibility of complex and powerful techniques for security improvement and automation in smart homes. To achieve that, a subsystem for object detection and face recognition was implemented, utilizing advanced face encoding techniques with feature extraction and a set of transformations being applied to human face objects.

Given the configuration the system is built upon, namely a relatively low resolution and a non-high-quality input image, cheap and slow devices to build up IoT modules, and average hardware used to run recognition services, the quantitative evaluation of the system is yet to be performed. The recognition accuracy measurement together with the comparison with other similar systems remains as a part of future work. Also, future work will include the upgrades of the system with more controllers and higher accuracy sensors. On the software side of the project, there is always room for more efficient and more reliable algorithms and services.

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DATA ANALYTICS

Analysis and Comparison of Exact and Approximate Bin Packing Algorithms

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***Abstract*—In this paper we describe the Bin packing problem (BPP) and evaluate standard state of the art approaches to its solution. Because BPP is NP-hard [1] , there is no exact algorithm which solves the problem in polynomial time. We describe several approximate algorithms and the exact Martello-Toth-Procedure (MTP) for solving BPP. Approximate algorithms are executed in polynomial time, but they do not give optimal solutions in general. MTP searches the solution space with the help of lower bounds and approximate algorithms to minimize the solution space. For approximate algorithms we use the worst-case-to-optimal-solution ratio as a measure of effectiveness. We evaluate the relative deviation from optimal solutions for all described approximate algorithms using instances of BPP for which proven optimal solutions are found. We compare the MTP algorithm performance to those results in order to demonstrate its effectiveness.**

***Index Terms*—Bin packing problem, discrete optimization, Martello-Toth-Procedure**

I. Introduction

The bin packing problem (BPP) is one of the most common optimization problems today. Every day millions of BPP instances are solved for the needs of parcel delivery companies. Because of this, increasingly efficient algorithms for solving this problem are needed to reduce cost and improve effectiveness. The problem can be defined as follows: n items of different sizes need to be packed into bins. The aim is to pack them in such a way that a minimal amount of bins is needed. The formal definition of the problem would be:

- n is a positive natural number representing the number of items.
- Items sizes are marked with a_1, a_2,...,a_n.
- There are $M = \inf$ bins marked S_1, S_2,...,S_M of size C.
- $c_{ij} = 1$ if item i is assigned to bin j.
- Find the minimal number of bins $B \ll M$ so that:
  - each item is assigned to only one bin:

$$\sum_{j=1}^{B} c_{ij} = 1, \forall i \in \{1, 2, ..., n\} \quad (1)$$

  - no bin capacity is exceeded:

$$\sum_{i=1}^{n} a_i \cdot c_{ij} \leq C, \forall j \in \{1, 2, ..., B\} \quad (2)$$

The described problem is a NP-hard [1] problem so often, in practice, it is not feasible to find the exact solution. Thus, a good enough solution is searched for. This is done using approximate algorithms and heuristics. In order to verify and compare the effectiveness of approximate algorithm a worst-case-to-optimal-solution ratio is used as a measure of their quality. When an exact solution can be found in real time the main aim is to reduce the amount of time needed for providing a solution. In this paper we implement effective, commonly used approximate algorithms and a state of the art exact Martello-Toth-Procedure (MTP) algorithm [2]. We compare their performance and demonstrate the effectiveness of the MTP algorithm when it can be used.

The rest of this paper is organized as follows. In Section II we present approximate approaches. In Section III we present lower bounds and reduction procedure used in MTP algorithm. In Section IV we present the MTP approach. In Section V we present the evaluation results of our experiments. In Section VI we summarize our work and present future steps in this work.

II. Approximate algorithms

Approximate algorithms provide good enough solutions for the BPP problem. For these algorithms a worst-case-to-optimal-solution ratio is defined as:

$$r(A) \geq \frac{A(I)}{z(I)}, \forall I \quad (3)$$

where I indicates the instance, $A(I)$ is the solution (number of bins required) of the instance provided by the approximate algorithm and $z(I)$ is the optimal solution of the instance.

This measure is often transformed into asymptotic form in order to provide more comparable results. Real number $r^{\infty}(A)$ is defined as minimal value so that for some positive number k

$$\frac{A(I)}{z(I)} \leq r^{\infty}(A), \quad \forall I : z(I) \geq k. \tag{4}$$

Worst-case-to-optimal-solution ratio shows how poor a heuristic algorithm can be when it builds the worst solution compared to the optimal. Value of $r(A)$ is always greater than or equal to 1. In II-A, II-B and II-C we describe the approximate algorithms First fit decreasing (FFF), Best fit decreasing (BFD) and Worst fit decreasing (WFD) implemented as part of our work and further used by the MTP algorithm.

A. First fit decreasing

FFD starts with all bins closed and all items unassigned and ordered in decreasing order by their sizes. It then repetitively selects an item and then tries to assign it to the first open bin with enough residual capacity. If there is no such box then an unopened bin is selected, opened and the item is assigned to it. This is repeated until all items are assigned.

The time complexity of this procedure is $O(n \log n)$ if specialized data structures are used. The expressions (5), (6), (7) and (8) hold for the solutions of the FFD algorithm (proven in [3]).

$$FFD(I) \leq \frac{11}{9} z(I) + 4 \tag{5}$$

When transformed to asymptotic form it becomes the expression show in (6).

$$r^{\infty}(FFD) = \frac{11}{9} \tag{6}$$

For instances where the item size is $a_i \in \left\langle 0, \frac{c}{2} \right]$ it can be shown that expressions (7) holds.

$$FFD(I) \leq \frac{71}{60} z(I) + c \tag{7}$$

For instances where the items size is $a_i \in \left\langle 0, \frac{c}{4} \right]$ it can be shown that expression (8) holds.

$$FFD(I) \leq \frac{23}{20} z(I) + c \tag{8}$$

B. Best fit decreasing

The best fit decreasing algorithm starts with all bins closed and all items unassigned and ordered in decreasing order by their sizes. It then repetitively selects next bin with lowest residual capacity if exists and assigns item to that bin. If no such bin exists then an unopened bin is selected, opened and the item is assigned to it. This is repeated until all items are assigned.

The time complexity of this procedure is $O(n \log n)$ if specialized data structures are used. The expressions (9), (10), (11) and (12) hold for the solutions of the BFD algorithm (proven in [3]).

$$BFD(I) \leq \frac{11}{9} z(I) + 4 \tag{9}$$

When transformed to asymptotic form it becomes the expression show in (10).

$$r^{\infty}(BFD) = \frac{11}{9} \tag{10}$$

For instances where the item size is $a_i \in \left\langle 0, \frac{c}{2} \right]$ it can be shown that expression (11) holds.

$$BFD(I) \leq \frac{71}{60} z(I) + c \tag{11}$$

For instances where the item size is $a_i \in \left\langle 0, \frac{c}{4} \right]$ it can be shown that expression (12) holds.

$$BFD(I) \leq \frac{23}{20} z(I) + c \tag{12}$$

C. Worst fit decreasing

The worst fit decreasing algorithm starts with all boxes closed and all items unassigned. It then repetitively selects an item and then tries to assign in to an open box with enough capacity which has highest residual capacity. If no such box exists then an unopened box is selected, opened and the item is assigned to it. This is repeated until all packages are assigned to a box. The time complexity of this procedure is $O(n \log n)$ if specialized data structures are used.

The expressions (13) and (14) hold for the solutions of the WFD algorithm (proven in [4]).

$$WFD(I) \leq \frac{11}{9} z(I) + 4 \tag{13}$$

When transformed to asymptotic form it becomes the expression shown in (14).

$$r^{\infty}(WFD) = \frac{11}{9} \tag{14}$$

III. Lower bounds and reduction

For purposes of MTP algorithm, using general description of BPP described in I, a possible mathematical formulation of the problem is:

minimize

$$z = \sum_{i=1}^{n} y_i \tag{15}$$

subject to

$$\sum_{j=1}^{n} w_j x_{ij} \leq c y_j, \quad i \in N = \{1, ..., n\} \tag{16}$$

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j \in N \tag{17}$$

$$y_i = 0 \ or \ 1, \quad i \in N \tag{18}$$

$$x_{ij} = 0 \ or \ 1, \quad i \in N, j \in N \tag{19}$$

where

$$y_i = \begin{cases} 1, & \text{if bin i is used;} \\ 0, & \text{otherwise.} \end{cases} \tag{20}$$

$$x_{ij} = \begin{cases} 1, & \text{if item j is assigned to bin i;} \\ 0, & \text{otherwise.} \end{cases} \tag{21}$$

It is supposed that the weights w_j and c are positive integers, and that:

$$w_j < c \ , \forall j \in N. \tag{22}$$

With this mathematical model the following lower bounds for number of needed bins are determined.

A. Lower bound L_1

The continuous relaxation of the BPP given by

$$0 \leq \ y_i \leq 1, \qquad i \in N \tag{23}$$

$$0 \leq x_{ij} \leq 1, \qquad i \in N, j \in N, \tag{24}$$

can be solved as

$$z = \sum_{i=1}^{n} \frac{w_i}{c}$$

which gives lower bound L_1 as

$$L_1 = \left\lceil \sum_{j=1}^{n} w_j / c \right\rceil$$

.

B. Lower bound L_2

Given any instance I of BPP, and any integer α, $0 \leq \alpha \leq c/2$, using

$$J_1 = \{j \in N : w_j > c - \alpha\} \tag{25}$$

$$J_2 = \{j \in N : c - \alpha \geq w_j > c/2\} \tag{26}$$

$$J_3 = \{j \in N : c/2 \geq w_j \geq \alpha\}; \tag{27}$$

the following is defined:

$$L(\alpha) = |J_1| + |J_2| + max\left(0, \left\lceil \frac{\sum_{j \in J_3} w_j - (|J_2|c - \sum_{j \in J_2} w_j)}{c} \right\rceil\right). \tag{28}$$

Lower bound L_2 is then defined using (28) as

$$L_2 = max\{L(\alpha) : 0 \leq \alpha \leq c/2, \alpha \in Z\}. \tag{29}$$

By the dominance rule L_2 dominates over L_1.

C. Reduction

Reduction is used to reduce search space of possible solutions. Reductions described in MTP algorithm are based on the following dominance criterion.

Initially, a feasible set is defined as a subset $F \subseteq N$ such that $\sum_{j \in F} w_j \leq c$. Given two feasible sets F_1 and F_2, we say that F_1 dominates F_2 if the value of the optimal solution which can be obtained by imposing for a bin, say i^*, the values $x_{i*j} = 1$ if $j \in F_1$ and $x_{i*j} = 0$ if $j \notin F_1$, is no greater than the value that can be obtained by forcing the values $x_{i*j} = 1$ if $j \in F_2$ and $x_{i*j} = 0$ if $j \notin F_2$. A possible way to check such situations is using the following criterion

Dominance criterion Given two distinct feasible sets F_1 and F_2, if a partition of F_2 into subsets $P_1, ..., P_l$ and a subset $\{j_1, ..., j_l\}$ of F_1 exist such that $w_{j_h} \leq \sum_{k \in P_k} w_k$ for $h = 1, ..., l$, then F_1 dominates F_2.

If a feasible set F dominates all others, then the items of F can be assigned to a bin and removed from N, where N is defined at the begining of section III. Checking all such situations, however, is clearly impractical. The algorithm MTRP used in MTP limits the search to sets of cardinality not greater than 3 and avoids enumeration of useless sets. It considers the items according to decreasing weights and, for each item j, it checks for the existence of a feasible set F such that $j \in F$, with $|F| \leq 3$, dominating all feasible sets containing item j. Whenever such set is found, the corresponding items are assigned to a new bin and the search continues with the remaining items. It is assumed that, on input, the items are sorted in non-decreasing order. On output z^r gives the number of optimally filled bins, and for $j \in N$,

$$b_j = \begin{cases} 0, \text{if item j has not been assigned;} \\ \text{bin to wich it has been assigned, otherwise.} \end{cases}$$

Time complexity of MTRP is $O(n^2)$

D. Lower bound L_3

Reduction procedure MTRP can be used to determine a new lower bound L_3. Lower bound L_3 is determined with lower bound L_2 and procedure MTRP. After execution of procedure MTRP for an instance I of BPP, let z_1^r denote the output value of z^r, and $I(z_1^r)$ the corresponding residual instance, defined by item set $\{j \in N : b_j = 0\}$. It is obvious that a lower bound for I is given by $z^r + L(I(z_1^r))$, where $L(I(z_1^r))$ denotes the value of any lower bound for $I(z_1^r)$.(Note that $z_1^r + L(I(z_1^r)) \geq L((I))$.) Suppose now that $I(z_q^r)$ is relaxed in some way and MTRP is applied to the relaxed instance, producing the output value z_2^r and a residual relaxed instance $I(z_1^r, z_2^r)$. A lower bound for I is then $z_1^r + z_2^r + L(I(z_1^r, z_2^r))$. Iterating the process we obtain a series of lower bounds of the form

$$L_3 = z_1^r + z_2^r + ... + L(I(z_1^3, z_2^r, ...)).$$

Iterations are repeated while there are still unassigned items in residual relaxed instance of BPP. Procedure for determining lower bound L_3 uses lower bound L_2 as L. Items are sorted in non-increasing order. Time complexity for executing procedure for determining L_3 is $O(n^3)$. It is obvious that $L_3 \geq L_2$.

IV. MTP ALGORITHM

Algorithm MTP is exact algorithm which uses branch and bound method with "first fit decreasing" branching strategy. The items are initially sorted according to decreasing weights. At each decision node, the first free item is assigned, in turn to the feasible initialized bins (by increasing index) and to a new bin. At any forward step, (a) procedures L_2 and L_3 are called to attempt to remove the node from the search space and reduce the current problem; (b) when no removing occurs, approximate algorithms FFD, BFD, and WFD are applied to the current problem, to try and improve the best solution so far. In addition, the following dominance criterion between decision nodes is used. When the current item j^* is assigned to a bin i^* whose residual capacity $\overline{c}_{i^*}$ is less than $w_j + w_n$, this assignment dominates all the assignments to i^* of items $j > j^*$ which do not allow the insertion of at least one further item. Hence such assignment "closes" bin i^*, in the sense that no item $j \in \{k > j^* : w_k + w_n > \overline{c}_{i^*}\}$ is assigned to bin i^*. The bin is "re-opened" when the first item $j > j^*$ for which $w_j + w_n \leq \overline{c}_{i^*}$ is considered. Since at any decision node the current residual capacities $\overline{c}_i$ of the bins are different, the computation of lower bounds L_2 and L_3 must take into account this situation. An easy way is to relax the current instance by adding one extra item of weight $c - \overline{c}_i$ to the free items for each initialized bin i, and by supposing that all bins have capacity c.

V. EVALUATION RESULTS

After implementing exact algorithm MTP and approximate algorithms FFD, WFD and BFD in programming language Python, programs are executed on several different instances of BPP. Used instances are Falkenauer [5], Scholl [6] and Schwerin [7].

A. Falkenauer

Instance of this dataset is divided into two classes of 80 instances each: the first class has uniformly distributed item sizes (set 'Falkenauer U') with n between 120 and 1000, and c = 150. The instances of the second class (set 'Falkenauer T') includes the so-called triplets, i.e., groups of three items (one large, two small) that need to be assigned to the same bin in any optimal packing, with n between 60 and 501, and c = 1000. Boxplot diagram which shows relative deviation from optimum for approximate algorithms FFD, BFD and BFD is showed in figure 1.

B. Scholl

Instances of this dataset are divided into three sets of 720, 480, and 10 samples, respectively, uniformly distributed instances with n between 50 and 500. The capacity c is between 100 and 150 (set 'Scholl 1'), equal to 1000 (set 'Scholl 2'), and equal to 100 000 (set 'Scholl 3'), respectively. Boxplot diagram which shows relative deviation from optimum for approximate algorithms FFD, BFD and BFD is showed in figure 3.

C. Schwerin

They are divided into two sets ('Schwerin 1' and 'Schwerin 2') of 100 instances each with n = 100 and n = 120, respectively, and c = 1000. Boxplot diagram which shows relative deviation from optimum for approximate algorithms FFD, BFD and BFD is showed in 2.

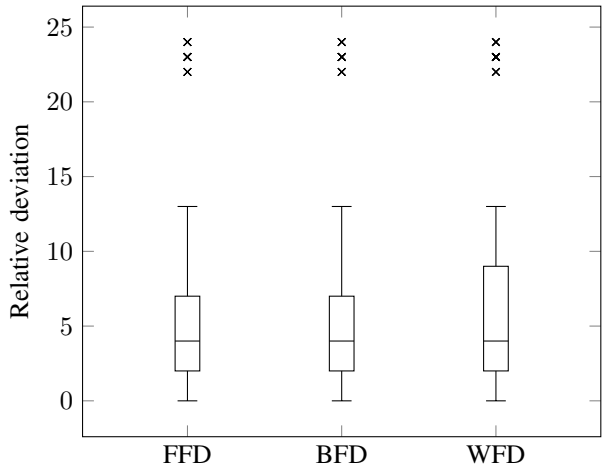

Fig. 1: Box plot for instances from Falkenauer set

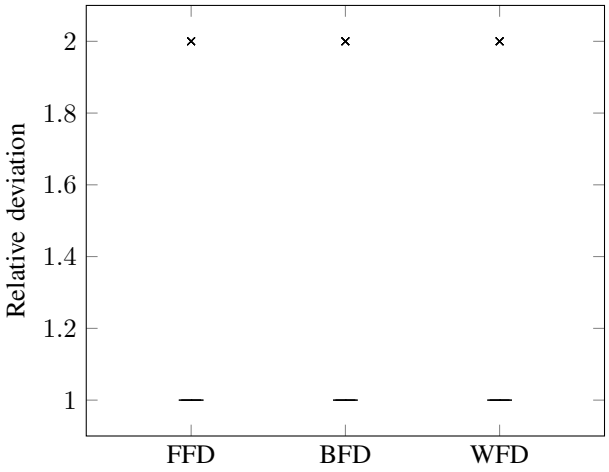

Fig. 2: Box plot for instances from Schwerin set

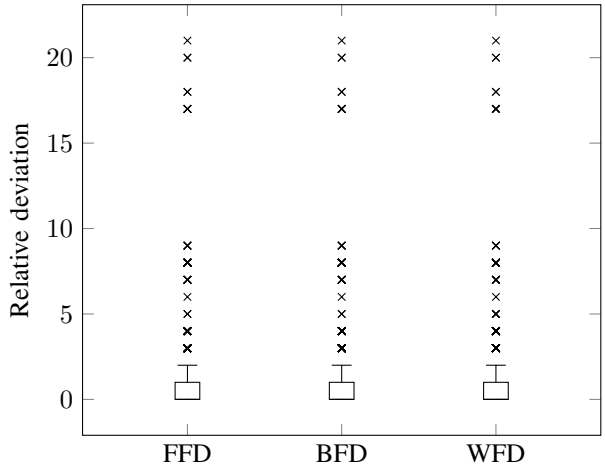

Fig. 3: Box plot for instances in Scholl set

D. MTP

Results of exact algorithm MTP are determined by executing algorithm for each instance set for 5 minutes are showed in table I.

TABLE I: Results of executing algorithm MTP

Instance	Number of optimal solutions found	Total number of problems
Falkenauer	107	160
Scholl	1115	1210
Schwerin	195	200

VI. Conclusion

BPP is NP-hard problem, so often in practice, it is not feasible to find the exact solution. Thus, a good enough solution is searched for. We presented three approximate algorithms FFD, WFD and BFD and showed box plot of their relative deviation from optimum. When an exact solution is required the main aim is to reduce the amount of time needed for providing a solution. In this paper we implement a state of the art exact MTP algorithm and demonstrate its effectiveness.

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Comparison of Relational and Time-Series Databases for Real-Time Massive Datasets

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***Abstract* - Many contemporary technical systems, like IoT environments, are designed to work perpetually and collect data in a form of time series. To enable efficient data aggregation and analysis with time interval constraints, a special type of databases optimized for time-series has been developed. In this paper, we conduct a thorough performance comparison of a time-series database InfluxDB and a widely used object-relational database PostgreSql. We present our findings and outline scenarios in which a certain database has a performance advantage.**

Keywords - time-series databases; performance analysis; InfluxDB; PostgreSql

I. INTRODUCTION

Historically, time-series data has mostly been associated with applications in finance, but with recent increase in popularity of Internet of things (IoT) platforms, the importance of time-series data has grown as well. Nowadays, time-series data exists in various areas, such as financial markets, weather forecasting, medical and biological experiments and more [1][2][3][4]. Large amounts of data exchanged between servers, applications and sensors in a particular time order resulted in time-series databases becoming a standard for storing and retrieving data. A time-series database (TSDB) is a database type which is optimized for time-series and time-stamped data [5].

In this paper we describe main characteristics of time-series databases and cases where it is more efficient to use time-series databases as well as cases where using relational databases has shown better results. Using Visual Studio .NET environment, pgAdmin platform and InfluxDB command line we measured the duration of querying data from a relational database PostgreSQL and a time-series database InfluxDB. We compared the time needed for: querying data with a certain time interval constraint, data aggregation with a time interval constraint, data aggregation with a time interval constraint grouped by time intervals, data aggregation with a time interval constraint grouped by indexed attributes and finally, inserting data into a database. Given results show that a relational database holds an advantage over a time-series database when it comes to querying raw, non-aggregated data. On the other hand, the main advantage of using a time-series database over a relational database includes faster aggregation and faster result grouping by various time intervals.

The rest of the paper is structured as follows: In Section 2 we describe main characteristics of time-series databases focusing on InfluxDB. In Section 3 we describe the experimental setup which includes PostgreSQL and InfluxDB database configurations. The results of measurements are presented in Section 4 and finally, the conclusion is given in Section 5.

II. RELATED WORK

A time-series database is a database type which is optimized for time-series and time-stamped data. Time-series include measurements or events that are tracked, monitored, sampled and aggregated over time. They can be related to server metrics, application performances, network data, sensor data and other types of analytics data [6].

A time-series database is optimized for measuring change over time. It is built for handling metrics, events and measurement that are time-stamped and it allows users to create, update, destroy and organize various time-series more efficiently. The key difference between time-series database and a relational database is in the way data ordering is managed. While relational databases do not imply a particular order of inserted data (order by clause must be used), time-series databases index and process data with goal to optimize queries that imply ordering in time. Thus, one of the main differences between the two is the way indices are implemented. Otherwise, time-series and relational databases are architecturally similar. Other notable differences include the tradeoffs when it comes to adhering to ACID properties versus performance. Time-series databases do not need to necessarily ensure durability and strong consistency as time-series data is usually immutable and generated in a unique point in time. In addition, it is not necessary to collect all the possible data, e.g. when continuously collecting a data from a sensor, it is may not be necessary to store all data points. For instance, InfluxDB provides eventual consistency.

Nowadays, an increasing number of companies are generating large streams of metrics and events prompting the need for time-series databases in order to facilitate efficient data access [5]. However, time-series databases, due to their optimizations, do not always show favorable properties when it comes to tackling more general purpose tasks. From an engineering standpoint, it is important to understand in which use cases time-series databases perform better when it comes to query execution time, as well as general resource consumption. Some research effort has been devoted into addressing these issues [4][7][8]. For instance, in [8] the authors test InfluxDB

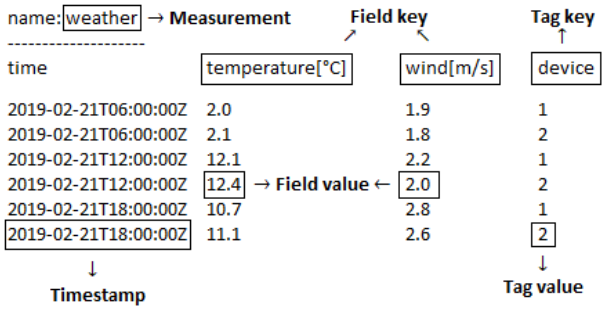


Figure 2. Data structure

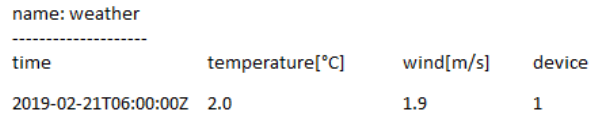


Figure 3. Point

performance on a very large real-world dataset containing 450 million power consumption readouts. The authors focus the tests on data insertion speed and disk storage consumption parameters. In our paper, we aim to further strengthen the results found in the literature by performing additional experiments on a real-world dataset. Apart from the data insertion experiments, we also conducted several data aggregation experiments.

Currently, the one of the most popular time-series databases is InfluxDB [9] and as such, we have decided to utilize it for the purposes of performance comparison with a relational database. InfluxDB is an open-source schemaless time-series database with a set of optional components. It is written in Go programming language and it is optimized to handle time-series data in particular. The database environment provides InfluxQL, a SQL-like query language. The open-source version TICK Stack provides full time-series database platform including the InfluxDB core [5].

All data in the InfluxDB database has a column named *time*. Column *time* stores timestamps in RFC3339 UTC format and is associated with particular data. Another required part of InfluxDB's data structure are fields which consist of a field key and field value. Field keys are strings and they store metadata. Field values can be of type string, float, integer or Boolean and they represent the data. The collection of field-key and field-value pairs form a field set. Fields are not indexed and they are a required piece of InfluxDB's data structure. Tags are optional, and they consist of a tag key and tag value which are both strings that store metadata. Different combinations of all the tag-key and tag-value pairs form a tag set. Unlike fields, tags are indexed and optional. Measurement acts as a container for tags, fields and the *time* column and the measurement name represents the description of the data that is stored in associated fields. A single measurement can belong to different retention policies. Retention policy describes how long InfluxDB keeps the data. In an InfluxDB database, a series is a collection of data that share a retention policy, measurement and tag set. Finally, a point is the field set in the same series with the same timestamp [10].

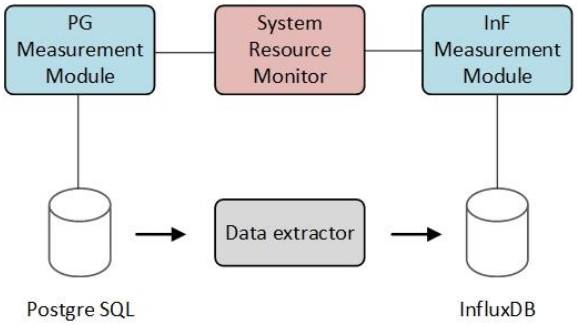


Figure 1. Experimental Environment Architecture

In the example shown in Fig. 1, *weather* represents the measurement name. Columns *temperature* and *wind* form fields with field keys *temperature* and *wind*. Values 2.0-11.1 are field values referring to *temperature* and values 1.9-2.6 are field values referring to *wind*. Column *device* is a tag with a tag key *device* and two tag values (1 and 2). An example of an InfluxDB point is presented in Fig. 2.

In a general sense, an InfluxDB measurement is similar to a table of a relational database, tags are similar to indexed columns, fields are similar to unindexed columns and points are similar to table rows.

III. EXPERIMENTAL SETUP

In this section, we describe the experimental setup used to perform measurements on the PostgreSQL and InfluxDB databases.

A. Environment

All measurements were performed on a 64-bit computer with an Intel Core i5 processor and 12 gigabytes of RAM available.

In the conducted experiment, we have collected a real-world real-time dataset consisting of twenty million records and have stored it in a PostgreSQL table. Time differences between two records in the table varied depending on numerous parameters and can vary from milliseconds to days. Specifically, the table stored twenty million records and had thirty-nine attributes. The data has a time range from December 8th, 2017 at 19:11:49 to January 12th, 2018 at 22:59:52 (UTC). There is no recorded data from December 25th, 2017 to January 1st, 2018. The first most significant attribute contained a timestamp which corresponded to the moment in time in which the record was received and the second most significant attribute contained an object identifier. We created indexes on the mentioned columns.

The architecture of the implemented experimental environment is presented in Fig. 3. In order for the InfluxDB database to contain the same data as the PostgreSQL database, a *Data extractor* module has been created. Its purpose is to retrieve records from PostgreSQL, create an InfluxDB point depending on a received record and insert the point into the InfluxDB measurement. Indexed columns are equivalent to tags inside an InfluxDB measurement which means that the tag is going to store the same object identifiers stored inside

the mentioned indexed column. The rest of the data was stored in fields, except for timestamps which were stored in a special *time* column.

Measurement module has been implemented in order to facilitate measuring operations of query execution time and to monitor general system resource consumption. It consists of three submodules: a *PostgreSQL Measurement* module which measures PostgreSQL query execution time, an *InfluxDB Measurement* module which measures InfluxDB query execution time and a *System Resource Monitor* which measures system performances during query executions. The first two submodules create a stopwatch instance, starting it before executing the query and then stopping it when there are no more query results to read. The execution time is measured in milliseconds. The third submodule is started simultaneously with one of the submodules which measure query execution time. It measures the processor utilization and the available memory during the query execution.

B. Experiments

The following experiments were performed to compare the performance of databases in specific working conditions. After each experiment the machine was restarted to ensure equal testing conditions.

1) Querying data

This experiment was designed to check a performance of a standard query, without data aggregation, on several time intervals. Specifically, 3 interval lengths were selected:

- Interval 1: December 9th, 2017 to December 10th, 2017 (one day)
- Interval 2: December 9th, 2017 to December 16th, 2017 (one week)
- Interval 3: December 9th, 2017 to December 23rd, 2017 (two weeks)

Experiments were performed five times each, with the average values plotted in Fig. 4. The SQL query used for this experiment is given below (InfluxQL query is similar):

```
SELECT timestamp, coilid
FROM positionsample
WHERE timestamp >= '2017-12-09' AND
timestamp < '2017-12-10'
```

2) Aggregating data

The aggregation experiment was designed to test how the databases perform when an aggregation function is used on the data selected from a specific time interval. In this experiment, the average value of a PostgreSQL column and an InfluxDB field was selected. The following intervals were used:

- Interval 1: December 9th, 2017 to December 16th, 2017 (one week)
- Interval 2: December 9th, 2017 to December 23th, 2017 (two weeks)
- Interval 3: December 9th, 2017 to January 9th, 2018 (one month)

Experiments were performed five times each, with the average values plotted in Fig. 5. The SQL query used for this experiment is given below (InfluxQL query is similar):

```
SELECT AVG(position)
FROM positionsample
WHERE timestamp >= '2017-12-09' AND
timestamp < '2017-12-16'
```

3) Aggregating data grouped by time intervals

This experiment was performed to evaluate how the aggregation function performs on a data selected from a certain time interval when it is necessary to group the data by a certain parameter. In this experiment, the data was groped by the hour, as presented in the query below. The same intervals were used as in the experiment described in Section 3.B.2.

Experiments were performed five times each, with the average values plotted in Fig. 7. The SQL query used for this experiment is given below (InfluxQL query is similar):

```
SELECT date_trunc('hour', timestamp),
AVG(position)
FROM positionsample
WHERE timestamp >= '2017-12-09' AND
timestamp < '2017-12-10'
GROUP BY 1
```

4) Aggregating data grouped by indexed attribute/tag

The following experiment is set up in the same way as the aggregation experiment described in Section 3.B.3. However, in this experiment, the data was grouped using an indexed attribute (PostgreSQL) and a tag (InfluxDB). The same intervals were used as in the experiment described in Section 3.B.3.

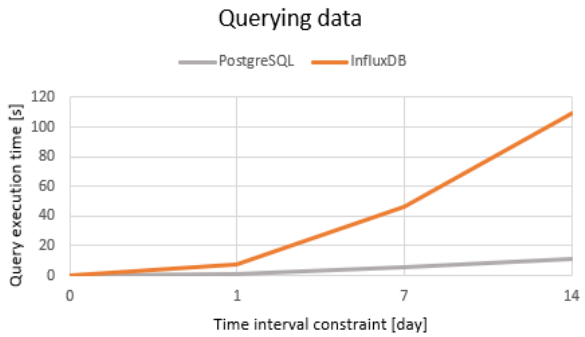
Experiments were performed five times each, with the average values plotted in Fig. 8. The SQL query used for this experiment is given below (InfluxQL query is similar):

```
SELECT AVG(gapdriveside)
FROM positionsample
WHERE timestamp >= '2017-12-09' AND
timestamp < '2017-12-16'
GROUP BY equipmentoid
```

Here it is important to note that the `equipmentoid` has an index in PostgreSQL and is a tag in the InfluxDB.

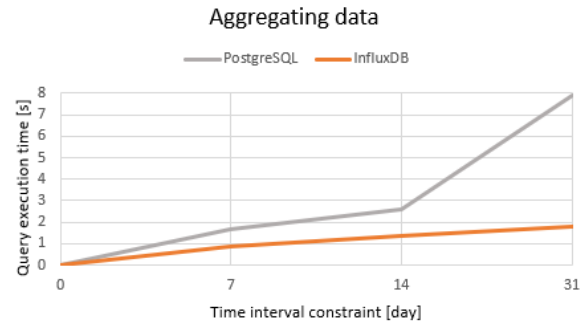
5) Inserting data

Experiments were performed five times each, with the average values plotted in Fig. 9. For both PosgreSQL and InfluxDB the data was inserted in batches (bulk insert) and the batch size was 1000 data points. There were 3 test cases each containing 500, 5000 and 50000 data points. After each experiment the machine was restarted to ensure equal testing conditions.



Standard deviation			
DB	1	7	14
PostgreSQL	0.071 s	0.287 s	0.565 s
InfluxDB	0.121 s	0.393 s	0.535 s

Figure 4. Querying data



Standard deviation			
DB	7	14	31
PostgreSQL	0.065 s	0.010 s	0.010 s
InfluxDB	0.015 s	0.015 s	0.071 s

Figure 5. Aggregating data

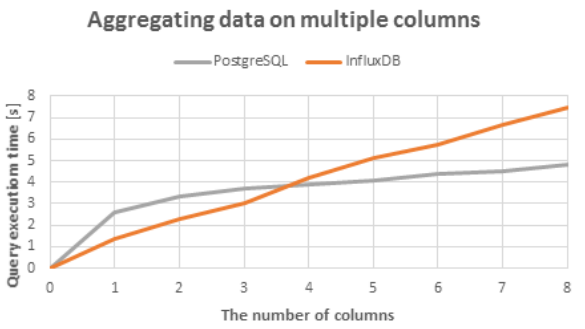
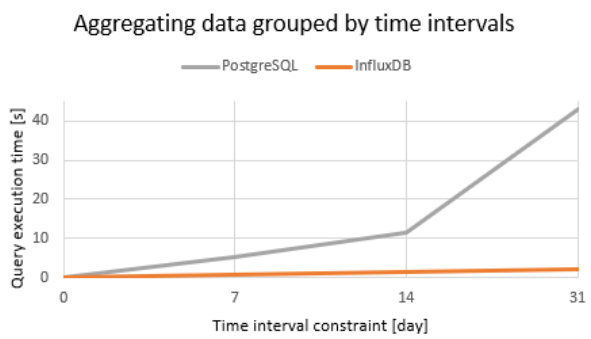


Figure 6. Impact of number of columns on performance

IV. RESULTS AND DISCUSSION

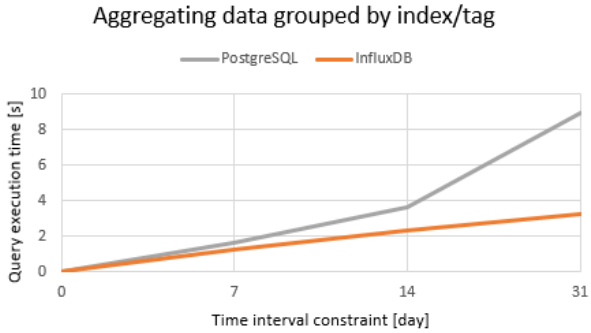
A. *Querying data*

Querying raw, non-aggregated data with a certain time interval constraint from a single column/field is more efficient using the PostgreSQL database as indicated by the shorter execution time. In addition, the InfluxDB database consumes more processor time and memory. Comparison of average query execution time for this case is presented in Fig. 4. The standard deviations for the measured values are relatively small and are therefore



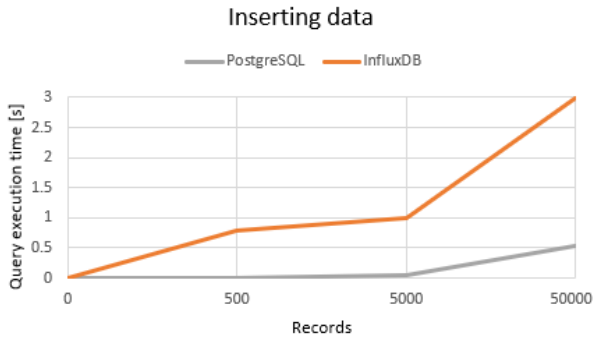
Standard deviation			
DB	7	14	31
PostgreSQL	0.037 s	0.038 s	1.741 s
InfluxDB	0.014 s	0.036 s	0.055 s

Figure 7. Aggregating data grouped by time intervals



	Time interval [day]		
DB	7	14	31
PostgreSQL	0.012 s	0.012 s	0.072 s
InfluxDB	0.004 s	0.018 s	0.033 s

Figure 8. Aggregating data grouped by indexed attribute/tag



Standard deviation			
DB	500	5000	50000
PostgreSQL	0.002 s	0.004 s	0.031 s
InfluxDB	0.024 s	0.014 s	0.070 s

Figure 9. Inserting data

presented in the table below the figure. With a time range of one day to two weeks, query execution time is 83.52%-89.42% shorter in the case of using PostgreSQL database compared to using InfluxDB database. Since the results are not required to be in a particular order (in this case ordered by time), the result is within expectations.

PostgreSQL is fast and well optimized in selecting unordered data.

B. Aggregating data

Aggregating data with a time interval constraint from a single column/field is more efficient using the InfluxDB database due to exhibited shorter execution time. Comparison of average query execution time for this case is presented in Fig. 5 with standard deviations presented below the figure. By increasing the number of queried columns/fields, certain changes in InfluxDB performance occur. With each additional queried field, query execution time rises almost linearly. This effect can be seen in Fig. 6. (data for the experiment having a 2 week time interval is presented). For a smaller number of queried columns, PostgreSQL spends more time on query execution than InfluxDB. However, with an increasing number of queried columns, query execution time increases slower in comparison to InfluxDB and eventually query execution time becomes shorter compared to InfluxDB. With a time range of one week to one month, query execution time is 46.87%-77.62% shorter in case when InfluxDB database is used compared to using PostgreSQL database. This effect shows that PostgreSQL performs better in cases when it is necessary to perform simultaneous aggregation over multiple fields.

C. Aggregating data grouped by time intervals

Aggregating data with a time interval constraint from a single column/field and with result grouping by time interval is more efficient using InfluxDB. Comparison of average query execution time for this case is presented in Fig. 7 with standard deviations presented below the figure. Querying data with the same time interval constraint but with different time grouping (e.g. by day and by week) doesn't significantly affect InfluxDB query execution time but it significantly affects PostgreSQL query execution time. Shorter grouping time interval results in longer PostgreSQL query execution time. With a time range of one week to one month, query execution time is 76.82%-95.30% shorter in the case of using InfluxDB database compared to using PostgreSQL database.

D. Aggregating data grouped by indexed attribute/tag

Aggregating data with a time interval constraint from a single column/field and with result grouping by indexed attribute/tag is more efficient using the InfluxDB database. It is also visible that the execution times are lower in both experiments than it was the case in the previous experiment. Comparison of average query execution time for this case is presented in Fig. 8 with standard deviations presented below the figure. With a time range of one week to one month, query execution time is 24.76%-63.20% shorter in the case of using InfluxDB database compared to using PostgreSQL database.

E. Inserting data

Inserting records/points into a table/measurement is more efficient using the PostgreSQL database due to shorter execution time in the performed experiment, using batch size of 1000. Comparison of average inserting time is presented in Fig. 9 with standard deviations presented below the figure. With a range of five hundred to fifty thousand records/points, inserting time is shorter by 81.90% - 98.45% in case of using PostgreSQL database compared to using InfluxDB database. The main conclusion of this experiment is that writing performance of InfluxDB requires careful consideration and fine-tuning. It is recommended to use larger batches, when applicable, as this can improve the writing performance.

F. System resource monitoring

Selecting values from a PostgreSQL column with a time interval constraint of two weeks resulted in processor utilization maximum increase of 35.43% when compared to the idle state, presented in Fig. 10. The query hasn't significantly affected the memory usage as shown in Fig. 11. Selecting values from an InfluxDB field with the same time interval constraint resulted in a maximum processor utilization increase of 50.69% presented in Fig. 12 and a maximum drop in the available megabytes of 63.21% presented in Fig. 13.

Selecting the average value of a PostgreSQL column with a time interval constraint of one month resulted in processor utilization increase of 60.82% at most compared to the idle state. The query hasn't significantly affected the memory usage. Selecting the average value of an InfluxDB field with the same time interval constraint hasn't significantly affected general system resource consumption.

Selecting the average value of a PostgreSQL column with a time interval constraint of one month and the result grouping by one day resulted in a maximum processor utilization increase of 58.56% and a maximum decrease of the available megabytes of 2.56% when compared to the idle state. Selecting the average value of an InfluxDB field with the same time interval constraint and result grouping hasn't significantly affected general system resource consumption.

Finally, selecting the average value of a PostgreSQL column with the time interval constraint of one month and the result grouping by indexed attribute resulted in a maximum processor utilization increase of 59.89% when compared to the idle state. The query hasn't significantly affected the memory usage. Selecting the average value of an InfluxDB field with the same time interval constraint and result grouping hasn't significantly affected general system resource consumption.

V. CONCLUSION

One of the advantages of using a time-series database InfluxDB over using a relational database PostgreSQL is the shorter time needed to execute aggregation functions over data. Test cases described in Section 4 show that the execution time for the operation of aggregation with time interval constraints is 46.87%-77.62% shorter in the case of using InfluxDB when compared to using PostgreSQL database. Another advantage includes faster result grouping by various time intervals without creating additional indexes as well as result grouping by indexed attributes/tags. In the mentioned test cases, aggregation

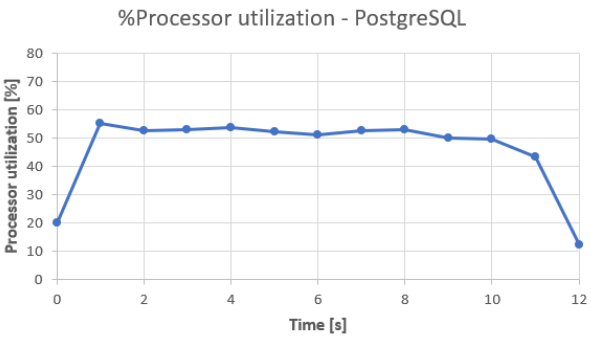


Figure 10. Processor utilization - PostgreSQL

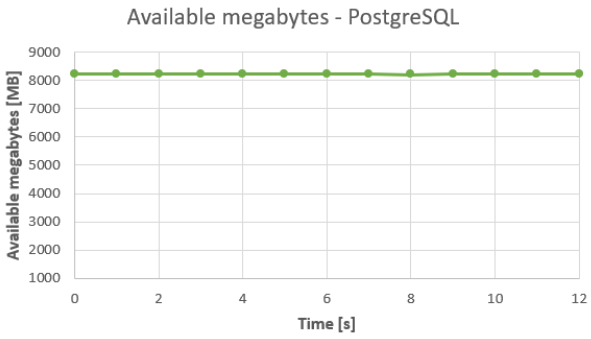


Figure 11. Available megabytes – PostgreSQL

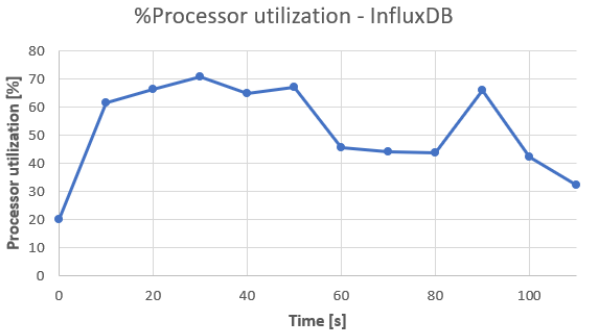


Figure 12. Processor utilization - InfluxDB

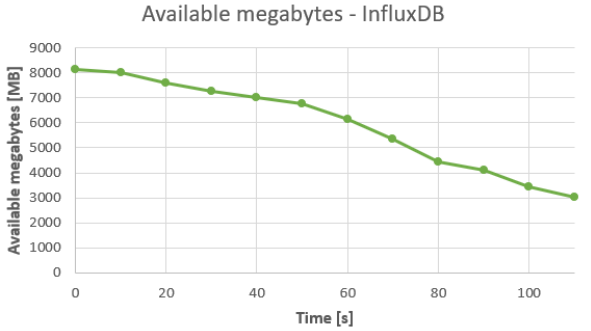


Figure 13. Available megabytes - InfluxDB

execution time with a time interval constraint and result grouping by time interval is 76.82%-95.30% shorter and aggregation execution time with time constraint and result grouping by indexed attribute/tag is 24.76%-63.20% shorter in the case of using InfluxDB compared to the use of the PostgreSQL database. These characteristics represent the main advantages in using time-series databases because massive datasets are mostly useful to users when they are aggregated and grouped.

The disadvantage of using the InfluxDB database lies in slow querying of non-aggregated data. Querying data with a time interval constraint results in an 83.52%-89.42% shorter query execution time in the case of using PostgreSQL compared to using InfluxDB database.

Using time-series databases greatly benefits users whose main concern is processing a large amount of data with time interval constraints in a short amount of time. A large amount of available memory is desirable for optimal InfluxDB database usage.

The future research efforts will focus on checking how the batch size impacts the performance of InfluxDB insertion operations. Additionally, it would be beneficial to explore how the varying data set size impacts the performance of the experiments presented in this paper.

ACKNOWLEDGMENT

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Performance of Common Classifiers on node2vec Network Representations

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Abstract - In this paper we evaluate the performance of different multi-class classifiers on network graphs. Since the node embedding techniques have been widely used to represent and analyze networks structures, we decide to transform network data (nodes and links) into attributes which are descriptive and contain correct information of its structure. For this purpose, we use a *state-of-the-art* algorithmic framework *node2vec*, which has been shown to outperform other popular methods when applied to multi-label classification as it manages to efficiently learn a mapping of nodes to a low-dimensional space of features. Applying this framework, we generate a set of representations for nodes of multiple network data sets. Using the generated representations, we evaluate the performance of common classifiers. We perform cross-validation and parameter tuning to get the best possible model of each classifier type. To compare their performance, we computed Precision, Recall and F1-score for each model on each data set. Following that, the obtained results are analyzed and compared.

I. INTRODUCTION

Networks are a universal language for describing and modeling complex systems in science, nature and technology. Since the data describing these systems has become available, network science researchers have developed various techniques to extract features from complex networks, which then can be used in various applications, such as detecting communities and predicting new friendships in social media or predicting the protein's functional labels. Although they have relied on user-defined heuristics to extract features, in recent years approaches have been devised that automatically learn to encode network structures into embeddings [2]. These network representation learning (NRL) approaches are based on deep learning and nonlinear dimensionality reduction. Introducing such generated features has led to state-of-the-art results in network-based tasks.

A challenging machine learning task in networks is the node classification problem. This problem has been proven to be useful in many real-world applications, especially in social network studies. The fact it requires not only network node attributes, but also the information of the linkage structure, shows it is more complex comparing to traditional classification problems. Additionally, in contrast to traditional classification, the network topology should be considered, as it contains the neighbors label information, which may be important and decisive.

Many techniques have been recently developed to generate representations of network nodes. These can be divided based on presence or absence of the node feature information in generating node embeddings. Techniques that use only network structure for that purpose try to find embeddings of nodes to low-dimensions so that similar nodes in the network have embeddings that are close together. The other group of techniques use both node features and network structure. It generates node embeddings by aggregating neighborhood information, which consist of node attributes and defined distance between nodes.

Since social networks attracts more and more research attention, we develop and analyze a procedure of multi-label classification on node embedding generated on this kind of network, using only the information extracted from the network structure. In our experiment we apply *node2vec* framework to generate node embeddings for Cora, Citeseer and Wiki social networks. The generated node embeddings are used to learn and evaluate common multi-class classifiers: ridge and lasso regression, nearest centroid and support-vector classifier [9]. Their performances are compared using well established measures: Precision, Recall and F1-score. The evaluation results obtained from conducted experiment strongly suggest that embeddings generated by *node2vec* framework can be successfully used as feature vectors for node classification algorithms.

The rest of the paper is organized as follows. Section II presents the related work. The algorithm *node2vec* is briefly described in section III, while the experiment is described in section IV. Obtained results from the experiment are presented in section V. Section VI concludes the paper.

II. RELATED WORK

Typical approaches to unsupervised network feature learning include some form of a network's matrix representation analysis. These methods are akin to dimensionality reduction techniques and are usually based on similar algorithms. Although several methods based on the network's matrix representation analysis were proposed (*e.g.*, Modularity Maximization [3] and TADW

[4]), such approaches do not scale well to larger networks due to the necessary step of matrix factorization.

Both edge modeling and deep learning methods have been proposed as an alternative to matrix factorization based methods. Edge modeling methods aspire to capture the network structure by modelling various probability distributions of vertex to vertex relations. An example is LINE [5], which models both joint and conditional probability distribution of connected vertices to capture the first and second-order proximity representations. These methods are severely restricted in encoding global network structures as they consider only observable vertex connectivity information.

Several unsupervised network representation learning models based on random walks have been proposed in recent years to alleviate this problem. DeepWalk [6] pioneered the approach by viewing random walks through graphs as sentences in a text corpus. DeepWalk applies a text representation learning method to learn generic representations of such walks and assign them to starting vertices. Although DeepWalk showed promising results, *node2vec;* a more flexible solution of exploring node neighborhoods using a biased random walk would prove to be better when applied across a wide range of different networks.

III. NODE2VEC ALGORITHM

In this section we define the *node2vec* algorithm along with the corresponding definitions from [1].

Node2vec is developed at Stanford University by Aditya Grover and Jure Leskovec in 2016. It is an efficient scalable algorithm for feature learning in networks. The algorithm is in accordance with established principles in network science, providing flexibility in discovering representations conforming to different equivalences.

For feature learning in networks in a semi-supervised manner the *node2vec* algorithm optimizes a custom graph-based objective function using SGD. The learned feature representations maximize the likelihood of preserving network neighborhood of nodes in a *d*-dimensional feature space. To generate network neighborhoods for nodes the 2nd order random walk approach is used.

The algorithm can be divided in three phases which are executed sequentially: preprocessing to compute transition probabilities, random walk simulations and optimization using SGD. Each phase is parallelizable and executed asynchronously, contributing to the overall scalability of the algorithm. In the subsections A, B and C the phases are briefly explained.

A. Computing transition probabilities

The first step of the *node2vec* algorithm is choosing an appropriate notion of a neighborhood, which allows learning representations that organize nodes based on their network roles and/or communities they belong to. This is achieved by developing a flexible biased random walk procedure that can explore neighborhoods in a BFS as well as DFS fashion.

They defined a 2nd order random walk with two parameters p and q which guide the walk. Parameter p controls the likelihood of immediately revisiting a node in the walk while parameter q allows the search to differentiate between "inward" and "outward" nodes. Both parameters allow search procedure to interpolate between BFS and DFS. Considering a random walk that just traversed edge (t, v) and now resides at node v, for decision on the next step the transition probabilities π_{vx} on edges (v, x) leading from v are evaluated. The unnormalized transition probability is set to $\pi_{vx} = \alpha_{pq}(t, x) \cdot w_{vx}$, where

$$a_{pq} = \begin{cases} \frac{1}{p} & if \ \ d_{tx} = 0 \\ 1 & if \ \ d_{tx} = 1 \\ \frac{1}{q} & if \ \ d_{tx} = 2 \end{cases} \quad (1)$$

And d_{tx} denotes the shortest path distance between nodes t and x.

B. Simulation of random walks

Random walks provide a convenient mechanism to increase the effective sampling rate by reusing samples across different source nodes. By simulating the walk of length l, where $l > k$, k samples for $l - k$ nodes are generated at once due to the Markovian nature of random walk. Since the representations are learned for all nodes, the random walks of length l are simulated starting from every node. Formally, having the ith node in the walk denoted as c_i and starting with $c_0 = u$, nodes c_i are generated by the following distribution:

$$P(c_i = x | c_{i-1} = v) = \begin{cases} \frac{\pi_{vx}}{Z} & if \ \ (v, x) \in E \\ 0 & otherwise \end{cases} \quad (2)$$

Where π_{vx} is the unnormalized transition probability between nodes u and x, and Z is the normalizing constant.

C. Optimization phase

The *node2vec* algorithm formulates the feature learning in networks as a maximum likelihood optimization problem. To solve this problem the authors extended the Skip-Gram architecture [10] for feature learning by randomized procedure that samples many different neighborhoods of a given source node u.

Formally, for every source node $u \in V$ of a given network $G = (V, E)$ a network neighborhood of node u generated through a neighborhood sampling strategy S, denoted as $N_S(u) \subset V$, is defined. Furthermore, let $f: V \rightarrow \mathbb{R}^d$ be the mapping function from nodes to features representations to be learnt, where *d* represents the number of dimensions of feature representations. To learn features the following objective function, which maximizes the log-probability observing a network neighborhood $N_S(u)$ for a node u conditioned on its feature representation *f*, is optimized:

$$\max_f \sum_{u \in V} \log Pr(N_S(u) | f(u)) \quad (3)$$

By taking the assumptions of the conditional independence of observing neighborhood nodes and symmetry in feature space the optimization problem (3) becomes tractable.

IV. EXPERIMENT

In this section, we describe the experimental setup of evaluating the performance of *node2vec* on network classification tasks using common classifiers.

We choose three networks, undirected unweighted graphs, to evaluate the algorithm on:

1. **Cora** [7], a research paper set containing 2,708 machine learning papers which are categorized into 7 classes. The citation relationships between the papers form the edges of the network.
2. **Citeseer** [8], another research paper set containing 3,312 publications and 4,732 connection between them classified into 6 classes
3. **Wiki** [7], a collection of 2,405 web pages with 17,981 links sorted into 19 categories

All three of the chosen data sets represent forms of social networks with the Wiki data set being a much denser network than Cora or Citeseer.

We learn the embeddings on these data sets using *node2vec* for all pairs of the *p* and *q* in [0.1, 0.25, 0.5, 0.75, 1.0]. During extensive preliminary experiments we found that the following hyperparameter values provide relevant representations across used data sets:

- Number of walks per node is set to 100
- Length of walk per node is set to 10
- Representation dimension is set to 128
- Skip-Gram window size is set to 10

We also found that minor changes of those values do not influence the quality of learned representations. The important difference from the hyperparameter values used in the original work is that, unlike them, we used a large number of short walks.

We choose four types of common classifiers to test the embeddings on:

- Ridge regression – a linear regression classifier with L2 regularization
- Nearest centroid classifier – a classification model that assigns labels to unseen data by determining the class of the closest centroid of seen data
- Lasso regression – a linear classifier that models the probability of a class label using L1 regularization
- Support-vector classifier – a non-probabilistic classifier based on support-vector machines with the goal of maximizing the width of the margin while keeping accuracy at a high level

We further examine the performance of the support-vector classifier using both a linear and a *rbf* kernel. For the *rbf* kernel of SV Classifier the gamma hyperparameter was chosen as the inverse of the number of dimensions of feature vectors, which is 128 in our setup.

Since the classification task is a multi-class problem, ridge regression and SVCs were trained using one-vs-rest strategy (OVR). The lasso regression classifier was trained using both one-vs-rest and multinomial multi-class strategies. The nearest centroid classifier is inherently a multi-class classifier.

For all classifiers we performed a 10-fold cross-validation of the regularization parameter for values in [0.01, 0.15, 0.25, 0.5, 2, 4] while using 50% of the data set for that purpose. The model is trained ten times, every time on a different set of 9 folds and validated on the remaining one. The rest of the data set is then used for testing the models.

For each combination of *node2vec* parameters and each classifier we track the accuracy, precision, recall and F1-scores on the test samples.

The accuracy measure is defined as the percentage of correctly classified samples:

$$Accuracy = \frac{TP+TN}{TP+TN+FN+FP} \tag{4}$$

The precision measure is defined as the percentage of positively classified samples which are ground-truth positive:

$$Precision = \frac{TP}{TP+FP} \tag{5}$$

The recall measure is defined as the percentage of correctly classified positive samples:

$$Recall = \frac{TP}{TP+FN} \tag{6}$$

The F1-score is defined as the harmonic mean of precision and recall:

$$F_1 = \frac{2 \times Precision \times Recall}{Precision + Recall} \tag{7}$$

where TP, FP, TN and FN stand for true positive, false positive, true negative and false negative samples respectively.

Both micro and macro scores were stored for precision, recall and F1-measures. Micro scores are calculated globally by considering all samples from all classes, macro scores are calculated on a per class basis and averaged.

V. RESULTS

In this section, we present and evaluate the results of the experiment on test set. We take the F1-macro score as the main measure of the performance of the classifiers.

We show the *node2vec* parameters as well as the regularization parameters for classifiers of each type that scored the best F1-macro scores for Cora (Table 1), Wiki (Table 2) and Citeseer (Table 3) data sets.

Cora			
Classifier	*p*	*q*	Regularization
Ridge regression	0.75	0.75	0.01
Multinomial lasso regression	0.25	0.25	2.00
Linear SVC	0.75	0.25	2.00
RBF SVC	0.50	0.50	0.15
OVR Lasso regression	0.75	0.25	0.25
Nearest centroid	0.25	0.25	0.15

Table 1 Results on Cora data set for optimal set of parameters

Wiki			
Classifier	*p*	*q*	Regularization
Ridge regression	0.25	1.00	2.00
Multinomial lasso regression	1.00	1.00	0.50
Linear SVC	1.00	0.75	0.50
RBF SVC	0.10	0.50	0.15
OVR Lasso regression	0.10	0.75	0.25
Nearest centroid	0.10	0.75	0.01

Table 2 Results on Wiki data set for optimal set of parameters

Citeseer			
Classifier	*p*	*q*	Regularization
Ridge regression	0.75	0.10	0.50
Multinomial lasso regression	1.00	0.10	0.01
Linear SVC	0.75	0.10	4.00
RBF SVC	0.25	0.10	0.01
OVR Lasso regression	0.75	0.10	0.50
Nearest centroid	0.25	0.10	0.01

Table 3 Results on Citeseer data set for optimal set of parameters

The accuracy and F1-macro scores for the best scoring classifiers of each type on each data set are shown in Table 4 and Table 5 respectively.

Accuracy			
Classifier / Data set	Cora	Wiki	Citeseer
Ridge regression	0.80	0.63	0.57
Multinomial lasso regression	0.82	0.64	0.58
Linear SVC	0.81	0.64	0.58
RBF SVC	0.84	0.67	0.69
OVR Lasso regression	0.82	0.63	0.57
Nearest centroid	0.76	0.57	0.53

Table 4 Accuracy of best performing classifiers across all three data sets

F1-macro			
Classifier / Data set	Cora	Wiki	Citeseer
Ridge regression	0.79	0.44	0.51
Multinomial lasso regression	0.81	0.54	0.52
Linear SVC	0.81	0.54	0.52
RBF SVC	0.83	0.56	0.65
OVR Lasso regression	0.81	0.54	0.52
Nearest centroid	0.74	0.49	0.51

Table 5 F1-macro score of best performing classifiers across all three data sets

As can be seen from measured data, the best performing classifier is the support-vector classifier with an RBF kernel on all data sets. This is not surprising since the RBF SVC is the most complex classifier tested.

The performance difference of the RBF SVC classifier is most notable on Citeseer while on both Wiki and Cora the linear SVC and logistic regression classifiers score similarly. Since RBF SVC is the only non-linear classifier tested, we can conclude that the feature space constructed by *node2vec* on both Cora and Wiki data sets linearly separates the target classes without explicit knowledge of them. The same cannot be said for the Citeseer data set, where the nonlinear nature of RBF SVC gives it a significant advantage.

The classifiers scored high scores across the board on the Cora data set whereas their performance is significantly lower on the Wiki data set. This can be attributed to the larger size and complexity of the Wiki data set.

To further analyze the influence of *node2vec* random walk parameters, we plot the F1-scores of the RBF SVC with respect to *p* and *q* parameters of *node2vec*.

Figures 1 through 3 show the influence of the *q* parameter on the results of the classifier, while Figures 4 through 6 show the same for the *p* parameter. In order to show the influence of a single parameter on classifier performance, we take the average of the scores with respect to the other parameter as the second coordinate of the plotted points.

We can notice easily the difference in quality of the embeddings on the Cora data set compared to Wiki and Citeseer. While varying both *p* and *q* values on Cora leads to the discovery of a local maximum, both Wiki and Citeseer data sets show a tendency towards high *p* values and low *q* values. As high *p* values encourage revisiting of previously seen nodes and high *q* values encourage exploration of deep walks, we can speculate that both the Wiki and the Citeseer data sets show a strong information locality, encoding better embeddings with highly localized walks.

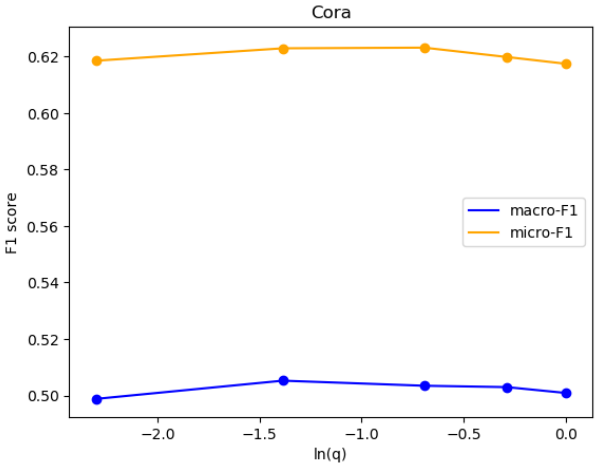

Figure 1 performance of the RBF SVC classifier with relation to *node2vec* parameter *q* on Cora data set

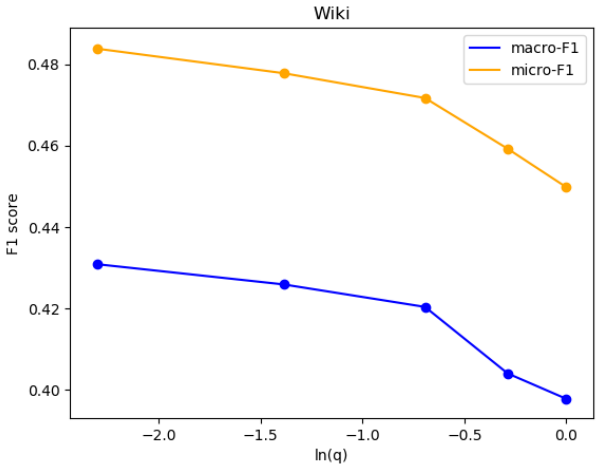

Figure 2 performance of the RBF SVC classifier with relation to *node2vec* parameter *q* on Wiki data set

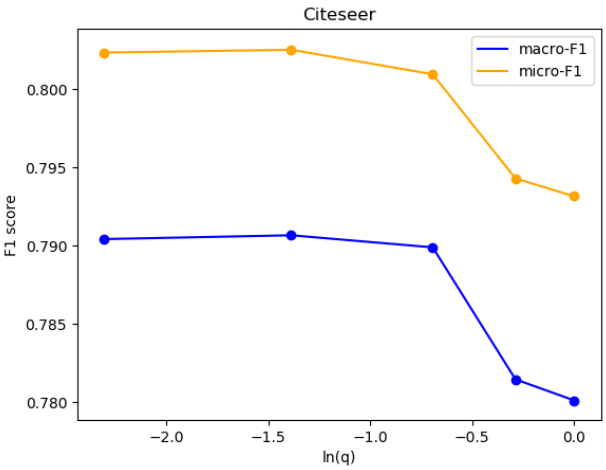

Figure 3 performance of the RBF SVC classifier with relation to *node2vec* parameter *q* on Citeseer data set

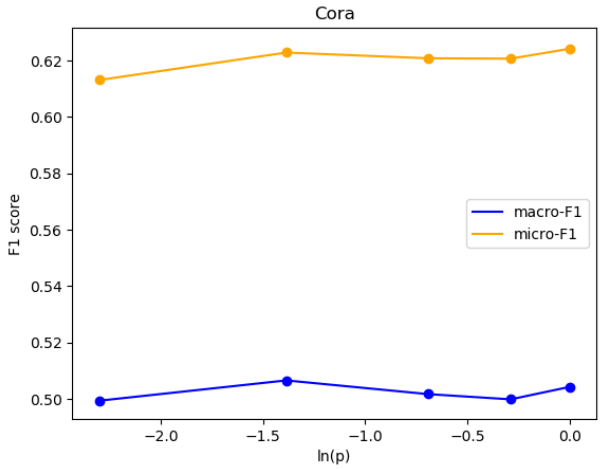

Figure 4 performance of the RBF SVC classifier with relation to *node2vec* parameter *p* on Cora data set

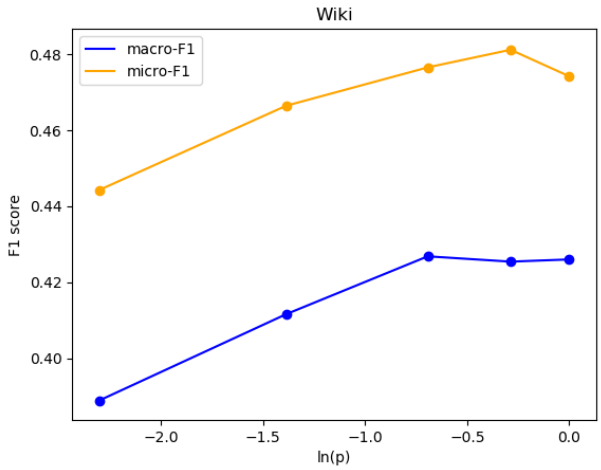

Figure 5 performance of the RBF SVC classifier with relation to *node2vec* parameter *p* on Wiki data set

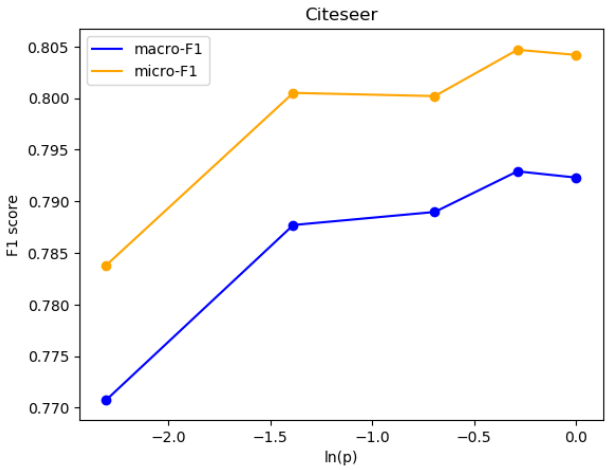

Figure 6 performance of the RBF SVC classifier with relation to *node2vec* parameter *p* on Citeseer data set

VI. Conclusion

In this paper, we studied the performance of common classifiers on network embeddings encoded by *node2vec*. We used four common types of classifiers: ridge classifier, nearest centroid, logistic regression and SVC. We explored the quality of the produced embeddings and the difference between the performance of the different classifiers. We further analyzed the influence of *node2vec* parameters on the results of our best performing classifier – RBF SVC.

To compare the classifiers on a realistic data set, we used freely available social network subset data sets which contain realistic topologies of networks. The used data sets were labeled with multiple classes. We measured the performance of the classifiers using common measures: Precision, Recall and F1-score.

The obtained results were analyzed, and we concluded that the performance of *node2vec* embeddings varies greatly depending on the target network complexity reaching high points of F1-score of 0.83 and low points of 0.56 on the more complex networks. We've also shown how the influence of the random walk parameters of *node2vec* on classifiers' performance can indicate the properties of network relations.

To enforce the given classifiers' results, a detailed statistical analysis could be performed comparing the performance of *node2vec* to a simple baseline approach. Furthermore, an analysis of the influence of all *node2vec* parameters on the classification ability of common classifiers on real-world data sets is left for future work.

Acknowledgments

The authors acknowledge the support of the Croatian Science Foundation for this research through the Reliable Composite Applications Based on Web Services (IP-2018-01-6423) research project. This research has been partly supported by the European Regional Development Fund under the grants KK.01.1.1.01.0009 (DATACROSS) and KK.01.2.1.01.0111 (OperOSS). The Titan X Pascal used for this research was donated by the NVIDIA Corporation.

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Analysis and Synthesis of Fountain Sound

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***Abstract* - Fountains are appealing visual and acoustic additions to outdoor and indoor spaces. By pouring or jetting water, fountains produce pleasant and tranquil sounds of flowing water and water bubbles. The sound of the fountain depends on its water feature style that produces sound with the particular sound level, frequency and temporal envelope characteristics. In this paper, analysis of frequency spectrum and variations in a temporal envelope of the fountain sound are performed. Methods for the synthesis of fountain sound are outlined, including physical modeling synthesis and conventional sampling synthesis using prerecorded sound waveforms.**

Keywords - fountain; sound; analysis; synthesis

I. INTRODUCTION

City fountains are a popular amenity and decoration, pleasant both for eyes and ears. The pleasant flow of water helps mask background noise, separating us from various city noises. During the summer months they even assure some amount of cooling due to water droplets that spread some short distance around the fountain. In this paper fountain sound has been measured and analyzed, and methods for computer synthesis of fountain sound outlined.

II. FOUNTAINS ANALYZED

Sounds of three fountains in Zagreb, Croatia have been analyzed. They are the following:

1. Fountain near NSB (National University Library)

Fountain complex consists of five separate fountains, Fig. 1, controlled by a computer with various programs for different temporal evolutions of waterjets. Every fountain consists of two sections, with 2x26 single jet nozzles, 2x6 nozzles for droplets, 2x4 water cannons, one multi-jet nozzle, rotating head with 5 single jet nozzles and foggers.

2. Fountain at King Tomislav square

This is the fountain with multiple waterjet nozzles, one central and numerous peripheral arranged in two rings (16 + 60) and 4 on the north, east, south and west, Fig. 2. Using computer, temporal evolutions of waterjets are available.

3. Fountain Manduševac

It is the small fountain with a single waterjet nozzle (fizz jet, foam), Fig. 3. Waterjet height is quite low and there is considerable sound coming from water overflowing to drainage. The fountain has historical meaning as it is related to several centuries old water source that was finally in 1987 converted to a fountain as we found it today.



Figure 1. Fountain near NSB



Figure 2. Fountain at King Tomislav square



Figure 3. Fountain at Manduševac

III. MEASUREMENTS AND ANALYSIS IN TEMPORAL AND FREQUENCY DOMAIN

A. Measurement Equipment

Sound was recorded in the evening at 44.1 kHz sampling rate and 16-bit resolution, using Zoom H1 V2 Ultra-Portable Digital Audio Recorder. Sound levels were measured with CEM DR-805 Sound Meter at the edge of fountains. Analysis in temporal and spectral domain has been performed using YMEC - Audio spectrum analyzer software.

B. *Fountain Near NSB*

Waveform, spectrum, spectrogram and envelopes are illustrated in Figs. 4-8 and sound levels in Table I.

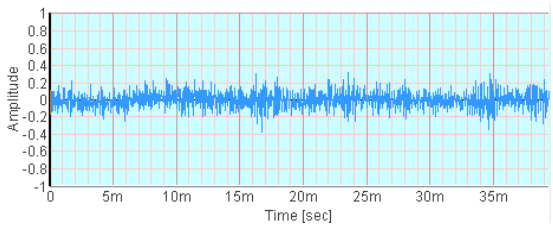

Figure 4. Waveform

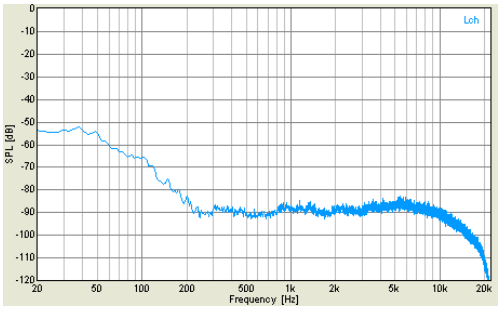

Figure 5. Spectrum (4 s average)

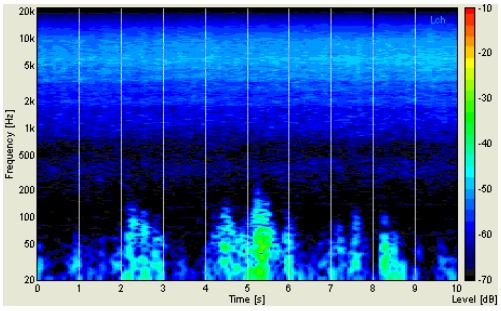

Figure 6. Spectrogram (10 s)

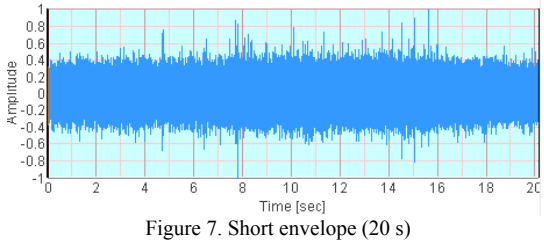

Figure 7. Short envelope (20 s)

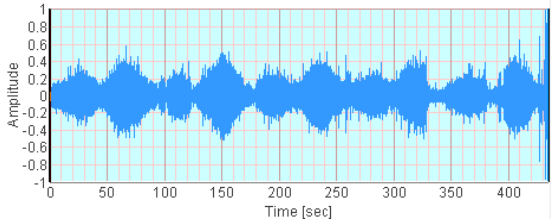

Figure 8. Long envelope (450 s cycle)

TABLE I. SOUND LEVEL dB(A)

Program segment	Max.	Aver.
Low	73,4	72,9
Medium	78,1	77,3
High	86,1	85,2

Amb. aver.: 55.5 dB(A)

(all recordings during the program with single jet nozzles)

C. *Fountain at King Tomislav Square*

Waveform, spectrum, spectrogram and envelopes are illustrated in Figs. 9-13 and sound levels in Table II.

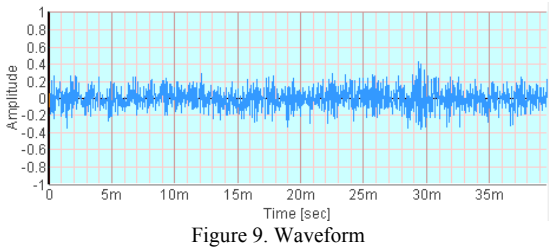

Figure 9. Waveform

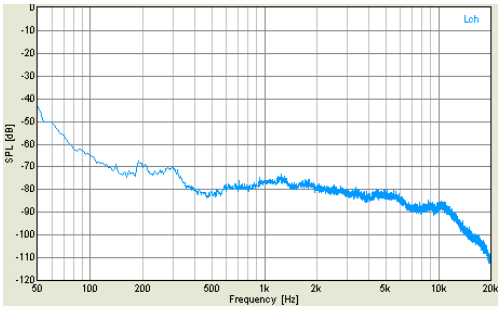

Figure 10. Spectrum (4 s average)

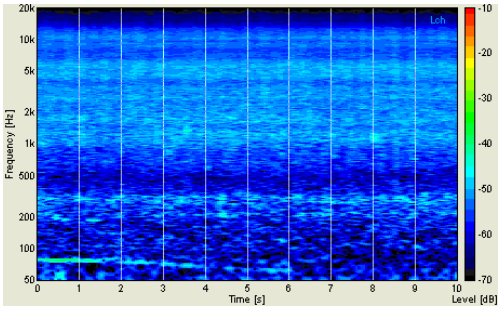

Figure 11. Spectrogram (10 s)

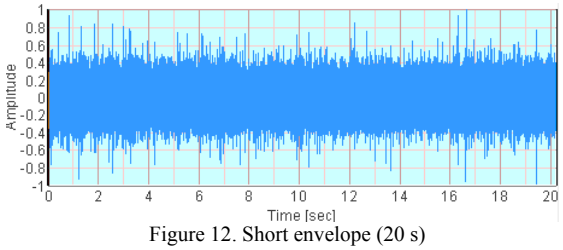

Figure 12. Short envelope (20 s)

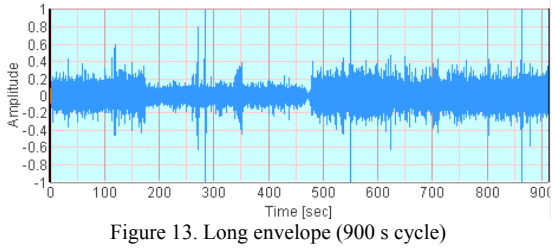

Figure 13. Long envelope (900 s cycle)

TABLE II. SOUND LEVEL dB(A)

Program segment	Max.	Aver.
Low - 1	67,8	67,3
High - central	71,9	70,9
Low - 2	68,1	67,7
High - all	73,5	72,6

Amb. aver.: 49.6 dB(A)

D. *Fountain Manduševac*

Waveform, spectrum, spectrogram and envelopes are illustrated in Figs. 14-18 and sound levels in Table III.

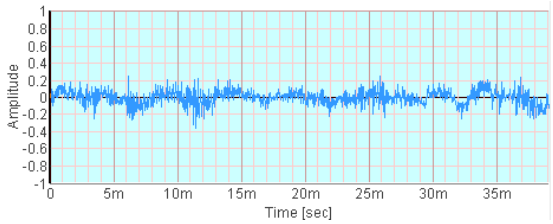

Figure 14. Waveform

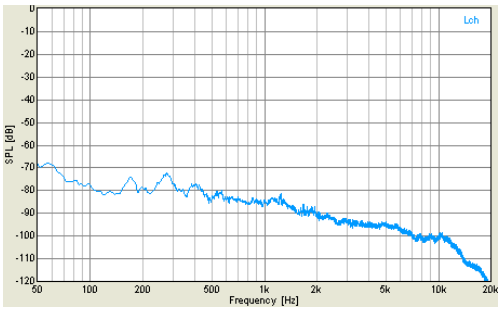

Figure 15. Spectrum (4 s average)

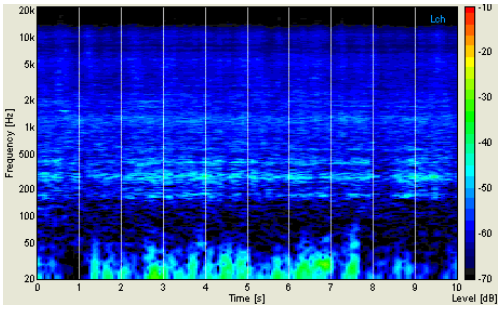

Figure 16. Spectrogram (10 s)

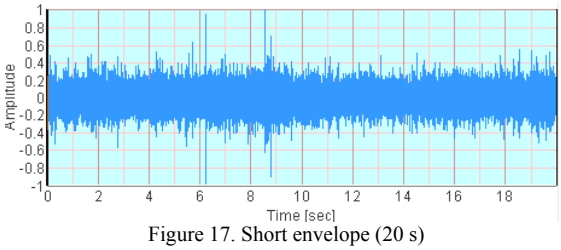

Figure 17. Short envelope (20 s)

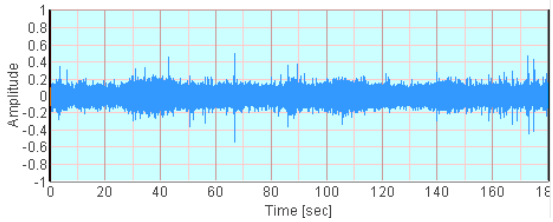

Figure 18. Long envelope (180 s steady)

TABLE III. SOUND LEVEL dB(A)

Program segment	Max.	Aver.
Steady	69,2	68,6

Amb. aver.: 57.0 dB(A)

E. *Similarities and Differences*

Despite various fountains, waveform, and spectrum are to an extent similar. They resemble the noise waveform and spectrum. First and second fountain have considerable energy in low frequency part of the spectrum (below 500 Hz). Recordings were performed in the evening, from 20:00 - 22:00, with no significant traffic to influence this part of the spectrum. There is a severe decline after 10 kHz in all cases. Mid part of the first fountain resembles a white noise, and of second and third fountain pink (1/*f*) noise. Measured sound levels are from 70-85 dBA, with higher values for larger fountains. Differences exist in a long term envelope due to different programs for water temporal evolutions controlled by a fountain dedicated computer. Two fountains have numerous programs (near NSB and at King Tomislav square), while one has constant, steady flow (Manduševac).

IV. PHYSICAL MODELING

Physical modeling of fountain sound is based on physical processes that correspond to water movements in a fountain. This is a quite complex subject [1-5] and in this section, there is just a brief overview of some methods used. Methods may be quite computationally intensive and are interesting primarily from a theoretical perspective.

A. *Sources of Fountain Sound*

The main sources of fountain sound are:

- water drop to the water
- water drop to the surface
- babbling due to the cavitation
- mixing of waterjets
- water overflowing the basin
- water drainage from the basin

A water drop falling in the water is shown in Fig. 19 and water drop splash after hitting the hard surface in Fig. 20.



Figure 19. Water drop falling in the water (Al Sampang, Pixabay)

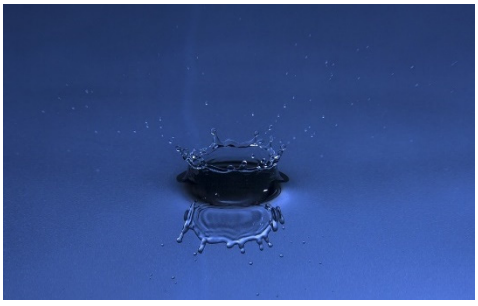

Figure 20. Water drop splash to a hard surface (Al Sampang, Pixabay)

B. *Physical Modeling Using Models from Fluid Dynamics*

The method illustrated in the Fig. 21, according to [1], uses a fluid simulator. At each time step it needs information about the fluid surface geometry, with bubble correspondences between these time steps. Using geometry information bubble's frequencies and transfer magnitudes are computed and used for the synthesis of bubble's sound.

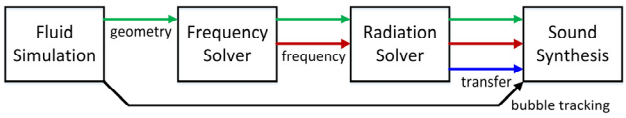

Figure 21. Bubble sound synthesis using fluid simulator

Five types of bubble actions between the time steps are shown in Fig. 22, according to [1].

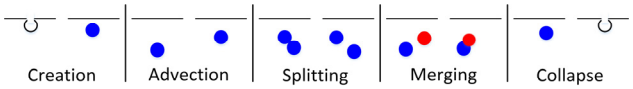

Figure 22. Types of bubble actions between time steps

C. *Water Drop to Hard and Water Surface*

There exist other approaches concerning the synthetic generation for simulating water drops. A single water drop to a hard surface in time domain is illustrated in Fig. 23a and drop to the water surface in Fig. 23b, in line with [2]. The difference is in single acoustic pulse and several pulses that fade out over the time. When water drops onto a hard surface, there is no additional oscillatory contribution after the main sound pulse.

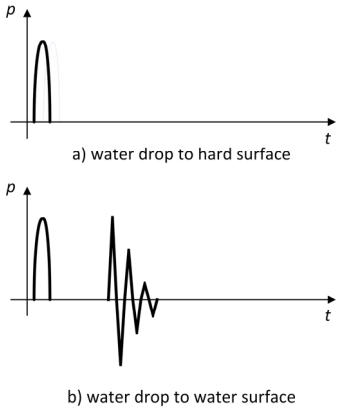

Figure 23. Single water droplet falls on hard and water surface

D. *Extension to Large Number of Droplets*

Naturally, one water drop is not enough; there is a need for numerous water droplets for realistic simulation. As fountains have water basins, water drops to the water surface should be simulated with thousands of water drops. To achieve more natural sound, water drops can be distributed in time and amplitude (caused by drop sizes) by randomization, Fig. 24, according to [2].

While physical modeling is of value for theoretical considerations, it is far easier to achieve good synthesis of fountain sound with the application of sampling synthesis.

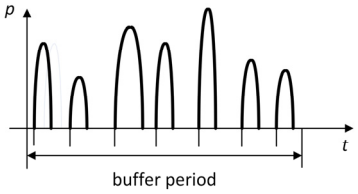

Figure 24. Water drops distributed by randomization

V. SAMPLING SYNTHESIS

The main advantage of sampling synthesis in comparison with physical modelling synthesis is that it doesn't require detailed understanding of physical processes that generate sound and that required processing power is much lower. Very details of sound models are now contained in stored waveforms without the need for extensive real-time calculations [6-8].

A. *Waveform Synthesis*

Waveform synthesis requires a fairly high sample rate, depending on the required frequency range of the output signal. E.g., 44.1 kHz can be used if 0 - 20 kHz (22 kHz) frequency range is required. Fountain sound is nonperiodic and to the extent nonstationary. Due to this fact, synthesis is different from simple repeating of a waveform corresponding to one period of the signal. Seed waveform is sampled fountain sound instead of the fundamental waveform, as in periodic signals. Samples from a wavetable are repeated in a loop, (1), (2):

$$x_{sw}(t) = s[t \bmod L_s] \tag{1}$$

$$\boldsymbol{s} = [s_0, s_1, \ldots, s_{L_s-1}] \tag{2}$$

where is

$x_{sw}(t)$ sampled waveform
s_i waveform samples stored in a table $\boldsymbol{s}$
L_s number of samples in a waveform table $\boldsymbol{s}$

To capture only spectral variations in fountain sound it is necessary to choose a longer period, but with a steady or compressed level dynamics. Signal level dynamics is later incorporated in envelopes. By listening, it was determined that optimal wav sequence should be about 2 s. For shorter sequences (0.5 s and 1 s) one can hear repeating signal when looping (noise doesn't have silences points), that is much harder to detect with 2 s sound loop. Otherwise, pronounced discontinuities are present at frequency f_l, (3):

$$f_l = \frac{f_{sw}}{L_s} \tag{3}$$

where is

f_{sw} sampling rate for waveform
f_l frequency of looping discontinuities
L_s number of samples in a waveform table

At a waveform sequence of length of 2 s produces this frequency at very low 0.5 Hz, and such discontinuities are not pronounced.

B. *Envelope Synthesis*

Changes in envelope (signal level dynamics) can be coded width much lower sampling rate, e.g., 10 Hz would suffice due to slow changes in an envelope of a fountain

sound signal. As envelope is coded with much less data, 20 s can be used for a duration of short envelope. Short RMS (Root Mean Square) envelope samples are given by (4):

$$s_{se}(k) = \sqrt{\frac{1}{K_1}\sum_{t=kK_1}^{t=(k+1)K_1-1} x_s^2(t)} \quad (4)$$

where is

x_s signal samples
s_{es} short envelope samples
K_1 ratio of signal and short envelope sampling rate

Short envelope is formed from short envelope table, (5):

$$x_{se}(t) = s_{se}[(t\ div\ K_1)\ mod\ L_{se}] \quad (5)$$

where is

x_{se} short envelope samples
L_{se} number of short envelope samples in a table

Modulating the waveform is achieved by multiplying the output of waveform loop with the output of envelope loop.

C. *Waterjet Temporal Evolution* Programs

Long envelope is caused by changing waterjet heights provided by a dedicated fountain computer that generates various temporal evolutions of waterjets. Few waterjet programs (also called sequence patterns), regarding waterjet height evolution through the time, are shown in Fig. 25.

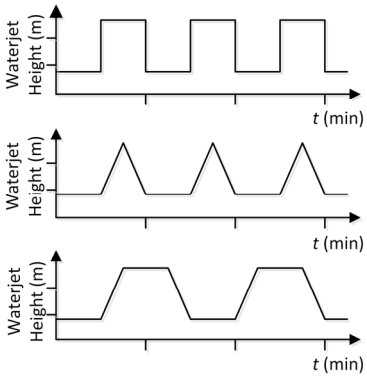

Figure 25. Few simple examples of water programs

Waterjets temporal evolution programs can be sampled with sample rate lower than an envelope during steady state of fountain noise. Sampling rates of 1-2 Hz are sufficient. Long RMS envelope (e.g., 180 s = 3 min) is given by (6):

$$s_{le}(k) = \sqrt{\frac{1}{K_2}\sum_{t=kK_2}^{t=(k+1)K_2-1} x_s^2(t)} \quad (6)$$

where is

x_s signal samples
s_{le} long envelope samples
K_2 ratio of signal and long envelope sampling rate

Long envelope is formed from long envelope table, (7):

$$x_{le}(t) = s_{le}[(t\ div\ K_2\ )\ mod\ L_{le}] \quad (7)$$

where is

x_{es} long envelope samples
L_{le} number of long envelope samples in a table

Sampling rates are summarized in Table IV.

TABLE IV. SAMPLE RATES AND RATIOS FOR VARIOUS ELEMENTS

Element	Sample rate [Hz]	Ratio to waveform sample rate
Waveform	44100	1
Short envelope	10	$K_1 = 4410$
Long envelope	2	$K_2 = 22050$

Overall synthesis is shown in Fig. 26.

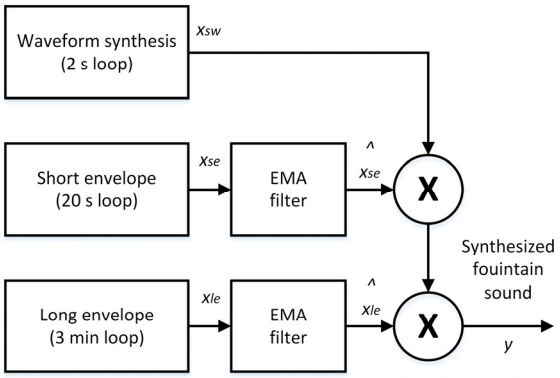

Figure 26. Sampling based synthesis of fountain sound

Exponential Moving Average (EMA) is placed after each envelope generator. It acts as a low-pass filter that smooths out transitions between samples, looping discontinuities and filters out spurious spikes that may be present in recorded envelopes. EMA gives more weight to the most recent data points and is defined by (8):

$$s_t = \alpha x_t + (1-\alpha)s_{t-1} \quad (8)$$

where is

x_t signal to be smoothed at time instance t
s_t value of the EMA at time instance t
α smoothing factor

The time constant τ of EMA is the time for the smoothed response to the unit step function to reach ≈ 63.2% of the signal. The relationship between the smoothing factor α, sampling time interval ΔT and time constant τ, under assumption $\Delta T << \tau$ is given by (9):

$$\alpha = \frac{\Delta T}{\tau} \quad (9)$$

The synthesized signal is given by (10) as a product of waveform synthesis, EMA smoothed short envelope synthesis and EMA smoothed long envelope synthesis.

$$y(t) = x_{sw}(t)\hat{x}_{se}(t)\hat{x}_{le}(t) \quad (10)$$

D. White and Colored Noise Excitation

Instead of using sampled waveform, the next level of abstraction is substituting waveform with noise generator, as one presented in [9]. From spectrums of recorded fountain sounds, pink noise seems to be the most appropriate. The spectral power density of pink noise decreases by 3 dB per octave (proportional to 1/f). The difference between white and pink noise is illustrated in Fig. 27. White noise can be produced as a stream of uncorrelated random numbers. For the range [-1,1] and uniform random variable $X \sim U([0,1])$, white noise is generated according to (11) [9-11]:

$$x_{white}(t) = 2X - 1 \quad (11)$$

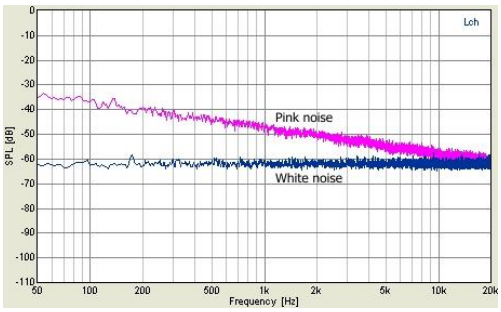

Figure 27. White vs. pink noise spectrum

Pink noise can be achieved with acceptable quality by filtering the white noise using the Paul Kellet's "economy" method (that approximates a 10 dB/decade filter) [10,11]. Equations (12)-(15) are repeated in a loop $t = 0, 1, 2, \ldots$ for each new sample, $x_{white}(t)$ producing $x_{pink}(t)$, initial values $b_0(0)$, $b_1(0)$ and $b_2(0)$ are set to 0, according to [10,11]:

$$b_0(t+1) = 0.99765\, b_0(t) + 0.0990460\, x_{white}(t) \quad (12)$$

$$b_1(t+1) = 0.96300\, b_1(t) + 0.2965164\, x_{white}(t) \quad (13)$$

$$b_2(t+1) = 0.57000\, b_2(t) + 1.0526913\, x_{white}(t) \quad (14)$$

$$x_{pink}(t) = b_0(t) + b_1(t) + b_2(t) + 0.1848\, x_{white}(t) \quad (15)$$

Overall synthesis is shown in Fig. 28 and is given by (16):

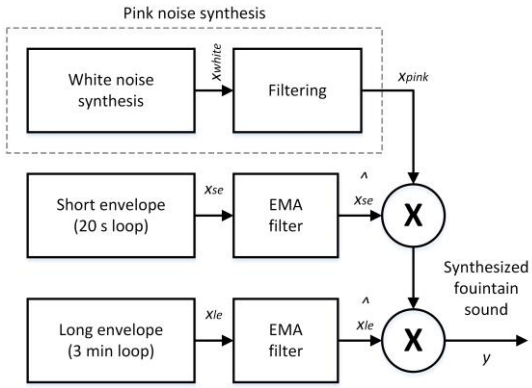

Figure 28. Pink noise based synthesis of fountain sound

$$y(t) = x_{pink}(t)\hat{x}_{se}(t)\hat{x}_{le}(t) \quad (16)$$

The audio results are much less realistic fountain sound than with waveform synthesis, yet still could be used with visual cues like a screensaver.

Synthesized fountain sound using waveform synthesis is shown in Fig. 29 and using pink noise in Fig. 30. In waveform synthesis can be noted 2 s waveform loops. Pink noise synthesis shows less structure in the signal because pink noise is produced continuously and not in 2 s loop.

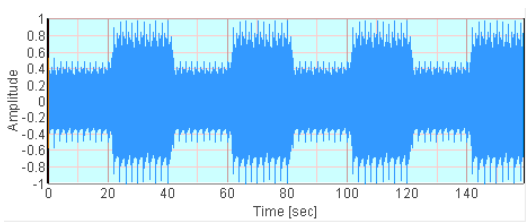

Figure 29. Fountain sound using modulated waveform synthesized signal

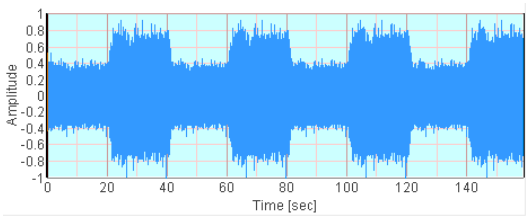

Figure 30. Fountain sound using modulated pink noise signal

Overall, pink noise excitation seemed to be an interesting approach, but the results in terms of subjective listening were not satisfactory, due to missing water bubbling sounds coming from the fountain water basin and the use of stationary pink noise spectrum.

VI. Conclusion

Fountains are beautiful additions to urban sceneries. They differ in shape and number, size and variety of waterjets nozzles; however, their sound spectrum has many similarities. Sound spectrum is continuous with no discrete components, has considerable energy at low frequencies below 500 Hz, mid frequency part of fountain sound resembles white or pink noise and there is a significant decline after 10 kHz. The sound level at the edge of fountains is considerable and is about 75-85 dBA. This makes conversation with normal voice difficult, but also provides nice masking sound assuring speech privacy. Two main methods of water sound synthesis are mentioned: physical modeling and sampling synthesis. Sampling synthesis was considered in more detail. System for fountain sound synthesis that considers waveform, short and long envelope changes is presented. Instead of sampled waveform, filtered white noise (e.g., pink noise) can be used for further simplification, but with much less sound realism.

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Detecting Aircraft Piston Engine Problems by Analysis of Engine Parameters

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***Abstract* - The majority of general aviation aircrafts use piston engines that are considerably less reliable than turbine engines. Most problems of aircraft piston engines are reflected in engine temperature parameters like cylinder head temperature (CHT) and exhaust gas temperature (EGT) that are recorded by engine monitor. Three approaches for detection of engine problems are presented. Many problems may be detected by comparison of statistical distributions of CHTs and EGTs from individual cylinders. Incipient exhaust valve failure may be detected from temporal EGT pattern containing low frequency fluctuations. The life of the exhaust valve depends on its operating temperature. Because EGT is the major contributor to the overheating of the exhaust valve and its cooling mostly depends on the CHT, the remaining life of exhaust valve may be assessed from cumulative sum of EGT and CHT during the period of use.**

Keywords - aircraft; piston engine; engine monitor; fault detection

I. INTRODUCTION

General aviation aircraft four or six-cylinder, direct-drive or in some cases geared, horizontally opposed, air-cooled, carbureted or injected piston aircraft engines. These are mostly four stroke engines that use aviation gasoline called Avgas and are built based on old proven technology, still use magnets, with no electronic control and ignition used. Such engines consist of a significant number of parts. During engine operations explosive combustion process is happening in individual cylinders. Linear movement of pistons in cylinders back and forth also needs to be converted into a rotational motion [1]. Piston engines are significantly (several times) less reliable than turbine counterparts, but are still used in most general aviation aircrafts because turbines are generally too powerful, burn a lot of fuel and have very expensive maintenance and overhauls. They fit well within the required power output range, fuel consumption and maintenance costs. The six-cylinder Continental piston engine, IO-550-B, is shown in Fig. 1. The engine can be considered as a collection of multiple single cylinder engines that share some common components for the whole engine, like a block, oil sump, crankshaft, carburetor, part of fuel injection system, part of the exhaust system, turbocharger, engine accessories etc. Cylinders are of the same dimensions, pistons of the same mass and dimensions (all with marginal differences) and are fed by common engine elements. In that way, one can expect that during engine operation, individual cylinders would exhibit similar characteristics in terms of cylinder head temperature (CHT) and exhaust gas temperature (EGT).



Figure 1. Six-cylinder Continental IO-550-B engine

II. ENGINE MONITOR

An engine monitor is an advanced instrument that monitors numerous parameters of an engine [2-5], primarily CHT and EGT for each individual cylinder. Turbine inlet temperature (TIT) is also included in case of turbocharged engines. Some additional parameters may be also included as the fuel flow FF, engine rotational speed (revolutions per minute, RPM), outside air temperature OAT and some derived parameters as an EGT span, CHT cooling rate, and calculated % of HP. Monitoring is based on the notion that irregularities in the engine combustion process indicative of most engine problems should be quickly reflected in CHTs and EGTs. Data are displayed simultaneously in the form of a bar graph with a full bar height denoting EGT and a missing bar CHT, Fig. 2. It gives a clear and concise picture of engine temperatures suitable for a quick scan and interpretation with the use of catalogued patterns (various engine problems are reflected in specific bar patterns that are usually catalogued in a manual accompanying an engine monitor) [3-5]. Nice video tutorials are given in [6]. Versions for twin engine aircrafts also exist. Measured engine parameters are also logged for later download and analysis by the corresponding visualization software, like EzTrends [7]. Engine parameters that are most often monitored by various engine monitors are listed in Table I.



Figure 2. Engine monitor JPI 700 (modified from JP Instruments)

TABLE I. MONITORED ENGINE PARAMETERS

Parameter	Description
EGT	Exhaust Gas Temperature
CHT	Cylinder Head temperature
OIL TEMP	Oil Temperature [1]
OIL PRES	Oil Pressure [1]
TIT1	Turbine Inlet Temperature 1[1]
TIT2	Turbine Inlet Temperature 2 [1]
OAT	Outside Air Temperature
CDT	Compressor Discharge Temperature [1]
IAT	Intercooler Air Temperature [1]
CRB	Carburetor Air Temperature [1]
CDT - IAT	Intercooler cooling
RPM	Rotations Per Minute
MAP	Manifold Pressure
%HP	% Horse Power
CLD	CHT cooling rate [2]
DIF	EGT span [3]
FF	Fuel Flow [1]

[1]optional, [2]fastest cooling cylinder, [3]difference between the hottest and coolest EGT

III. STATISTICAL DISTRIBUTION OF TEMPERATURES AMONG CYLINDERS

As already mentioned, piston engine can be comprehended as a collection of simple single cylinder engines that share some common elements. If an engine is operating correctly, there should be uniformity between cylinder CHTs, EGTs, and if an engine with two turbochargers is used, between TITs, Fig. 3 [8].

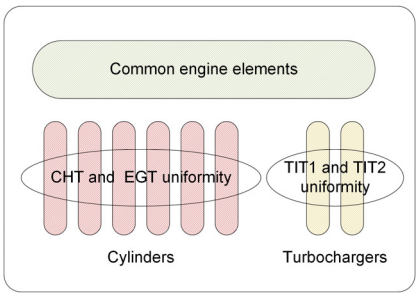

Figure 3. Uniformity of temperatures among separate elements of an engine

Deviation from temperature uniformity between cylinders (and turbochargers if exist) is related to many engine problems and as such can be used for fault detection. This, however, can't capture problems in common engine elements.

One common approach for displaying CHTs and EGTs of an engine is the flight summary, Fig. 4. Flight summary is a simple description of engine parameters collected during one whole flight presented by EzTrends software. It shows minimum, maximum, and average values of important engine parameters. Temperature asymmetries can be easily spotted in red and blue curve in Fig. 4 showing minimum and maximum CHT temperatures. However, this approach is missing finer details of statistical distribution. More informative description of engine parameters during one whole flight can be represented in the form of histograms, showing underlying frequency distribution (shape) of a set consisting of engine parameter data [9], that can be calculated by some statistical software from engine parameters downloaded from engine monitor.

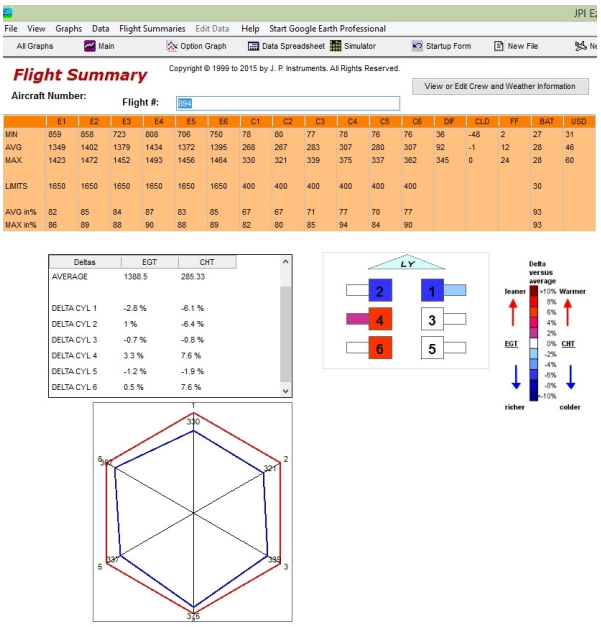

Figure 4. Flight summary showing basic statistic of CHTs and EGTs

CHT and EGT histograms reflect deviations from usual statistical distributions due to some of engine problems. If it is assumed that the probability of all cylinders exhibiting same statistical deviations is very low (would assume multiple cylinder failures at the same time) then comparing statistical histograms between individual cylinders may help to detect a large class o engine problems.

Long term histograms for CHT and EGT, from one cylinder, are shown in Fig. 5 and Fig. 6. These histograms relate to data downloaded after the whole flight. Short term histograms relate to a shorter period (e.g., 10 min) enabling to capture changes in CHT and EGT statistic much quicker. Corresponding histograms for CHT and EGT are shown in Fig. 7 and Fig. 8. Bin sizes are 10 for CHT and 20 for EGT.

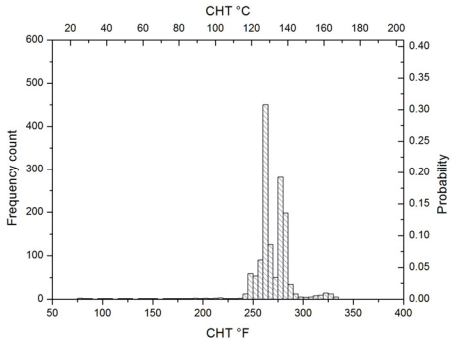

Figure 5. CHT histogram – whole flight

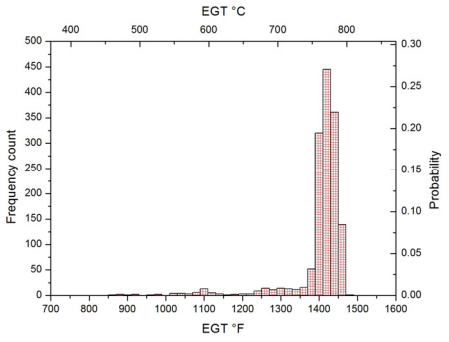

Figure 6. EGT histogram – whole flight

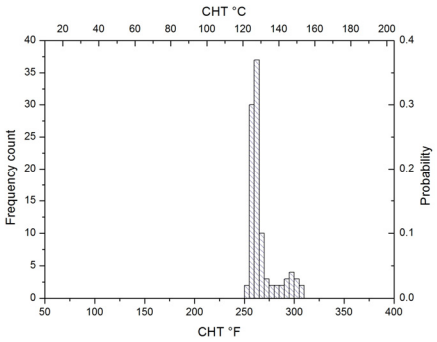

Figure 7. CHT histogram – 10 min section

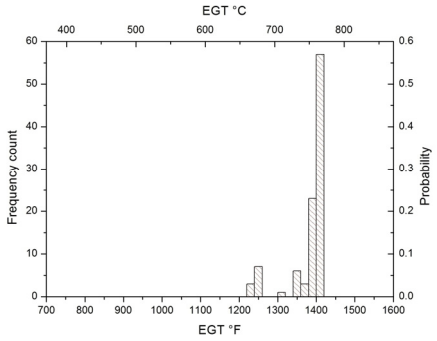

Figure 8. EGT histogram – 10 min section

When comparing two empirical statistical distributions, a useful approach is to apply Kolmogorov-Smirnov, or K-S test. Cumulative distributions are used for comparison instead of discrete probability density functions. For a discrete random variable with probability density function $p(x)$, the cumulative distribution can be determined by (1):

$$C(x) = P(X \leq x) = \sum_{x_i \leq x} P(X = x_i) = \sum_{x_i \leq x} p(x_i) \quad (1)$$

With two statistical distributions $p_1(x)$ and $p_2(x)$, and cumulative distributions, $C_1(x)$ and $C_2(x)$, K-S statistic determines the maximum of the absolute magnitude of the deviation between cumulative distributions, Fig. 9, (2):

$$d \equiv \sup_x |C_1(x) - C_2(x)| \quad (2)$$

The maximum is determined over x and it falls into an interval [0,1]. The null hypothesis is rejected at level α when (3) is satisfied:

$$d > c(\alpha)\sqrt{\frac{n+m}{nm}} \quad (3)$$

where n and m are sizes of first and second sample and $c(\alpha)$ is given by (4):

$$c(\alpha) = \sqrt{-\frac{1}{2} ln\alpha} \quad (4)$$

When samples are of the same size (3) changes to (5):

$$d > c(\alpha)\sqrt{\frac{2}{n}} \quad (5)$$

Non-binned probability distributions $p_1(x)$ and $p_2(x)$ are spiky. Also, due to permissible CHT span of ≈ 30-40 °C (50-70 °F) and EGT span of ≈ 40-50 °C (70-90 °F) for fuel injected and ≈65-80 °C (120-150 °F) for carbureted engines [5], there may be sizable shift among these distributions along the x-axis. Such distributions differ too much for application of the K-S test. To alleviate this, new probability

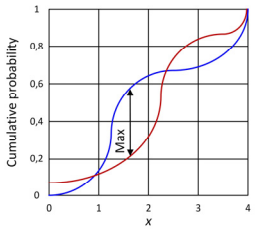

Figure 9. Comparison of two distributions using K-S statistic

distributions $p_{N1}(x)$ and $p_{N2}(x)$ are calculated by adjacent-averaging $p_1(x)$ and $p_2(x)$, (6), (7) with modes m_{N1} and m_{N2} and cumulative distributions $C_{N1}(x)$ and $C_{N2}(x)$. Values for M are set to 12 for CHT and 31 for EGT, due to a different number of points in distributions (350 vs. 900).

$$p_{N1}(x) = \frac{1}{2M+1} \sum_{i=-M}^{i=M} p_1(x+i) \quad (6)$$

$$p_{N2}(x) = \frac{1}{2M+1} \sum_{i=-M}^{i=M} p_2(x+i) \quad (7)$$

To calculate K-S statistic cumulative distributions $C_{N1}(x)$ and $C_{N2}(x)$ are shifted by modes m_{N1} and m_{N2}, (8):

$$d \equiv \sup_x |C_{N1}(x - m_{N1}) - C_{N2}(x - m_{N2})| \quad (8)$$

K-S statistics between six CHT distributions from the six-cylinder, 224 kW (300 hp) Continental engine IO-550-B, for one particular flight are shown in Table II and Fig. 10.

TABLE II. K-S STATISTICS BETWEEN CHT DISTRIBUTIONS

	CHT 1	CHT 2	CHT 3	CHT 4	CHT 5	CHT 6
CHT 1	0	0.01444	0.05714	0.01974	0.02953	0.07035
CHT 2	0.01444	0	0.07005	0.02915	0.04309	0.08252
CHT 3	0.05714	0.07005	0	0.0607	0.02761	0.02649
CHT 4	0.01974	0.02915	0.0607	0	0.04077	0.06668
CHT 5	0.02953	0.04309	0.02761	0.04077	0	0.05258
CHT 6	0.07035	0.08252	0.02649	0.06668	0.05258	0

Flight: #894 Log records: 1463

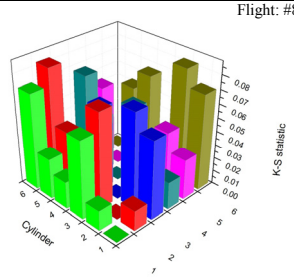

Figure 10. K-S statistics between CHT distributions

Similarly, K-S statistics between six EGT distributions for the same flight are shown in Table III and Fig 11.

TABLE III. K-S STATISTICS BETWEEN EGT DISTRIBUTIONS

	EGT 1	EGT 2	EGT 3	EGT 4	EGT 5	EGT 6
EGT 1	0	0.0634	0.02442	0.05879	0.03739	0.09893
EGT 2	0.0634	0	0.06205	0.08189	0.04818	0.09908
EGT 3	0.02442	0.06205	0	0.04976	0.04397	0.09564
EGT 4	0.05879	0.08189	0.04976	0	0.0786	0.0603
EGT 5	0.03739	0.04818	0.04397	0.0786	0	0.11237
EGT 6	0.09893	0.09908	0.09564	0.0603	0.11237	0

Flight: #894 Log records: 1463

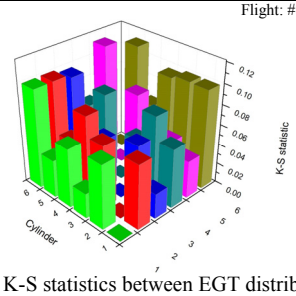

Figure 11. K-S statistics between EGT distributions

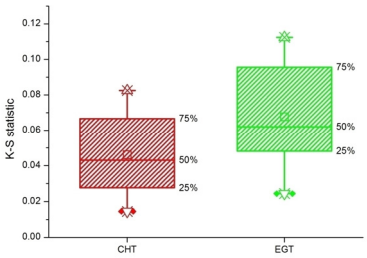

Figure 12. Percentiles of KS-statistics between CHT distributions and between EGT distributions

Distribution of K-S statistics between individual CHT distributions and between individual EGT distributions for the previous flight in form of Box chart is shown in Fig. 12.

IV. Failing Exhaust Valve Temporal Pattern

The exhaust valve is an important element of a piston engine. It seals the cylinder during the compression stroke, providing maximum combustion pressure for achieving maximum engine performance. Most common reason for unscheduled engine maintenance is associated with the exhaust valve problems caused by excessive heat [3]. Burnt exhaust valves are one of the largest repair issues present in an aircraft piston engine.

Exhaust valve problems [10-13] may be detected by conventional means of borescope inspections. Borescope infections may come at large intervals like once a year or so. However use of digital engine monitor may detect many exhaust valves impeding problems right as they develop, not waiting for the next borescope inspection.

Neglecting regular checks of exhaust valves may lead to stuck valves, bent pushrods and partial power loss. This may be quite severe problem in 4-cylinder engines, much less in 6-cylinder engines. In rare occasions exhaust valve failure may lead to piston failure and total power loss.

Intermittent exhaust valve problems may be temporary mitigated by leaning, as operation improves as the engine temperatures rise. However, this is an alarm bell for mandatory maintenance.

Exhaust valve problems are reflected in following two patterns as can be seen on a display of the engine monitor [5]. Pattern illustrated in Fig. 13 corresponds to a stuck valve and in Fig. 14 to a burned exhaust valve.

1. Loss of EGT for one cylinder

The missing EGT bar is indicative of a stuck valve.

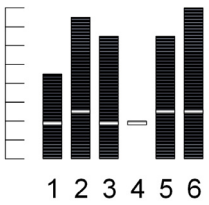

Figure 13. Stuck valve

2. Slow rise in EGT, low CHT

High EGT and low CHT is indicative of a burned exhaust valve.

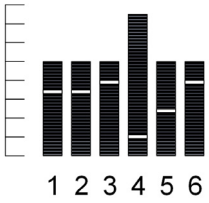

Figure 14. Burned exhaust valve

It is possible to detect incipient exhaust valve failure by analysis of engine monitor data. Most of the time problematic exhaust valve develops a hotspot (another type of problem would be a stuck valve). Incipient exhaust valve failure is preceded by slow, EGT temperature oscillations with a frequency of about one or two cycles per minute and amplitude of ≈ 17 to 33 °C (30 to 60 °F). Valve open and closes some 240 times per minute when engine is running. Slow oscillation in temperature is caused by the fact that the valve rotates about 1 cycle/minute at cruise and developed a hotspot on valve changes its position accordingly [12,14,15]. Such oscillations are difficult to note except if operating engine monitor in normalized view. Exhaust valve problem in development is illustrated in Fig. 15, showing erratic behavior in EGT of the second cylinder, and problem of increased severity, two months later, in Fig. 16, with developed regular oscillations of sizable amplitude. Upper six curves correspond to EGTs, and lower to CHTs.

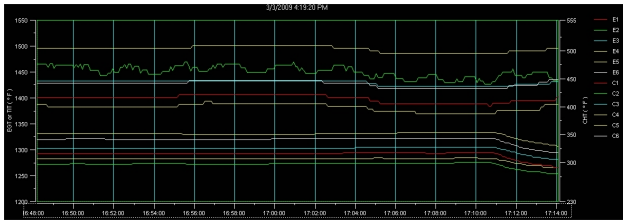

Figure 15. Exhaust valve problem in development

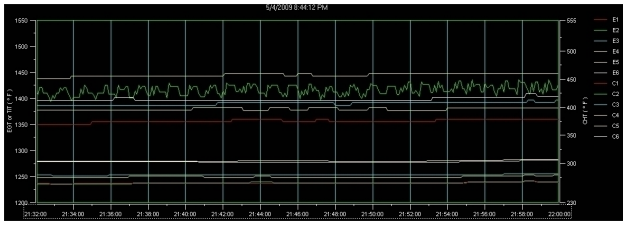

Figure 16. Exhaust valve problem of increased severity

Autocorrelation, is the correlation of a signal with its delayed copy expressed as a function of delay. In case of a discrete signal, the discrete autocorrelation r_x at lag l for a discrete-time signal $x(n)$ is given by (9), P is the max lag.

$$r_x(l) = \frac{1}{N-l}\sum_{N=0}^{N-1-l} x(n)x(n+l) \quad l = 0,1,2,\dots,P \quad (9)$$

It is much easier to calculate than FFT, yet it reveals the oscillations in the signal, [16]. To emphasize variations, but also to follow slower EGT changes, before the calculation, the signal was normalized by subtracting its moving average of previous 50 samples. Example of autocorrelation of EGT of healthy exhaust valve on one short 10 min segment (100 samples) is shown in Fig. 17.

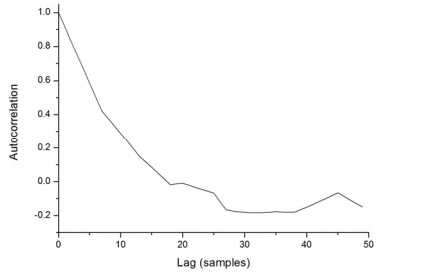

Figure 17. Autocorrelation of EGT of healthy exhaust valve

Example of spiky autocorrelation of EGT indicative of incipient exhaust valve failure, on the same 10 min segment, but from different cylinder, is shown in Fig. 18.

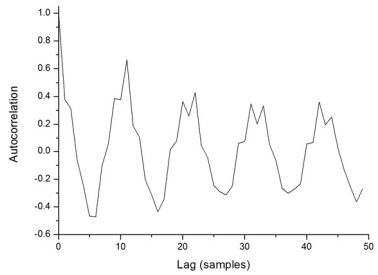

Figure 18. Autocorrelation of EGT of problematic exhaust valve

If the sampling rate of engine parameters is once every six seconds, then for half or one minute cycles there will be a peak in the autocorrelation of signal for the lags of about 5 or 10. This can be used for detection of a problem, by comparison r_x in close proximity Δ with a predetermined threshold L, (10), to find a prominent peak.

$$|r_x(l) - r_x(l \pm \Delta)| > L \qquad l = 8, \ldots, 12 \qquad \Delta = 1 \quad (10)$$

The values of interest for l in (10) are based on sampling engine parameters every six seconds, and one exhaust valve cycle per minute (also encompass two cycles per minute).

V. Cumulative Temperature and Remaining Life of Exhaust Valve

During the power stroke exhaust valves are exposed to high temperatures produced by the combustion. Valves absorb heat through convection and radiation. Although heat is absorbed by valves during the power stroke, the most heat is absorbed during the exhaust stroke. Majority of cooling (75%) of the exhaust valve is achieved through the valve seat face in contact to the seat insert. The rest (about 25%) of the cooling of the exhaust valve is achieved through the valve stem. Exhaust valve, seat, and guide are illustrated in Fig. 19 [3]. If exhaust valves are not seated properly, they are then subjected to severe and uneven heating. This heat can cause exhaust valves to weaken and fail [10-13].

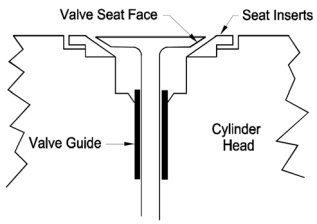

Figure 19. Exhaust valve, seat and guide, adopted from [3]

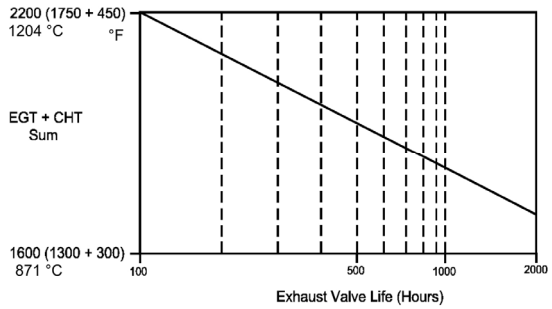

Figure 20. Effects of heat on the life of an exhaust valve, from [3]

The relationship between the expected life of the exhaust valve and the sum of the EGT and CHT of the corresponding cylinder is shown in Fig. 20 [3].

The temperature of an exhaust valve closely follows the EGT temperature. On the other hand, high CHT reduces the ability of cooling of the exhaust valve through the cylinder head. The combination of high EGT and high CHT is hence detrimental to the exhaust valve.

Engine damage generally doesn't happen at once. When operating an engine in a manner that generates excessive heat it may take several months before damage to an engine become so severe to be easily spotted by a pilot. As can be seen from Fig. 20, even a small reduction in the sum of EGT and CHT, that is due to heating and cooling capacity related to valve temperature, results in a marked improvement in valve life and reliability. There exists an empirical guideline that the sum of EGT and CHT should be kept below 982 °C (1800 °F). CHT should be kept below 204 °C (400 °F), preferably 193 °C (380 °F) for Continental engines and 216 °C (420 °F), preferably below 204 °C (400 °F) for Lycoming engines [12]. To assure long exhaust valve life, it is advised to keep CHTs low and exhaust gas clean (by leaning the mixture).

Analytical description of relationship from Fig. 20 may be represented by (11):

$$t_{life} = t_{max} - K log \frac{T_{sum}}{T_{sum,min}} \quad (11)$$

where is:

t_{life}	exhaust valve life under the sum of temperatures EGT and CHT
t_{max}	maximum exhaust valve life
T_{sum}	sum of EGT and CHT
$T_{sum,min}$	minimum sum of EGT and CHT (at t_{max})
K	coefficient of proportionality

The value of t_{max} can be set to engine TBO (Time Between Overhaul) interval. For practical purpose value of $K \approx 17000$, assuming the life of 2000 hours for the EGT+CHT sum of 927 °C (1700 °F).

Cumulative damage can be calculated based on the acquired data of CHT and EGT for a particular cylinder. In a loop that is repeated after each new engine parameters are recorded, the remaining life is decremented according to the time value determined from the sum of EGT and CHT. This can be repeated every six seconds, although slower pace, like minutes, would also suffice. Procedure in the form of pseudocode is listed next:

Remaining life = Maximum life / of a new exhaust valve */*

Loop (every six seconds):

{

Calculate the temperature sum of EGT and CHT

Determine how much of the exhaust valve life is lost at this temperature sum (EGT+CHT) during one loop cycle

Calculate the remaining life by subtracting the above value from the remaining life of the previous iteration

}

VI. Detection of Engine Problems

Engine monitors already have built-in preset limits (available limits vary by model) for the individual engine parameters and the use of limit checkers. When engine parameter p_i leaves assumed range, as in (12), defined by preset lower and upper limits $L_{pi,low}$ and $L_{pi,high}$ for the particular engine parameter, its vertical bar on the engine monitor flashes, indicating parameter exceedance [4,5].

$$L_{p_{i,low}} < p_i < L_{p_{i,high}} \tag{12}$$

Based on three concepts outlined in previous sections more sophisticated detection may be accomplished.

The first one is by comparison of CHT and EGT probability distributions. When K-S statistic between individual distributions exceeds predetermined threshold, it may indicate a potential problem. In that case for some pairs (i, j), one or both of following inequalities should be fulfilled, where N_c is the number of cylinders, (13),(14):

$$d_{CHT_{i,j}} > L_{CHT} \quad i,j = 1, \dots, N_c,\ i \neq j \tag{13}$$

$$d_{EGT_{i,j}} > L_{EGT} \quad i,j = 1, \dots, N_c,\ i \neq j \tag{14}$$

An additional requirement for the cylinder i to be problematic, is that (13) or (14) be fulfilled for a minimum number (e.g., 3) of pairs (i, j). A common value for limits L_{CHT} and L_{EGT} can be determined from K-S test criterion (5). Separate values for L_{CHT} and L_{EGT} could also be determined by analyzing the statistical distribution of K-S statistics between CHT and EGT distributions. Values of 99 percentile or higher determined from numerous flights may be chosen for limits. This approach is much simpler than comparing pattern with all catalogued patterns, however catalogued patterns (if described correctly in terms of rules) would direct to a particular engine problem [17].

Incipient exhaust valve failure pattern may be detected by comparing the autocorrelation function of EGT at legs in the vicinity of one minute position with the predetermined limit L_r, where both (15) and (16) are fulfilled.

$$r_x(l) - r_x(l+1) > L_r \tag{15}$$

$$r_x(l) - r_x(l-1) > L_r \tag{16}$$

Limit L_r can be set to the product of the constant K (e.g., K=0.15) and the autocorrelation value for the lag l, (17).

$$L_r = K r_x(l) \tag{17}$$

Increased risk of exhaust valve failure can be detected by comparing estimated remaining exhaust valve life $t_{life,rem}$ with the predetermined time limit $L_{t_{life}}$ that would warrant service inspection of the exhaust valve, (18). For practical purpose this limit may be set to 100 hours.

$$t_{life,rem} < L_{t_{life}} \tag{18}$$

VII. Conclusion

Piston engines are still the most popular engines used in general aviation aircrafts. They provide adequate power within the required range for such small aircrafts with reasonable fuel consumption and affordable maintenance. However, piston engines are relatively complex with many moving parts and numerous combustion explosions, making them significantly less reliable than turbine engines. Application of engine monitors and correct interpretation of acquired engine parameters may increase operational reliability of piston engines. In this paper, three methods for detection of impending engine failure have been proposed and outlined: use of symmetry (uniformity) among CHT and EGT statistical distributions, existence of low frequency oscillatory EGT temporal pattern that precedes the exhaust valve problem and the cumulative temperature sum of EGT and CHT that has an effect on the life of an exhaust valve and may predict its remaining useful life. Detection methods described here may be easily applied in software used for post flight analysis of downloaded engine logs. Real time application may also be possible in future versions of engine monitors.

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ROBOTICS AND AUTOMATION

Development of the complex modelling system for intelligent control algorithms testing

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***Abstract*—Testing is an essential stage of software and algorithms development, especially in the field of the cooperative control of multi-robot systems, where even one mistake could lead to the whole mission failure. Software-only simulation systems are unable to consider all real-world factors like sensors and motors inaccuracy. We have developed a complex modelling system for the purposes of studying the complex robot behaviour determined by intelligent algorithms. This paper presents basic approaches to general architecture of multi-robot systems, scenarios (missions) formalisation, communication between agents and robot navigation on the scene. The modelling complex is a client-server application, where the server-side allows controlling missions, monitoring and varying parameters of robots and the environment. Also, the application provides the capability for messaging between all participants of a mission, and identifying robots on the scene for navigation and testing purposes. The proposed system makes the development process easier and supports the process of creating reliable control algorithms for multi-robot systems.**

***Index Terms*—Simulation system, multi-robot system, intelligent control, testing, computer vision, control system architecture.**

I. Introduction

Robotics has become widespread in modern society, penetrating practically all spheres of human activity. The cooperative control problems for multi-robot systems are of particular interest, since they have the greatest number of possible applications in real life. At the same time, the development of reliable control systems for robots acting cooperatively in a priory unknown environment is recognised to be a non-trivial problem. Debugging and testing of different control and communication schemes is one of the most important stages of the development that affects the performance of multi-robot systems.

In many cases, conducting full-scale experiments for debugging and testing is accompanied by high financial and time costs. Conducting preliminary tests in a simulation environment can significantly reduce the costs. There are two basic approaches to the problem of testing: software-only simulation and mixed simulation using testbed platforms that incorporates both software and hardware parts.

A large number of software simulators have been developed specifically for multi-robot systems: V-rep, Webots, Gazebo, etc. The survey and comparison of existing systems can be found in [1], [2]. However, software simulators do not fully take into account the conditions of the physical environment, features of sensors and actuators, on-board computer limitations, and other various aspects of the functioning of real robots. In order to get closer to the real conditions of robots, mixed solutions are becoming popular. As a rule, the hardware part of the testbed platform includes simplified, and therefore cheaper, analogues of real robots, and the software part is used to simulate the work of various devices that are missing on the analogues. This allows mobile robots to partially or fully compensate for the absence or impossibility of using some types of sensors by simulating their work.

The mixed platforms may use a centralised architecture [3], in which mobile robots follow the direct instructions of the server according to a pre-calculated algorithm. However, the majority of such systems use fully decentralised approaches [4], [5] or partially decentralised [6], in which the server performs a part of resource-intensive calculations. The proposed testbed platform implies a partially decentralised architecture that allows using low-cost robots without any computing power losses. The main advantage of the system over analogues (e.g. [7]) is a potential ability of conducting multi-objective missions. A multi-objective mission is a set of tasks commonly solved by robots (for example, moving in a defined formation, area exploration, moving some objects from one location to another) that may be made sequentially or simultaneously.

The paper discusses the issues of building a partially distributed testbed platform that implements the mixed simulation approach. The main goal of the project is to create a user-friendly environment for testing and debugging intelligent control algorithms for multi-robot systems developed in our institute. In particular, the issues of organisation and interaction of various levels of the control system, implementation of support services that provide the functioning of the platform, organisation of a communication network, and mission descriptions are considered.

The main feature of the developed testbed platform is that it implements an original architecture of the control system that is aimed at providing effective completion of multi-objective missions, taking into account inhomogeneity of the group and various space-time restrictions. The architecture implies that known effective methods and approaches can be involved

The hierarchical control system architecture for mobile robots has been designed under support of RSF (grant №16-11-00053). The reported study was partially funded by RFBR according to the research project №19-08-00746.

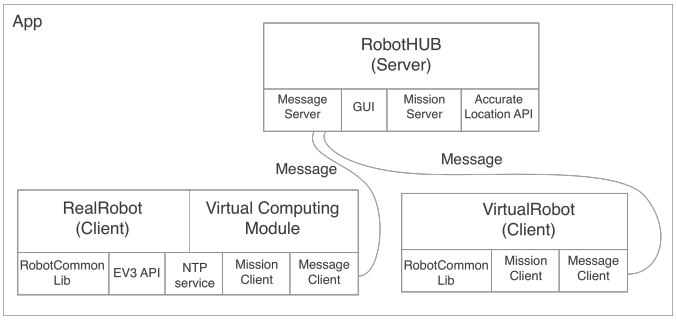


Figure 1: Application design

in solving problems arising at different control levels, from high-level robot action planning to implementation of various modes of operation of robots at the lower level.

The rest of the paper is organised as follows. At the beginning, the architecture of the testbed platform and the robot control system are presented. Next, we discuss the work of various services: messaging service, mission management service, and precise positioning service. Finally, we demonstrate the work of the platform on the example of completing the mission that includes a single task of remote control of a multi-robot formation in a given location.

II. General Architecture of the Simulation System

The simulation system is both a client-server and a distributed system. The server ensures efficient work of client applications, whereas the multi-robot control system in general is distributed, in the sense that decisions within a specific mission are made by agents independently.

The server side of the application includes auxiliary subsystems that are not directly involved in the execution of a mission, such as messaging service, mission management service, and the precise positioning service.

Clients in this case are applications running on real robots, virtual computing modules of real robots, and virtual robots. Real robots are mobile agents that are equipped with a certain set of sensors. Due to the limited computing resources of the selected platform, we decided to use additional applications running on machines with more computing power that would simulate the calculations carried out on board. Virtual robots have the same interaction interfaces as the real ones, but constitute a software solution. It serves to simulate slow-moving or completely static robots that are not equipped with sensors, but have large computing resources.

The interaction between all components of the system is carried out by means of the message service. The whole structure is illustrated by Fig. 1.

The server side is a Java application. This programming language was chosen to provide a unified code base for the server and the clients. Resources used in various services and applications are compiled into a single library (RobotCommonLib).

The application has a modular structure, the main elements of which are presented in this article.

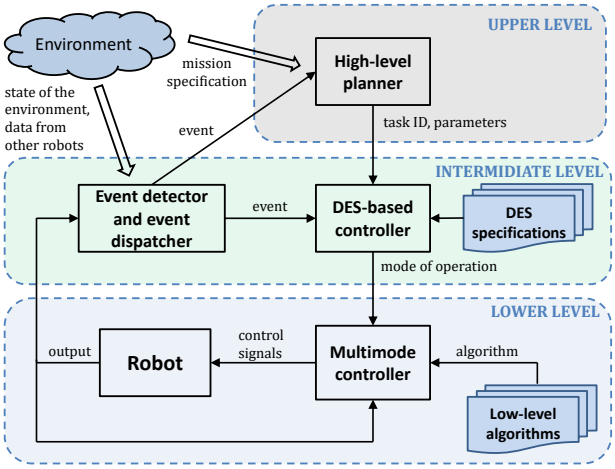


Figure 2: Structure of the three-level control system

III. Control System Architecture

Traditionally, multi-layered control systems are used to control robots acting cooperatively in an unknown environment. In the paper, we exploit a hierarchical control system architecture adopted from [8]. According to the architecture, the control system of a robot includes three levels (see Fig. 2): the upper level for managing tasks, the intermediate level for completing tasks, and the lower level for performing actions.

The main component of the upper-level is a high-level planner, which is responsible for distributing the tasks specified in the group mission among the robots and determining the order of their execution. It is assumed that tasks are characterised by their coordinates, type of operations, and additional parameters that determine how these operations should be carried out. A hybrid evolutionary approach developed in [9], [10] will be used to generate rational plans for the group. It provides a solution to the task allocation and path planning problems for multi-robot systems in dynamic environment, taking into account the wide range of restrictions imposed on the functioning of the group. The approach can be regarded as an any-time one, that is, it is capable to find a feasible solution in a fairly short time. According to the approach, plans are constructed for a certain period of time (planning period) and updated whenever the current planning period ends. To update the data and correct the plans, robots gather in a predetermined area, where communications (direct or indirect) between robots are possible. In order to be able to adjust an individual plan of a robot without coordination, we will employ logical methods based on the calculus of positively-constructed formulas [11]. Upon completion of the planning process, the high-level planner selects the task that must be completed first, and passes it to the intermediate level.

At the intermediate level, a special controller activates a suitable discrete event system (DES) that describes the logic of performing the task in terms of events. The activated DES, based on the observed events occurring due to the changes in the state of the environment and mission status, determines

the mode of operation relevant to the current situation. We exploit a logical DES class that can be modelled by a finite state machine. The Ramadge-Wonham supervisory control theory [12] is involved in the analysis and design of the logical DES. We will actively use a logical approach [13] to formalisation and analysis of this class of systems on the basis of positively-constructed formulas. This approach allows us to define requirements for the behaviour of a DES in a natural form using logic languages and effectively check its various properties using an inference machine. Examples of the application of this approach to analysing various properties of DES can be found in [14], [15].

The core of the lower level is a multi-mode controller that, based on the current mode of operation chosen by the intermediate level, activates a suitable low-level algorithm that implements the elementary behaviour (action) of the robot such as moving into a given location, path-following, leader-following, sending messages. It is worth noting that the lower level is the only one of the three that is hardware-dependent, since only at this level the control system directly affects the robot through actuators in order to perform elementary actions.

IV. Services of the modelling system

A. Messaging service

The service is based on the web socket technology. This technology provides a two-way exchange of textual information between the participants. The advantage of the technology is the use of TCP, which guarantees the integrity of network packages.

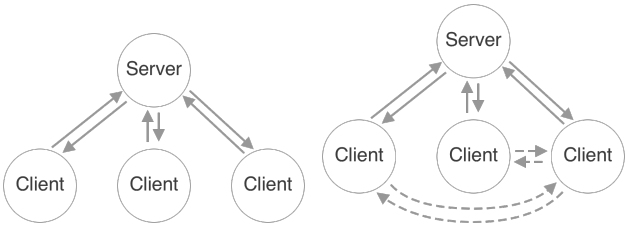
A message in the system is an object with a certain set of fields, which, when transmitted, is serialised into JSON string [16]. This format was chosen due to the low redundancy of service characters. Also, it can be easily read by a person, so it makes the service debugging process easier.

Messaging between clients is carried out through the server application. In this case, the server acts as a proxy, forwarding messages destined for another client based on the recipient's name. A message can also be sent to all clients if the message is marked as broadcasting. If the recipient is the server itself, it processes the message on its own. This approach saves the computing resources of the robot controller, since only one connection is established from the client to the server, and it is not necessary to connect each client to others.

It is assumed that all participants have the ability to send messages to all participants (Fig. 3a). However, it is possible to simulate the communication environment described by a graph with different number of connectivity components implying that participants can send messages only to a specific list of recipients (Fig. 3b). Message handling is provided by a callback service. During the execution of the client program, the agent can subscribe to all or specific messages and call the defined functions when an event occurs.

We distinguish several types of messages:

- INFO is a basic message with some general information;
- WARNING is a warning about various emergency situations;



(a) Physical topology (b) Logical topology

Figure 3: Topology of the messaging service

- ERROR is an error that makes it impossible to perform an action;
- COMMAND is an explicit indication of the action of the agent;
- REQUEST is a request for some information;
- RESPONSE is a response to the request;
- MISSION_START is a message for starting (or stopping) a mission;
- LOG is write to the log.

INFO, WARNING, ERROR messages can be processed in various ways during missions. Transmitted messages (hereafter, a message object) have the following format:

- Sender;
- Recipient;
- Type of message;
- Dispatch time;
- Message text.

Several experiments were conducted in order to determine the average data transfer rate and the delay between the agent and the server or between two agents.

The experiments show that the exchange of messages containing text strings without any kind of message processing takes about 20 ms. Transmitting a message object of the previously presented format from the server to an agent and receiving a response with one predefined string also took 20 ms. Creating a full agent's response with a complete message object (object creation, serialisation) takes 10ms additionally. The exchange that include the full message processing (parsing a message, determining the type, calling a function from a callback service) was done in 40 ms. Forwarding messages by the server does not affect the transmission time in any of the implementations (table I).

B. Mission management service

Following control system architecture presented in section III, we built a mission management service as in Fig. 4.

Table I: Average exchange time for different messages

Message	Duration, ms
"PING" — "PONG"	20
Message("PING") — "PONG"	20
Message("PING") — Message("PONG")	30
Message() with processing	40
Agent to agent	40
Fast proxy	40

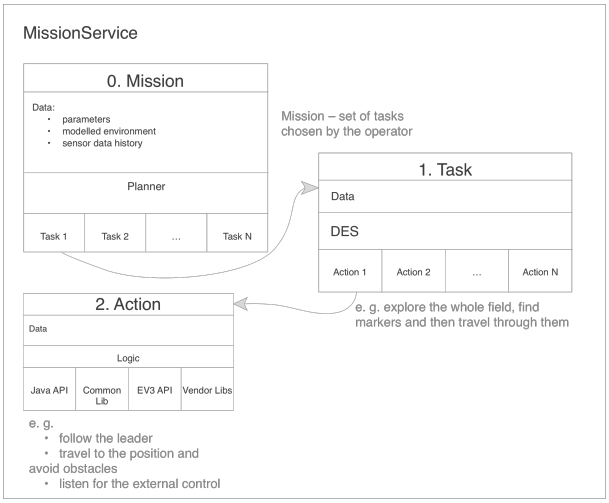


Figure 4: Mission service structure

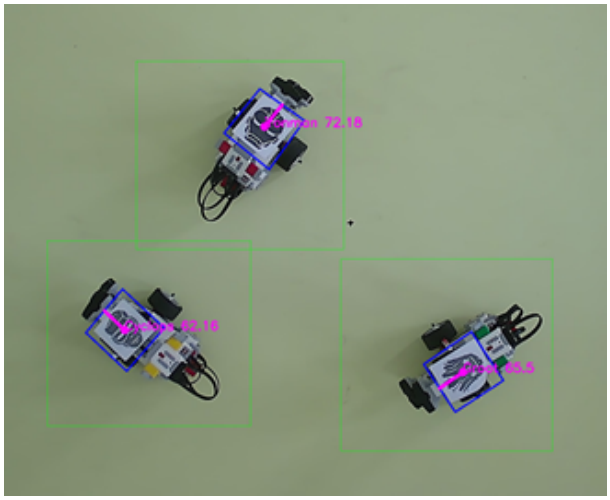


Figure 5: Robots identification example

The Mission (scenario) is a general description of goals and objectives. It represents an entity that provides storage of a list of tasks for execution, general parameters of a mission or parameters of specific tasks, a modelled environment (for example, physical fields), and some data from sensors.

The task includes formal description of corresponding DES and additional parameters. The Actions are implemented with low-level algorithms, for example, for agent movement, distributed leader selection, etc.

Programmatically, each mission is an object (a class inherited from the root class of missions) with specific functions for starting and ending a mission. The mission developer can call any tools built into the JDK and include compatible libraries when create a new mission. The classes of tasks and actions in their structure repeat the class of missions. Such division into 3 entities is necessary from the point of view of semantics for convenience of the mission developer. However, such decomposition may not be carried out for some tasks.

The mission accomplishment supposes the execution of the following steps:

1) The operator specifies a mission as a list of tasks to be done with additional parameters and sends it to the high-level planner (centralised or distributed).
2) The planner, as soon as it finishes calculations, sends an organised list to each robot. In case of the distributed planner there is no need to send it to agents over network.
3) The agent activates a requisite DES which define action logic by switching state machine functions according to environment events in order to accomplish the current task.

C. Precise positioning service

The service of determining the exact location of robots on the testbed is designed to solve three main tasks: the global positioning system simulation, the simulation of some sensors and visualisation. The first task is to simulate receiving the coordinates of the agent from such systems as GPS or GLONASS. In addition, the service allows considering the delay in obtaining these data and the signal distortion factor during transmission, if required by the conditions of the mission. The second task is due to the lack of hardware installation of all necessary sensors. For example, side range finders, which are used to prevent collisions with robots and obstacles in the blind zone of a real sensor, can be implemented this way. Finally, for ease of testing, it is necessary to visualise the process of accomplishing the mission using a real image or a stylised mini-map (Fig. 5).

In the current concept of the complex, we use several cameras, which take pictures of overlapping areas of the testbed. For further processing, the frames received from the cameras are combined into one large image. This approach allows easily scaling the dimensions of the testbed and, if necessary, changing the pixel density of the final image by adding new cameras, rather than replacing existing ones.

Identification of robots on the testbed is as follows:

1) The primary search for the object “robot” in the image. We use the Haar cascade classifier [17], trained on 20 thousand images, for this purpose. The developed classifier is resource efficient and invariant to small constructive changes of robots. It was empirically found that a false-negative error, when the robot cannot be detected, may occur in about 4% of cases. First of all, this is caused by the uneven illumination of the testbed and will be corrected during further work on the system.
2) Pre-processing the areas of interest obtained in the previous step. Each region is scaled, normalised, and passed through a number of other low-level handlers to increase the accuracy of high-level algorithms.
3) Processing the area using high-level computer vision algorithms. Each robot has a unique label located on its upper side, according to which the identification and determination of spatial characteristics takes place — the coordinates and the orientation vector (by calculating the homography). The study considered the use of various computer vision algorithms. During the experiments, it was revealed that for stable operation of ORB [18] and

BRISK [19], the area of interest must be scaled 5 times. It significantly slows down the frame processing speed (0.5 and 0.9 frames per second, respectively). The SIFT [20] algorithm, due to the resource-intensive calculations of the key points descriptors, also showed unsatisfactory results — 0.6 frames per second, on the average. The current implementation of the complex uses the AKAZE [21] algorithm, which shows stable and correct identification of robots at 1.5-2 frames per second.

At the moment, the service is fully operational and embedded in the system. However, we are constantly working to increase the speed of its work through the use of new low-level and high-level computer vision algorithms.

V. Experimental results

Experimental works were carried out on the testbed with robots built from the Lego Mindstorm EV3 kit. The robots are differential wheeled vehicles driven by two large gear motors. All of them are equipped with the following set of sensors: ultrasonic range-finder, infrared (IR) sensor, colour/luminance sensor, accelerometer.

The IR-sensor is used to measure the bearing angle and distance to the IR-beacon mounted on one of the robots. The accelerometer together with the designed accurate locations service imitates the on-board navigation system. The server sends information about robots' location determined by the accurate locations service to each robot periodically with a given frequency. This frequency correlates with the performance of the accurate locations service and the message service. The combined navigation system makes current location information more accurate, actual and independent of hardware restrictions. WiFi-adaptors are used to for data exchange between robots.

Since built-in time services of the EV3 Lego robots give incorrect results, we have developed an additional service functioning as NTP-client [22]. Current version of this client fetches the time offset from NTP-server and add it to the system current time on every call of the time function.

As an example of using the simulation testbed, consider a mission that consists of the only task, in which three robots should get together in a predefined location and move in a given formation, following operator commands.We assume that the formation control is based on the leader-follower scheme and there is only one leader that determines the movement of the whole group. The message with information about the mission, which is sent to all robots, is shown in listing 1. In accordance with this message, the mission involves the execution of the "remoteformationcontrol" task at the defined location (100,150). The structure of the formation is given by the table encapsulated in the message, where each row contains information about robot's ID, leader's ID, desired values for the distance and bearing angle to the leader. The first row corresponds to the formation leader.

Listing 1: Start mission message example

```
{ "from": "RoboServer",
  "to" : "broadcast",
  "msg_type": "MISSION_START",
  "payload": "{ "tasks": [
      { "name": "remoteformationcontrol",
        "location": {"x": 100, "y": 150},
        "course_angle_0": 180,
        "formation": [[1, 0,   0, 0],
                      [2, 1, 0.5, 30],
                      [3, 1, 0.5, 30]],
      },
  ]}"
}
```

The task of the group can be divided into three consecutive steps:

1) distribution of roles in the formation between robots and determining the coordinates of the robot in the vicinity of the gathering location (task location);
2) movement of the group to the task location;
3) depending on robot's role: either listen for and work out operator's commands (for the leader), or follow the leader, maintaining a desired relative position with respect to the IR beacon mounted on it (for the follower).

Each new stage begins only after the completion of the previous one.

For the implementation of simple actions related with the robot movement to a given point and tracking the IR beacon, we use modifications of the algorithms presented in [23], [24].

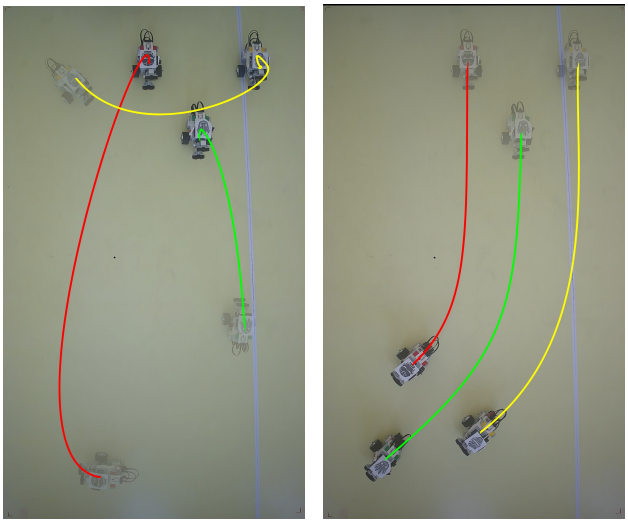
The operator launches the mission from the server application, specifies tasks to be done and parameters. After that the server sends a broadcast message with the instruction to launch the mission (listing 1) and shows up a remote control window.

Simulation results for the described mission is shown in Fig. 6. On the group gathering step (Fig. 6a) robots find a common location for gathering according to their random initial positions. After robots achieves the desired formation at the location, the leader starts the execution of movement commands from the operator until the stop message is received (Fig. 6b).

VI. Conclusion

In this paper, a description of the simulation system for testing intelligent control algorithms of multi-robot system was given. The main attention was paid to the development of the architecture of the system as a whole, as well as the implementation of services for determining the position of robots on the stand, information exchange, and mission management. Methods for the description and implementation of complex multi-purpose missions were proposed. The developed testbed platform is pretended to be used in two main ways: intelligent control algorithms validation and, additionally, as a learning environment for students to reinforce their knowledge in robot control systems.

The proposed architecture has several advantages over other simulation platforms. Unlike software-only systems, the mixed simulation approach can easily take into account the most part of physical aspects of the robot functioning. The mission



(a) Group gathering step (b) Moving in formation

Figure 6: Simulation results

service provides tools for describing long-term and multi-objective missions. The system admits the use of a wide range of effective methods to solve design problems arising at different control levels.

It should be noted that the development of the testbed platform has not been finished yet. However, for the moment, we have a set of basic services and tools required for testing of cooperative control schemes including intelligent ones. Work to implement available algorithms into the system is currently in progress. Further development also includes the implementation of the high-level planner as well as creation of high-level tools for describing missions and simulation scenarios.

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Algorithmic and programming approaches to the underwater terrain generation

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***Abstract*—Procedural reliefs are used for many purposes in military tasks, training operators to control autonomous vehicles in emergency and testing situations, game development, etc. The aim of this paper is to propose algorithmic and programming approaches to the problem of various realistic landscape generation. The proposed terrain generator is developed as a part of the programming simulation complex for the autonomous underwater vehicles intelligent group control. We suggest using specialized application architecture that allows to conveniently represent the landscape as a combination of independent layers and parts. We have developed the approaches for modifying terrain generation algorithmic schemes to fill layers and to combine relief parts in natural ways. These algorithmic schemes are based on Perlin noise and Diamond-Square algorithm. The visual results of the suggested approach software implementation are presented.**

***Index Terms*—terrain generation, underwater terrain, procedural terrain**

I. Introduction

3D-terrain models are used in various software systems [1], e.g. the robotic simulators for training operators to control autonomous vehicles in emergency and testing situations, the complexes for military tasks [2] and virtual mobile robot tests, computer games, etc. The landscape modeling is not the main purpose of these software systems but it takes an important role in the virtual environment generation. The intelligent single and group behavioral algorithms, the sensors and the onboard equipment require the complicated dynamic environment to produce realistic results of the algorithm implementation and the simulation generally.

The aim of this paper is to develop algorithmic and programming approaches to the problem of various realistically generated landscapes. The requirements to the developed program system are the high quality of the terrain generated (the lack of the artifacts, high detailing of the height map) and the ability to control the generation with customizable parameters.

There are a lot of approaches to procedural terrain generation. A functional description is the first way to create a terrain. The hill rising algorithm is a special case of functional description. The terrain is shaped by the iterative process of generating the surfaces of the following forms:

$$z = r^2 - (x_2 - x_1)^2 + (y_2 - y_1)^2, \qquad (1)$$

where (x_1, y_1) is the current point of computation, r is the hill radius, (x_2, y_2) is the top of the hill.

Many landforms have statistical self-similarity and can be represented with a sufficient degree of realism with the help of fractals [3]. Fractal algorithms [4] implement the approach to generating random surfaces with fractal behavior. Fault line (fault formation) algorithm, midpoint displacement algorithm, diamond-square and triangle division algorithms are the examples of the fractal algorithms [4]–[7]. Fractal algorithms are the most common category of terrain generation algorithms. They are of high-speed performance [8]. The main disadvantage is the generation of terrains of only one type within one zone. Textures obtained using these algorithms may contain artifacts (unpredictable changes of heights in adjacent points). This is caused by the specifics of the algorithm and the choice of generation parameters [8].

The last group of terrain generation algorithms is noise algorithms that contain value noise, Perlin noise, and simplex noise [9]–[11]. These algorithms allow one to generate height maps of good quality (without artifacts). One of their main advantages is "controllability". The "controllability" means that there are some parameters in the algorithm implementation which use to correct the size of the hills and mountains, their approximate quantity on the surface, etc. The speed of execution is less than the one of diamond-square and midpoint displacement algorithms.

Analysis of the literature and software implementations of the considered algorithms has shown that a group of noise algorithms is best suited for the problem of the generation of various and realistic landscapes. In particular, Perlin noise still retains its relevance and has many applications [12]–[15]. In addition, in some cases, it is advisable to use the diamond-square algorithm with Perlin noise algorithm or separately.

We propose a logic specification of the terrain using Layers and Parts. This allows us to use new and known terrain generation algorithms to create the Layer and then to modify or combine it with another one in different ways which are described in the "Algorithms and approaches" section. Both types of Layers and operations on them could be extended any time. Parts consist of several combined Layers and could be merged together by rules proposed in the paper to form a terrain. Such a structure of the terrain generator allows us to make realistic landscapes.

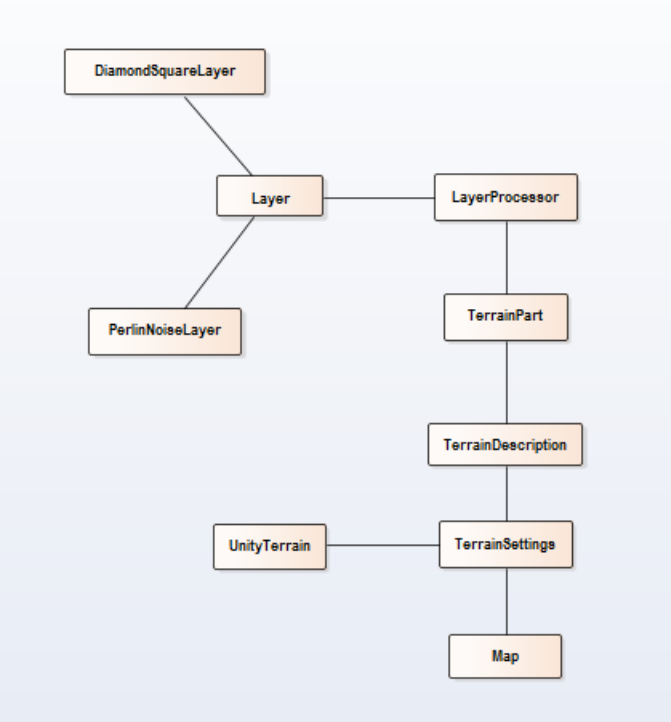

Fig. 1: The structure of the terrain generator.

II. Terrain generator

A. Structure

The terrain generator is developed as a part of the simulation program for the autonomous underwater vehicles intelligent group control. The use of third-party software instead of developing own platform for displaying graphics is due to the main requirement which is to reduce the time and development costs. The third-party software allows the developer not to explore texturing and shader programming processes. Game engines are the platforms that meet the specified requirements and are suitable for the task of software development for generating the terrain and the underwater environment in general. Unity game engine is used in the current project.

The terrain generator consists of three types of component. These are processors, controllers, and objects. Processors implement computational tasks, controllers monitor application state, and objects are the containers to store the information.

Terrain modeling subsystem includes (see Fig. 1):

- *Layer Processor*. It processes and transforms the height map information.
- *Form Controller*. It switches forms and saves their state during the interaction of the user with the application.
- *Application Controller*. It is responsible for saving and loading of landscape and all map data (textures, alpha map, objects, etc).
- *Layer*, *Landscape Part*, *Terrain State*, *Terrain Settings* and *Map* objects contain the information about the corresponding objects of selected subject area.

The internal logic of the component interaction during terrain generation is described below.

1) *Layer Processor* generates required *Layer* objects which are two-dimensional arrays of heights.
2) *Layer Processor* use ”combine” and ”normalize in range” methods to form the *Landscape Part* object.
3) *Terrain State* object has the *Landscape Part* fields: Underlay, Small Mountains, Medium Mountains, Big Mountains. They are filled by two-dimensional arrays of heights with the help of *Layer Processor*. The Underlay is a sandy or clay base of the landscape. The difference between the maximum and minimum heights of the Underlay is from 10 to 120 meters. In the Unity engine, the unit of measure corresponds to one meter. Small mountains are stone formations of 1-30 meters. Medium mountains have heights from 30 to 100 meters. The Big ones are over 100 meters and do not exceed the maximum Terrain height. The minimum and maximum heights are chosen correspond to the convenience of solving the problem and can be changed.
4) *Terrain Settings* are formed with the help of the ”form terrain” method of the *Terrain State* object. It contains the information which is used to save Unity Terrain settings to the file and load settings from it.

For the user, the terrain generation process is represented in four steps. It corresponds to the internal generation logic (the *Terrain State* object has four fields for the underlay, small, medium and big mountains). The terrain generator is developed as a part of the simulation software for the autonomous underwater vehicles intelligent group control. This means that in addition to the information about the terrain, one should save and store the information about the underwater environment state, object locations, underwater currents, the level of pollution, etc. A suitable solution is to use the *Map* object to save the terrain settings and the Terrain Unity object data.

B. Algorithms and approaches

The *Layer Processor* forms *Landscape Parts* by using the methods of Layer generation and combination. Next, the ”form terrain” method of the *Terrain State* makes the whole terrain from *Landscape Parts*. These operations use terrain generation algorithms which are described below.

Let us consider the layer generation using Perlin noise. As mentioned earlier, Perlin noise is often and quite successfully used in creating realistic relief. In this paper, Perlin noise algorithms is a basis of the developed approach. The results of the Perlin noise implementation can be varied in several ways. One can use different scales of noise, change the proportions of the grid by stretching or compressing along one of the axes, set the dependence between the coordinates of the horizontal plane. As an example, we can give the dependence expressed in the form $y = sin(x)$ to use it in sand hill generation (Fig. 2).

The listed variations of modification are used to generate a single layer (and implemented in the method ”to generate” of the *Layer Processor*). One can also combine layers in several ways. As part of this work, algorithms for addition and multiplication of layers are implemented by the analogy

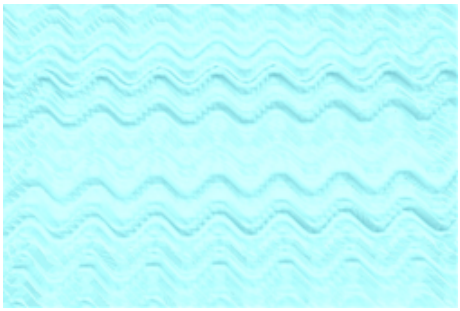

Fig. 2: Adding a sinusoidal relationship between the coordinates of the horizontal plane. The view of the three-dimensional surface from above is displayed.

of using the multiplication of two height maps in fractal landscapes [7]. Also the algorithms of coupling by the heights and related area are proposed.

Let us consider an example of the coupling by heights of two terrain layers filled by Perlin Noise (Fig. 3). Let h1 = 0.4, scale1 = 4, scale2 = 18, Hmax = 200 meters.

1) Create L1 and L2 terrains with scale1 and scale2 accordingly.
2) Sever heights [h1, 1] from L1 and normalize height map. Height map Temp1 is obtained.
3) Sever from L2 the areas where heights with identical coordinates (x, z) are less than those from L1. Denote the obtained height map by Temp2. Normalize it.
4) Multiply related heights from Temp1 and Temp2 (it is necessary to put on L1 height map Temp2 starting with height h1 but without visible seams).
5) Put the height map obtained on the forth step on L1 limited with [0, h1]. Normalize the result.

Coupling by areas is implemented in a similar way. It can be used to form a relief as a seamless mosaic from various square or rectangular zones (Fig. 4).

Thus, to create a single layer, standard Perlin noise or its modification (stretching and compression along the axes, etc.) is used. To create a part of the terrain (the underlay, large, medium or small mountains), a combination of from 3 to 8

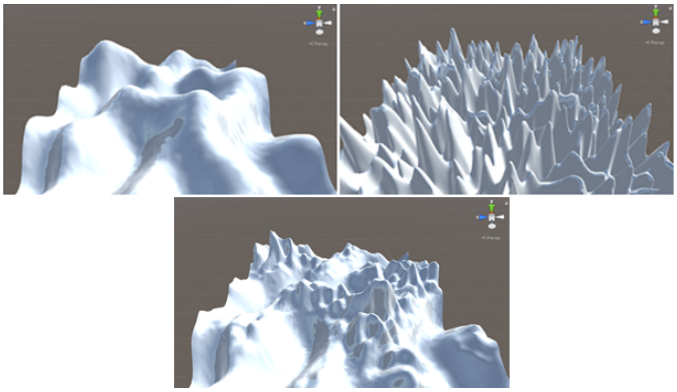

Fig. 3: The result of the coupling by heights at the required height.

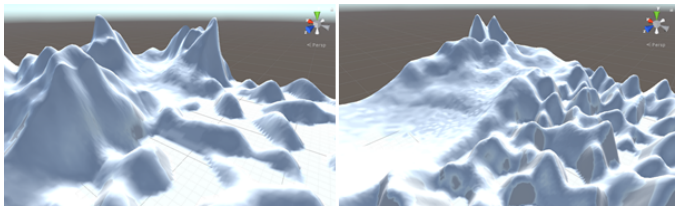

Fig. 4: The result of the coupling by areas at the required zones. One zone is a mountainous terrain with sharp peaks, and the other is hilly and smooth.

layers is used. To obtain the whole terrain, the algorithm of connecting terrain parts is used.

For the user, terrain generation occurs in four successive stages. After the generation of the sandy or clay bottom of the relief, large mountains are generated. It is necessary to shift the heights of large mountains so that the minimum heights of the large mountains are lower than some of the heights of the sandy hills. To calculate the shift coefficient, one can use the data of the maximum height of underlay, which is set in the menu by the user. The stage of joining of medium and small stony formations to the terrain occurs in a similar way.

Parameters for terrain parts are set via GUI. In particular, the user choose the textures used for each part of the relief. After receiving a single terrain object, this information is used to create a transparency map. It describes the percentage of brightness of each texture at each point on the map. During texturing, one can use Perlin noise and create a more diverse surface (Fig. 5). In addition, the transparency of textures can be set based on the height and steepness of the relief at a point.

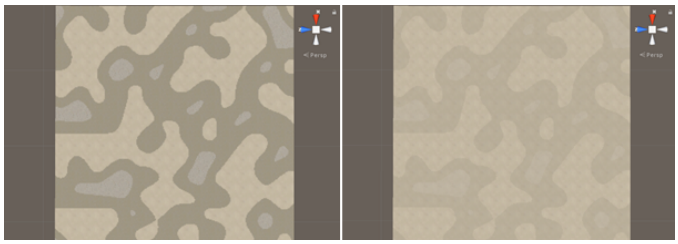

Fig. 5: The texturing using Perlin noise function and the result of different transparency map values.

The relief can be placed in a water "pool" after texturing. Water "pool" (Fig. 6) is a three-dimensional surface of the form:

$$h = \left(\frac{x}{a}\right)^n + \left(\frac{z}{b}\right)^n, \tag{2}$$

where x and z are the point coordinates in the horizontal plane, a and b are axial compression ratios, h is the height of the relief at the point (x, z).

Perlin noise is convenient to use if one need to build a complete height map with the specified parameters. If there are requirements to construct a height map, for example, with using square zones, like a mosaic, or it is necessary to replace unsuccessfully generated zones, then one can use the diamond-square algorithm. This algorithm also produces landscapes

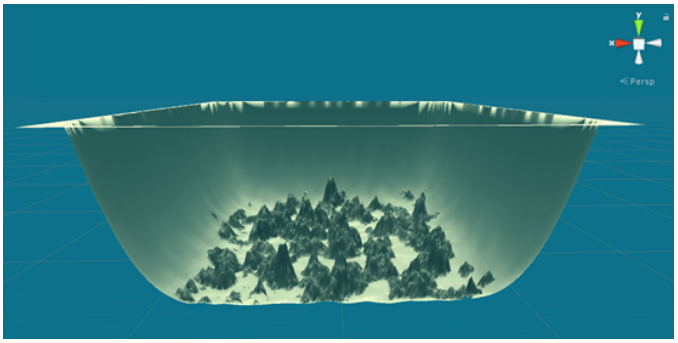

Fig. 6: The resulting terrain placed in the water ”pool”.

that differ in appearance from maps generated only by Perlin noise. We propose to use a modification of the diamond-square algorithm to aim listed features.

In order not to decrease the execution speed and to make the execution of diamond-square algorithm more controllable, we fix in advance the values of the heights at the boundaries of the height map zone. It is possible to generate boundary values using Perlin noise. If it is necessary to build a generation zone into an already existing terrain then the boundary values of the replaced zone should be copied. Both the standard diamond-square parameters and non-standard such as the coordinates of the center of the generation zone and its size become available in this modification. As a result, it is possible to re-generate individual terrain sections with different diamond-square parameters (Fig. 7), for example, to provide a junction from the mountains to the plains.

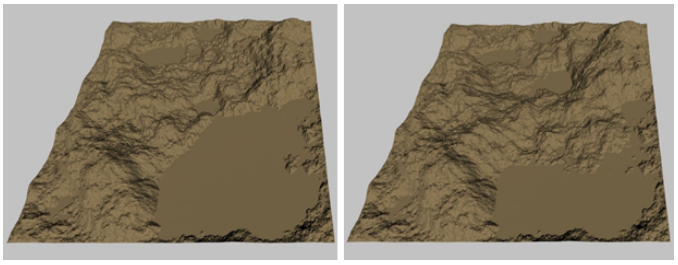

Fig. 7: The changing of the terrain parts using diamond-square modification.

A container that stores terrain data is created for saving and loading the landscape. It contains terrain settings such as maximum height, width and length, a list of used textures, and so on. ”Container” is filled with the information, serialized and saved to a file. Landscape restoration is done by loading settings from file, deserialization and setting them to the Terrain object. The application controller performs the saving and loading of the terrain.

The state of the terrain remains unchanged while switching between steps in the terrain editor. The state sequence allows the user to go back and view the results of the execution of the previous steps. Saving the terrain state make possible to replace the part of the terrain obtained in the previous step with the newly generated one.

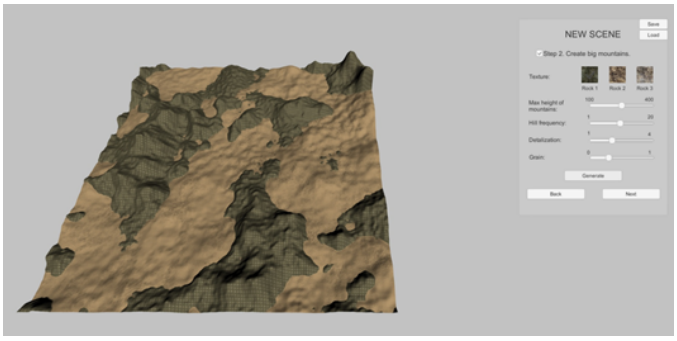

Fig. 8: The graphical user interface with parameters of generation and the result of the implementation of the proposed approach to the terrain generation.

III. The results of the implementation

All described algorithms and approaches to the generation are reflected in the GUI. The initial menu contains items for creating a new terrain or load from file a saved one. The maximum terrain height and the size of its base are determined in the relief settings menu. Steps 1-4 provide the ability to customize parameters of the terrain parts (Fig. 8). The user can select the Perlin noise scale of the main layer which determines how large will be the areas of hills. Map detailing determines the number of layers, i.e. appearance of relief and surface details. The granularity parameter determines how ”smooth” or ”rough” the rocky surface will be.

The built-in unity effect of fog is used for greater realism of the scene. Also such objects as barrels, containers, pipes and others are placed on the terrain generated. Objects can be placed both manually and procedurally. It is necessary to check the type of texture when user chooses procedural placement of the object. If the texture type is stone, then the object is placed on the surface and may slide according to Unity physics. If it is a sand, then the object is partially immersed in it (Fig. 10, 9).

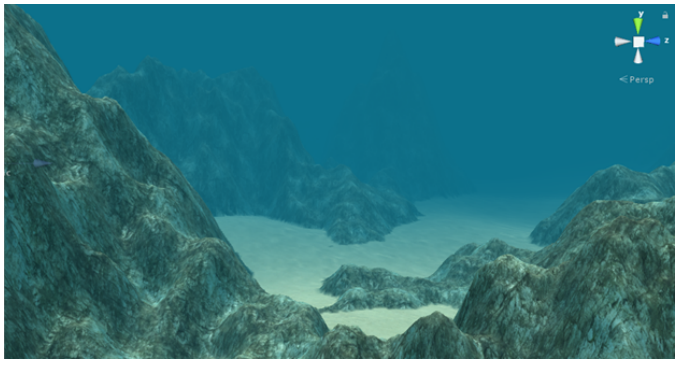

Fig. 9: The example of the landscape made using proposed approach to the terrain generation. The built-in fog effect is used.

The proposed logical representation of terrain in the form of Layers and Terrain Parts provides a rich toolkit for procedural generation of the landscapes. The algorithms for modifying

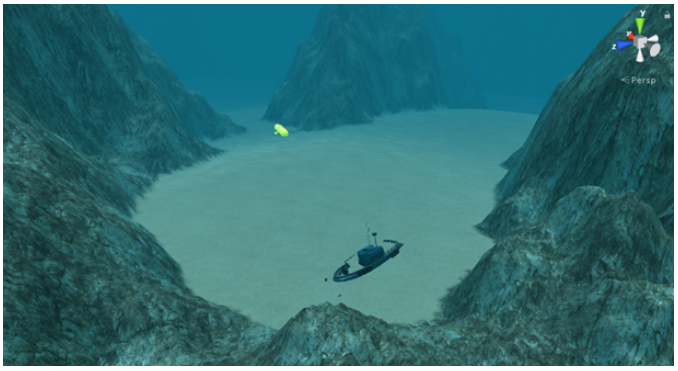

Fig. 10: The example of the landscape made using proposed approach to the terrain generation. There are the boat and the autonomous underwater vehicle models on the scene.

layers and their combination make generation more controllable. The diamond-square modification and the algorithms for stretching-compression and other processing of Perlin noise provide the variety and realism of the obtained terrains. The implemented terrain generation module is used as a component of the underwater environment generation subsystem of the developed simulation modeling complex.

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Unity based Urban Environment Simulation for Autonomous Vehicle Stereo Vision Evaluation

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***Abstract*—Testing and evaluation of sensor processing algorithms for autonomous vehicles is challenging due to the problem of collecting reference data. To ensure safety and robustness, many man-hours need to be spent in collecting and preparing such data. One solution to alleviate this problem is to use computer simulations. Computer simulations can model a real system with all its static and dynamic characteristics. This approach provides efficiency and precision when collecting data and reduces testing time. The aim of this paper is development of a simulation environment based on Unity where it would be possible to test sensors and algorithms for autonomous vehicles and show deviations from reference data. The proposed simulation model contains typical city objects and participants: roads, sidewalks, buildings, pedestrians, traffic signs and vehicles. In this paper we simulate motion and sensors from a single vehicle equipped with a stereo camera setup. The program environment Unity is used for designing the simulation, and behavioral scripts are executed with C# programming language. To showcase the testing of applicable algorithms, OpenCV class for computing stereo correspondence, using the semi-global block matching algorithm, is used on simulated stereo images and we discuss future development of the simulation.**

***Index Terms*—Autonomous Vehicles, Urban Scenario Simulation, Stereo Vision**

I. Introduction

Reliable perception is one of the key components of any autonomous system and entails analyzing and understanding a series of steps; from physical properties of the operation principle by which sensor collects data to high level semantic reasoning about the scene. Combining different sensor modalities enhances the chances of an autonomous robot or vehicle operating robustly in a wide range of scenarios. However, collecting sensor data in real-life scenarios takes resources and time; thus, in order to alleviate that step and prepare more adequately, prior testing and analysis can be performed in appropriately designed simulated environments. Indeed, recent reinforcement learning research extensively leverages simulations in order to train policies that would take impractically long in real-life and transfer them to reality [1].

Another challenge, besides collecting the real-world datasets, is getting reference, i.e., ground truth, data for evaluation purposes. For example, testing accuracy of vehicle localization based on stereo cameras or 3D laser range finders can be compared to more accurate sensor such as a differential GPS as done in the well-known KITTI dataset [2]. Another KITTI dateset example is evaluation of disparity computation from stereo cameras by comparing it to the point cloud measured by the 3D laser range sensor; however, depth evaluation for every stereo camera frame is not available since depth integration from several 3D scans is necessary. Furthermore, once datasets are recorded, evaluating semantic classification and multitarget tracking algorithms requires annotations by human experts [3]. Naturally, real-life datasets and experiments constitute a fundamental block and are irreplaceable for the development of autonomous vehicle algorithms and valuable insight papers have reported on the experience and lessons learned [4]–[6]; nevertheless, insights, testing, and reduction of development costs can be achieved by also exploiting benefits of appropriately designed simulation environments.



Fig. 1: Left camera images of the generated street curb and crossroad examples

In [7] a virtual urban environment was presented for conducting experiments with a fleet of autonomous vehicles as part of the project aiming to design novel transportation systems based on a fleet of small electric cars supervised by a central computer. An approach to urban traffic scenario simulator implementation and pertaining requirements along with an overview comparing at the time available simulators and the possibility of simulating DARPA Urban Challenge teams sensors were discussed in [8]. A lightweight simulator aiming at replicating urban features, such as road networks, curbs and general objects, including a realistic host vehicle was proposed in [9]. Therein, for the purposes of motion planning the authors also modeled other traffic participants which could interact with each other relying on intelligent agent-based

approaches. In [10] a photo-realistic virtual version of the KITTI dataset was presented that was automatically labeled with accurate ground truth for object detection, tracking, scene segmentation, depth and optical flow. The created dataset was use to demonstrate that deep learning algorithms pretrained on real data behave similarly in the real-world and the simulated one, while pre-training on virtual data improves performance. Research in [11] presented the development of an urban driving simulator named CARLA. It is an open-source simulator for development, training and validation of urban autonomous driving systems and offers flexible specification of sensor suites and environmental conditions. In the paper, authors also compared the performance of three different approaches to autonomous driving. Furthermore, in [12] used CARLA for analyzing the challenge of transferring driving policies learned in simulated environments to the real world. Given the above discussed advantages of simulated urban environments for testing development of autonomous vehicles, there exists multiple open source and commercial simulators [13]–[19].

NVIDIA Drive Constellation [14] uses the computing power of two different servers to create a cloud-based computing platform for autonomous vehicle testing. The first server runs the DRIVE Sim software that uses GPUs to generate a wide range of testing environments and scenarios. The second server contains DRIVE AGX Pegasus AI car computer that processes the simulated data as if it were coming from the sensors of an actual car. DRIVE Sim positions virtual car in the environment and sends data from sensors to Pegasus. Pegasus processes the data and sends driving commands back to DRIVE Sim. Together, the two servers create a digital feedback loop. Cognata [16] uses computer vision and deep learning algorithms to automatically generate a whole virtual city environment. Different weather conditions and lighting are added to stress test the system. Simulation engine combines TrueLife and PhysicsStudio to simulate the sensor interaction with the external materials to receive the most comprehensive autonomous driving simulation feedback loop. Virtual simulator enables to run thousands of different scenarios based on various geographic locations and driver behaviors. Apollo Simulation [15] is one of the solutions of the Apollo3.5 Platform. Its open functionality allows users to input different road types, obstacles, driving plans and traffic light states. Likewise, execution modes give users complete setup to run multiple scenarios and verify uploaded modules in the Apollo environment. Integrated Automatic Grading System in simulations tests via ten metrics; some of which are: speed limit, collision detection, traffic light recognition etc. It also provides users with 3D visualization of real-time road conditions and visualizes module output while showing the status of the autonomous vehicle. Cvedias SynCity [17] simulates various environments for autonomous applications, also providing sensor simulations of a vast number of real-world phenomena such as weather, day/night cycle and different traffic situations. It has flexible API that gives users the ability to customize before mentioned environment and independently control parameter and the scenario. It automatically generates ground truth for users with various occlusions and visibility constraints.

In the present paper we construct a simulated urban environment based on the freely available Unity engine. We model an urban-like neighborhood including other agents, such as cars and pedestrians, including intersections with traffic lights. The present paper focuses on the perception side of the autonomous vehicle control challenge; concretely, stereo vision. Stereo cameras are an omnipresent and popular sensor setup for autonomous vehicles, since they enables accurate ego-motion estimation and simultaneous localization and mapping, while also, being a vision sensor, they can be directly used for other vision-based challenges, such as semantic scene interpretation. The simulated vehicle with a stereo camera can drive along any predefined path and record data (examples of left camera images are shown in Fig. 1). Besides the two cameras simulating a stereo sensor setup, we placed a third camera that uses a special shader, so called Z-buffer, to generate ground truth depth information. Given that, disparity estimation algorithm accuracy can be compared to this reference data having at all times also available ground truth motion of the vehicle itself. We present an example of stereo disparity estimation from simulated stereo images using the semi-global matching algorithm [20].

The paper is organized as follows. In Section II we present the Unity 3D framework and describe some of its capabilities relating to simulating environments for autonomous vehicles. In Section III we describe the static and dynamic parts of the constructed urban environment, while in Section IV stereo image capture as well as ground truth generation is explained. In the end, Section V concludes the paper.

II. Unity 3D Simulation Framework

Unity is a cross-platform game engine developed by Unity Technologies and can be used for three-dimensional and two-dimensional games as well as simulations. It was first released in 2005 as an OS X-exclusive game engine. Over the years, Unity become available on 27 platforms; from standard computer operating systems and popular consoles to virtual and mixed reality devices. In the sequel we describe some of the used Unity features and tools [21].

A. Lighting

Lighting is provided by light objects or by creating ambient light and emissive materials. Unity has two basic lighting techniques: realtime and precomputed. In some situations both techniques can be combined to create a more realistic lighting scene. Directional, spot and point lights are set to realtime by default. Realtime lighting is basic way of lighting objects in the scene, where light rays from realtime lights do not bounce from the surface of object. In order to make a more realistic scenes we need to use global illumination that is part of the precomputed lighting technique. Static lighting effects are calculated and then stored in a reference texture map called a lightmap and this process is named *baking*. The effects of light sources on static objects in the scene are calculated and stored

to textures. Static lightmaps cannot react to changes in lighting conditions but precomputed realtime global illumination offers us a technique for updating scene lighting interactively. Lights can cast shadows from an object onto itself or onto other objects in scene. Shadows, naturally, add a degree of realism to the scene, because they bring out the scale and position of objects. Furthermore, for vision algorithms they can pose an additional challenge or be switched off for simplicity.

B. Cameras

Cameras in Unity are objects that transform a three-dimensional scene to a two-dimensional one which can be reproduced to viewer's screen. Position of camera defines the viewpoint and other components define the size and shape of the region that will be reproduced to viewer. A camera in the real world simulates perspective projection and this effect is for creating a realistic image. A camera that does not change the size of objects with distance is known as orthographic. Unity supports both views of the scene and they are known as camera projections. Perpendicular plane is set to the cameras forward direction to define the limit to how far camera can see. It is called the clipping plane, because objects at greater distance from the camera are clipped. There is also a corresponding near clipping plane that defines distance from camera at which objects will not be seen.

C. Mesh Geometry

Solid objects are made of a group of triangles arranged in three-dimensional space and is called a mesh. The mesh class stores all vertices in a single array, where each vertex is stored just once and each triangle is specified using three indexes of the vertex array. For correct shading the normal vector must be supplied for each vertex. A normal vector is perpendicular to the mesh surface at the position it is associated with. During shading each normal is compared with the direction of incoming light, thus when the two vectors are aligned the surface receives full brightness, otherwise it will be somewhere in between full brightness and complete dark.

D. Shader

Unity supports a wide range of shader types. Its features are enabled by using various texture slots and parameters. The standard shader incorporates *Physically Based Shading*. Physically Based Shading simulates the interactions between materials and light and has only recently become possible in real-time graphics. Physically Based Shading has a number of useful concepts, some of them are energy conservation and High Dynamic Range. Energy conservation ensures that objects never reflect more light than they receive.

E. Textures

Textures are standard bitmap images that are applied on the mesh to give better details since mesh only gives a rough approximation of the shape. For best representation of textures materials are applied. Materials use shaders to render texture on the surface of mesh, while shaders implement lighting and colouring effects to simulate different materials, because some materials are very complex they can combine multiple shaders. To ensure best representation of bumpy surfaces heightmaps are used. Heightmap stores an area where each point has a particular height from a baseline and are than converted to coordinates that are used to generate mesh.

F. Physics

Unity has implemented convincing physical behaviour that makes objects accelerate correctly and be affected by collisions and other forces. Two main components are rigid body and collider. When a rigid body is connected to an object it will immediately respond to gravity. Object with rigid body do not need rotation and position transformation to be moved around scene, instead forces should apply to push the object and let engine calculate the movements. Collider defines the shape of an object which responds in contact with other objects that have colliders applied to them. Collider is invisible and it approximates objects mesh to improve efficiency because mesh is usually complex object and calculations collisions between complex object slows down the physics engine.

III. Constructed Urban Simulation

The constructed simulation is placed in an urban environment implemented using the previously described Unity game engine. The environment contains typical city objects and participants like roads, sidewalks, buildings, pedestrians, traffic signs, and vehicles. To understand the implementation of these elements, Unity editor is briefly introduced. Most of the elements are constructed using standard assets provided by Unity or free assets from the Unity Asset Store.

A. Unity Editor interface

Unity provides a simple and user friendly interface. Two main tabs are Scene and Game. Scene tab shows current appearance of scene and enables numerous ways of editing added game objects and prefabs. All objects added in the scene are shown in Hierarchy tab where they can be arranged in desirable groups and order. Clicking on object in a scene or in the Hierarchy tab shows the objects Inspector tab. Inspector tab provides basic information about object and all components attached to it. Every object has Transform component that gives information about its local position, rotation and scale while wide range of other components (scripts, colliders and mashes, to name a few) is attached depending on objects usage. All imported assets and packages can be seen in Project tab and added to scene by simple drag and drop. Game tab, on the other hand, shows current game (or in this case, simulation) state. By clicking on play icon all components compile, notifying about potential errors and warnings in Console tab, and simulation starts from the main camera perspective.

B. Roads and sidewalks

Building of the proposed simulation starts by adding a Terrain game object on which sample scene of urban environment is placed. For the purpose of this simulation, terrain will be a



Fig. 2: Example of a generated intersection

big plain surface to simplify the rendering. To have a faithful representation of a city, it i necessary to add realistic roads and intersections. To achieve this, Simple Modular Street Kit and Low Poly Street Pack assets were used.These assets are available in Unity's Asset Store for free and enable various ways of implementing roads and intersections. Furthermore, the Low Poly Street Pack contains a large number of models of street signs and other street elements. By combining those two assets, making of city streets becomes a relatively fast process. The example of an intersection together with some other street elements is shown in Fig. 2.

C. Buildings

Besides roads, an integral part of every urban environment are its buildings. To surround the already implemented streets with them, the Simple Urban Buildings Pack 1, also free to import for Unity Asset Store, was utilized. It contains prefabs of five low poly buildings with already implemented optimisation technique called Level Of Detail (LOD) which reduces the load on the hardware and improves rendering performance when main camera is not close to them. Despite having only five buildings provided in asset, the city does not seem too repetitive thanks to diverse possibilities of modeling and rearranging the before mentioned prefabs.

D. Vehicles and pedestrians

Essential part of every urban environment simulation are agents, i.e., vehicles and pedestrians that populate it. To simulate these agents, available vehicles from Unity's Standard Assets were used. Standard Assets have everything needed for vehicles to move through streets by following defined way-points. CarWaypointBased prefab has an already implemented script components such as Car Controller, Car AI Control and Way-point Progress Tracker, that have numerous variables that can be changed to fine tune vehicle motion and physics. One of the vehicles is equipped with the main camera, whose perspective is seen when simulation is started, and two other cameras that simulate the stereo camera sensor. The main vehicle and game view are shown in Fig. 3.

E. The final urban scene

Using all the previously mentioned methods and elements, the implemented urban environment looks as shown in Fig. 4. The Terrains component for adding already existing trees in Unity was used to hide parts of it that should not be seen through main camera and to keep cities landlocked looks. Also, in Fig. 5 we shown the full Hierarchy tab with all the objects used to implement this example of an urban simulation.

IV. Capturing Stereo Images and Reference Data

Two cameras are used for capturing frames of the simulated city. They are mounted on the front of the car object and are symmetrical with respect to the car's main axis. These cameras are used to simulate the stereo camera with a fixed baseline and capture two images. Cameras were simulated with physical properties and had the focal length $f = 20\,\mathrm{mm}$, baseline $b = 40\,\mathrm{cm}$, and sensor size of $36\,\mathrm{mm} \times 36\,\mathrm{mm}$, while images were in ARGB32 color format and had resolution of 1024×1024. The quality of obtained disparity can then be checked by comparing it with the ground truth. Accompanying video showing an excerpt from the scene is available [1].

[1] https://youtu.be/2P0yYFxlVts



Fig. 3: Main vehicle and game view

A. Constructing the disparity map and ground truth

The semi-global block matching algorithm [20] is used to construct the disparity map from simulated stereo images. Implementation of this algorithm used in the paper is included in the OpenCV Library. The resulting image shows the distance of objects from the camera in a given frame. The distances are shown in the form of a gray-scale image, where parts of the disparity image that are closer to the camera are brighter and vice versa.

To compute the ground truth, a separate third camera was placed in between the stereo pair and used a special shader (Z-buffer) that is ran on the graphics card for every pixel in the frame. The shader encodes the depth in the form of grayscale images. Note that this discretizes the depth and for scenes with large depth variations various Z-buffer images should be created with different clipping planes as was done in the Tsukuba dataset [22]. Given the known depth Z, the corresponding ground truth disparity $d^\star$ for either left or right camera can be computed using the formula

$$d^\star = k \cdot \frac{fb}{Z}, \tag{1}$$

where k is the sensor scaling factor. Figures 6 and 7 show examples of the SGM computed disparity and the pertaining ground truth. We calculated the total error as percentage of erroneous disparities defined those that differ either absolutely by 5 px or relatively by 5% from the ground truth.

V. Conclusion

In this paper we presented a Unity based urban environment simulation for testing of autonomous vehicle perception algorithms. A model of a city was created together with other agents, such as cars and pedestrians, as well as intersections with traffic lights. A simulated vehicle equipped with sensors can then drive along a predefined trajectory and collect data. Specifically, in this paper we have demonstrated these capabilities for the omnipresent stereo camera by placing two virtual cameras on the moving vehicle. Besides capturing left and right camera images, the vehicle also has a dedicated third camera using a special shader that enables creation of depth ground truth data. Given that, we have shown how virtual stereo images can be used to compute the disparity image and compare it to the generated ground truth. For future work we plan to the city can be populated with more agents and other sensors can be added to the vehicle. Ground truth data can then be extended to 3D pointclouds and semantic labels.

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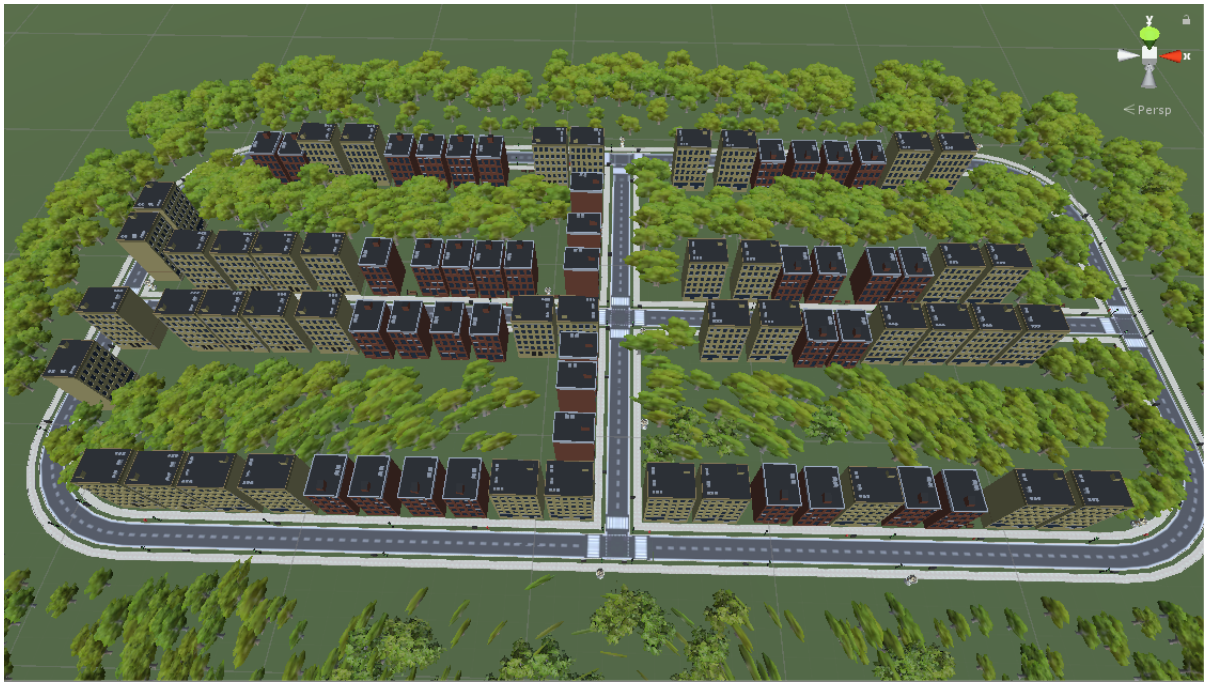

Fig. 4: View of the complete city



Fig. 5: The full Unity hierarchy tab

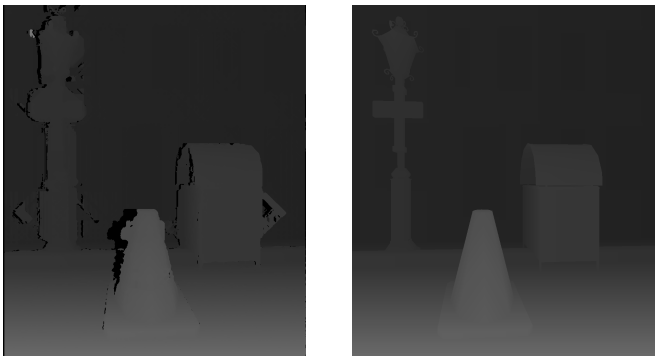

Fig. 6: Disparity and ground truth for the first example, SGM yielded accuracy of 86%

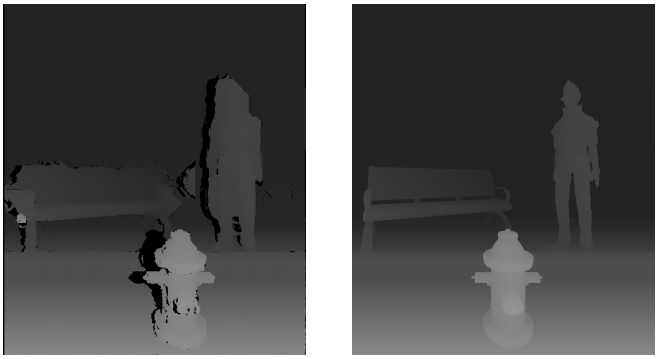

Fig. 7: Disparity and ground truth for the second example, SGM yielded accuracy of 85%

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Remote Control System Concept in Electric and Hybrid Marine Propulsion Objects

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Abstract – **Modern designs in shipbuilding industry, regardless of whether they are intended for cargo, passenger or particularly dedicated working ships and platforms, mostly use electric or hybrid propulsion. The new technology in marine propulsion and flexible operator´s position during maneuvering requires redesign of traditional remote-control system. The article proposes digitally organized, soft programmable, CAN communication-based concept, solving electric and hybrid marine propulsion specific request in controlling propeller speed, direction and ship maneuverability from bridge, wings or any fly deck on the ship as well offers to operator a real time propulsion system control and monitoring. This technical concept proposes modular expandable solution adapted to the needs of the new propulsion drive train and applicable in most modern marine electrically propelled objects.**

Keywords - Marine Electric Propulsion, Remote Control

I. INTRODUCTION

Large modern marine propulsion systems are composed of electrical or hybrid propulsion [1] and an operating station with maneuvering "Drive by Wire" throttle command unit and propulsion status display (Fig. 1).

Additionally, large ships include more than one propulsion system like thrusters, port engine, starboard engine. Since in some situations, like ship docking or maneuvering in narrow space is necessary for the operator to have the option of remote steering, operating stations are usually implemented in several key positions (wings, fly bridge, engine room…) [2], [14], [15]. In order to avoid any possible conflict only one steering position can have control over electric propulsion and all others are not in command. The role of remote control system is to establish hierarchical responsibility and synchronization between all possible maneuvering positions.

Traditionally, the synchronization is accomplished by system of servo motors embedded in throttles which assure that all throttles on all operating stations follow the current position of the throttle in control keeping the whole system updated. Then by switching control to the other operating station the operator can continue with maneuvering without the need for manual adjustment of throttle position.

Due to the presence of complex mechanical parts which may result in malfunction, the safety of ship management can be reduced. Therefore, specifically for marine electric and hybrid propulsion, we propose a remote-control system where servo motors are replaced by system of

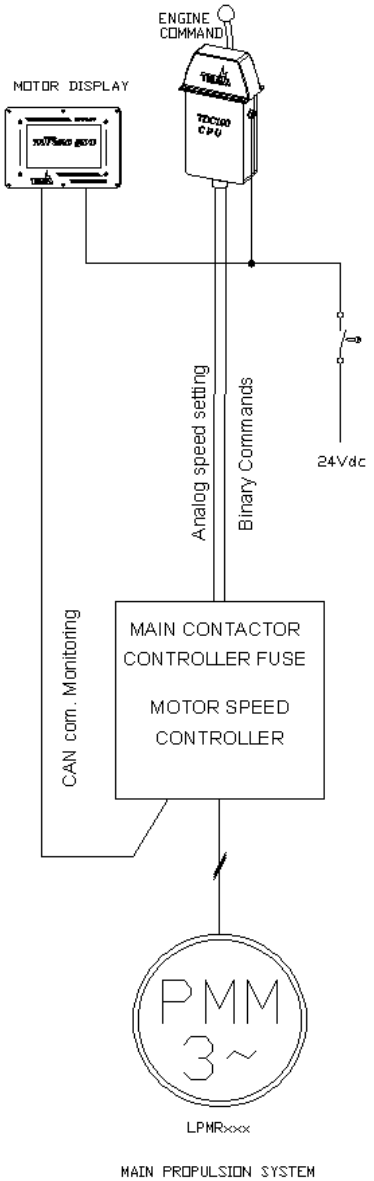

Figure 1. Basic configuration of electrical propulsion system [10]

microcontrollers that communicate via CAN (Controller Area Network).

Besides reducing mechanical failure probability this concept supports arbitrary number of electric propulsion units by adding corresponding number of throttles and assures independence in case of drive system malfunction.

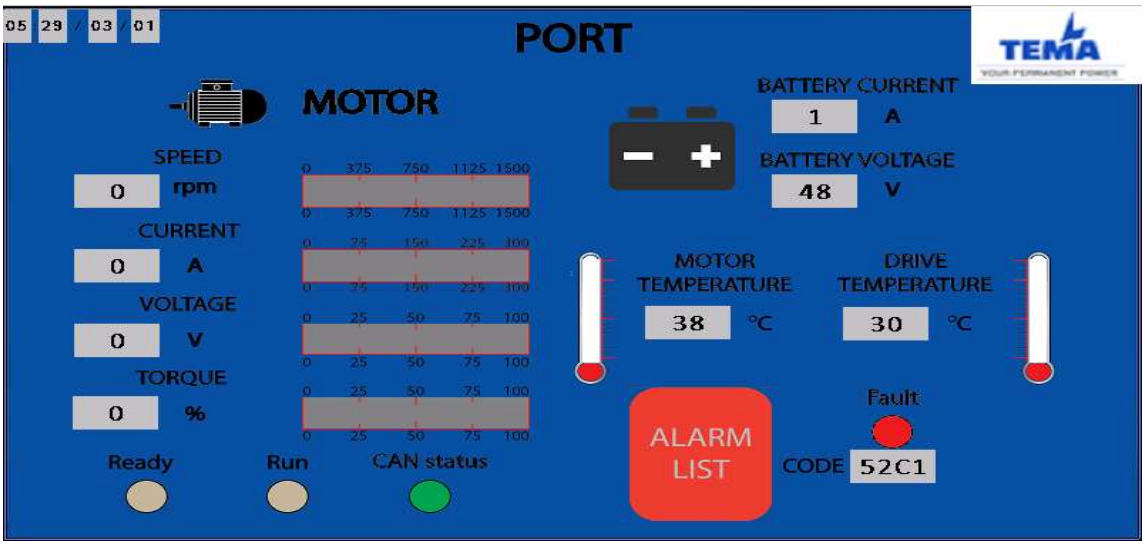

Figure 2. Propulsion system status display [10]

For this purpose, additional synchronizing display is incorporated on the main operating station and on the auxiliary operating stations the synchronization information on existing display are added (Fig. 4, Fig. 5, Fig. 6).

Following this logic, the bridge maneuvering system can be organized for single or twin propeller ships and auxiliary bow thruster or stern thruster propulsion system. The command place with operating station can be accommodated on the bridge, one or two wings, fly bridge, engine control room and engine room.

II. STATE OF THE ART

The problem that this work is dealing with was introduced in 1993. by Grabowski and Wallace [3]. They proposed solution by developing expert system which will assist operators in hazardous situations.

In [4] and [5] solutions are based on tablet technology. This means that all controls are compactly positioned on tablet screen allowing the operator to carry around operating station. The disadvantage of this kind of solutions appears when the operator, while holding controls, turns around facing the opposite direction. In this case if the operator keeps maneuvering because of inverted controls accidents can easily happen.

Scientists in [6] developed supporting maneuvering system for docking that, with support of AR visual system, shows 3D model of guide line which the operator follows for safe docking.

Since above proposed solutions focus primely on safe docking maneuver, we have developed CAN based Bridge Maneuvering System for monitoring and controlling modern marine propulsion systems based on high efficiency AC synchronous permanent magnet electrical motor controlled by fully digital real-time closed loop control algorithm [7], [8], [9].

This particular subject, as an interface between propulsion and operator, is poorly covered in conference papers and technical literature. Due to trends in marine propulsion systems that are based on electric concepts there are needs for additional effort investment in research and development of solutions for remote monitoring and control of modern electronic propulsion drives [12], [13], [14]. Accordingly, we propose maneuvering system specifically designed for remote control of modern high efficiency electric propulsion systems based on permanent magnet technology.

III. BRIDGE MANEUVERING SYSTEM

Here presented Bridge maneuvering system is propulsion to operator communication equipment developed specifically for ships powered by electric and hybrid marine propulsion that provides communication and overall monitoring of the system in real-time. Each maneuvering command throttle has associated microcontroller which continuously exchanges messages with central motor speed controller, using extended J1939 protocol [11]. In the extended J1939 protocol message, the first byte represents type of message, the second starting or destination address, the last byte serves as control mechanism and the remaining bytes are reserved for data. Some of predefined types of messages are: controller info, throttle position, engine settings and various alarms and errors. Obtained information, on the motor speed controller side, can be used directly in digital form or in some controller's configuration a local D/A converter can be requested that transmits given values to electric motor controller[13].

Digital core of the system is responsible for four different tasks:

- Throttle parametrization
- Maneuvering management
- Synchronization
- Display of system data

a) Throttle Parameterization

To accomplish correct engine behavior based on throttle position, parametrization of the system must first be performed. The process of parametrization takes place in service mode supported by built-in specific software tools what includes the potentiometer values adjustment. This means that minimal value on potentiometer is assigned to maximum backward position of the throttle, maximum value on potentiometer to maximum forward position and the arithmetical mean value between minimum and maximum value of potentiometer to neutral position of the throttle.

Additionally, this linear distribution of values allows us to distinguish direction orientation (greater then arithmetical mean value = forward and lesser then arithmetical mean value = backward). In some cases, this distribution of values can be defined by certain nonlinear function or based on values in given table [14].

b) Maneuvering management

The operator is managing the propulsion system via maneuvering throttle which can take three ranges of possible positions: neutral, forward and backward propeller speed commands. The movement of maneuvering throttle generates analog signal on potentiometer representing the angle of inclination of the throttle regarding to the neutral position. Microcontroller sends the signal to the additional module that converts analog input into digital, pack to the J1939 protocol message and sends it to electric motor speed controller. Based on received value the electric motor generates corresponding torque/speed in assigned direction to propeller shaft.

Beside digital communication commands the throttle command unit generates additionally separate control binary commands, like "System enable", "System idle" and direction "Ahead", "Astern" commands, referring classification society recommendation requests.

Associated separate display (Fig. 2) in this case presents overall system parameters like motor speed, current, voltage, torque, power, winding temperature, DC bus supply voltage, battery (if used) remaining energy capacity etc. In case of any system alarm occurred, the warning Alarm list sign is activated, and error code displayed. The operator has possibility to enter the alarm list for more detailed error explanation. The main page permanently displays the Enable and Run system status as well as monitoring communication channel functionality.

c) Synchronization

In case of multiple operating station positions (Fig. 3.) priorities must be defined. The operating stations form a system in which the position with highest priority is bridge, and all other positions have the same, lower priority. Operating stations with lower priority are unable to manage the ship. This default setting can be updated or changed in parametrization process.

Main operating station displays propulsion status page (Fig. 2.) and on additional display synchronization page. Synchronization display is connected to central microcontroller which contains information about all maneuvering throttles in the system. Secondary operating stations include display for showing the relationship with main operating station.

When the operator wants to switch control to auxiliary operating station the priority level must be changed. On synchronization display (Fig. 4.) the operator selects the function for giving permission for auxiliary operating station to take control. Once the control has been redirected the operator approaches operating station with highest priority and performs synchronization process. For this purpose, the maneuvering throttle must first be moved in neutral position (Fig. 5.) and then in position same as the throttle previously in charge.

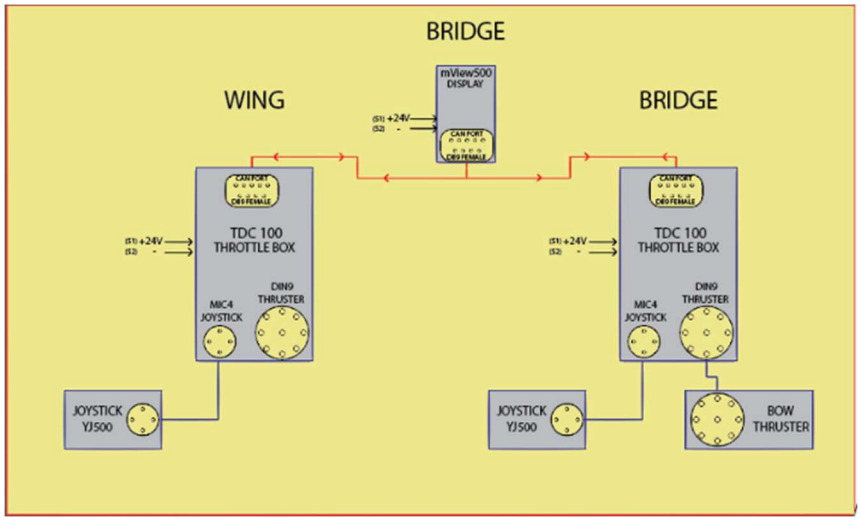

Figure 3. Multiple operating station system [10]

Moving throttle in correct direction from neutral position and reaching proximity of targeted position is considered as position matching. Until the matching is achieved i.e. synchronization process is complete the previous operating station position has control (Fig. 6.).

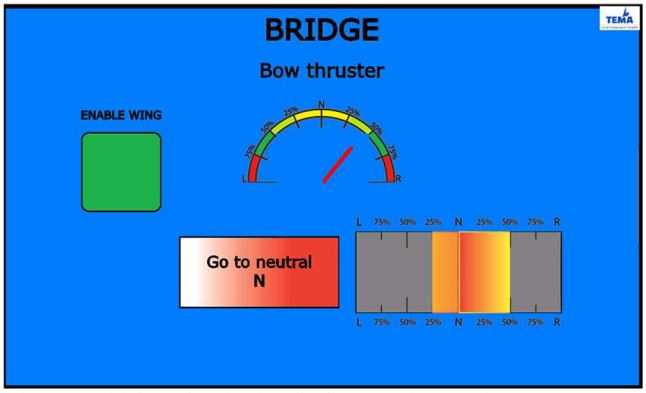

Figure 4. Initial synchronization display on main operating station. [10]

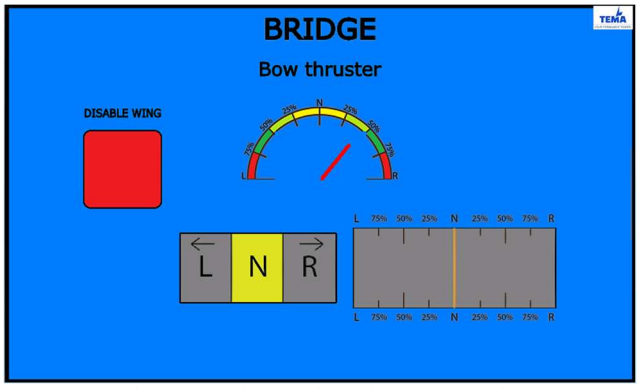

Figure 5. Synchronization display after redirecting control in process of synchronization [10]

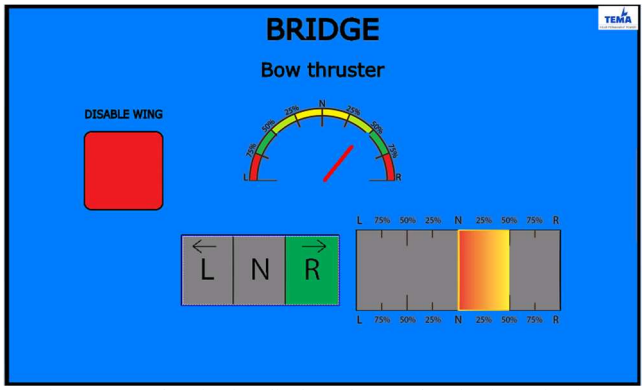

Figure 6. Synchronization display, after synchronization, wing in control [10]

For the main operating station to regain control the operator must select the function for disabling current operating station in control on the main synchronization display and repeat synchronization process now from the main operating station.

d) Display of system data

During maneuvering and synchronization processes the associated touch-screen 5" or 7" color display is used.

In ship management process it's important to monitor propulsion system parameters in real-time so that corresponding actions could be taken in case of alarm or error occurrence. Display microcontroller continuously receives data from motor speed controller, about speed, current, temperature, torque, power and power supply conditions or system malfunction errors in form of CAN communication signal (Fig. 2.). For malfunction history tracking by selecting the alarm list page, it's possible to get insight into the records of the last ten malfunction alerts (Fig. 7).

With increasing number of electric propulsion units the number of throttles on every operating station increases proportionally. However, this doesn't affect pre-set processes but implies repetition of defined activities for each throttle. If more than one propulsion system is used, each of them are separated on the level of remote control system, but it can be combined by separate communication channel on each motor speed control unit.

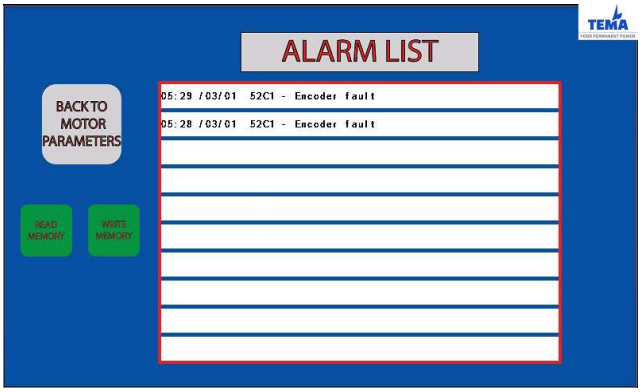

Figure 7. Alarm list display [10]

IV. CONLUSION

The paper presents original remote control system dedicated to main or auxiliary electric and hybrid marine propulsion system with incorporated system overall parameters, status and errors monitoring and data logging. This equipment permits direct digital connection to electric motor speed controller and provides multipoint operating station support, without using electromechanical components.

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Predictive Torque Vectoring Vehicle Control Based on a Linear Time Varying Model

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***Abstract*—In this paper we propose a torque vectoring and steering system based on a model predictive control (MPC) algorithm for a linear time varying (LTV) vehicle model. The goal is to ensure good reference tracking, while fulfilling various physical and design constraints. Non-linear vehicle model uses steering angle and wheel slip ratios as inputs. For control purposes, the model is linearized along the trajectory and then transformed to discrete time domain. Afterwards, the controller is tested using the sine with dwell driving manoeuvre with different prediction horizon lengths and different linearization approaches. Additionally, autonomously steered vehicle is compared to semi-autonomous vehicle in which the steering angle is determined by the driver and the results are discussed.**

***Keywords*—vehicle dynamics, model predictive control, torque vectoring, active safety, autonomous vehicle**

I. Introduction

Over the last few decades, the automotive industry has gone through countless changes. Nowadays, at the beginning of the 21st century, it is changing more rapidly than ever. Autonomous driving, increased use of hybrid and electric vehicles and infotainment systems are only some of the examples. As the passenger comfort increases, so do the safety requirements. Active safety systems became a standard in modern cars, not only to protect the passengers but other traffic participants as well. The legislation still differs from country to country, but these technologies are undeniably becoming more and more important throughout the world.

As opposed to standard active safety systems such as Anti-lock braking system (ABS) or Electronic stability control system (ESC), described in more details in [1], here a model predictive controller (MPC) is proposed to address vehicle stability regulation. MPC is a form of receding horizon control (RHC) approach where, at each time step, a sequence of optimal control inputs and states on a prediction horizon are calculated, but only the first input is applied to the system. Then the whole procedure is repeated. This method takes into consideration the dynamical model of a system, as well as its constraints.

This paper is based on control approaches described in [2] and [3]. In [3] a linear time-varying (LTV) MPC approach for controlling active front steering, active braking and active differentials in an autonomous vehicle are presented. Non-linear vehicle model, alongside with non-linear tyre model, is used for control design and simulation. Simulation results show that the LTV-MPC controller is able to stabilize a vehicle on a very low friction surface ($\mu = 0.3$). Another example of an autonomous path following via combined steering and independent braking can be found in [4], where a given path is followed using, so-called, three actuators approach. Low complexity MPC-based regulator calculates braking forces at the two sides of the vehicle, which are then passed to low-level braking logic which determines appropriate braking torques. It is shown that a slight increase in computational complexity (i.e. adding one more control input) results in significant performance improvement in terms of maximum entry speed. Similar LTV-MPC approach is used in [5]. Vehicle stability during a sudden lane change or excessive speed-entry in a curve on a high friction surface is regulated using differential braking strategy. Advantages of MPC in comparison to a linear quadratic regulator (LQR) are demonstrated in [6]. Just as in [4] and [5], MPC calculates breaking forces, which are used as an input of the low-level controller. Since MPC is able to take constraints into consideration, it provides more balanced use of breaking system than LQR. However, both controllers fail to maintain the stability of the system at higher speeds. Beal and Gerdes used MPC to enforce a safe handling envelope in which the driver is able to manoeuvre [7]. Control objects include keeping the vehicle inside the handling envelope (i.e. proposed constraints) and tracking the driver's intended behaviour. Controller design is verified using steer by wire rear wheel drive vehicle on a low friction surface. Additionally, a proof that the MPC stabilizes the vehicle regardless of the driver input is given. In [8], a constrained optimal control architecture to stabilize a vehicle near the limit of lateral acceleration using the rear axle electric torque vectoring configuration is proposed. Feasible reference path is calculated at every time step which ensures that the optimization problem always has a solution. The system is tested using a high fidelity vehicle model and a driver model in CarSim [9]. Another path following scheme can be found in [10]. Holistic cornering control (HCC) is designed in order to ensure track following, energy minimization and tyre reserve monitoring alongside with Driver command interpreter (DCI) which converts the drivers inputs to a target (or desired) state for the HCC to follow. HCC can have two different applications: differential braking on all four wheels or hybrid torque vectoring on the front and differential braking on the rear wheels. Therefore, it can be applied to conventional cars that do not have electric motors for actuation. Systematic online parameter selection

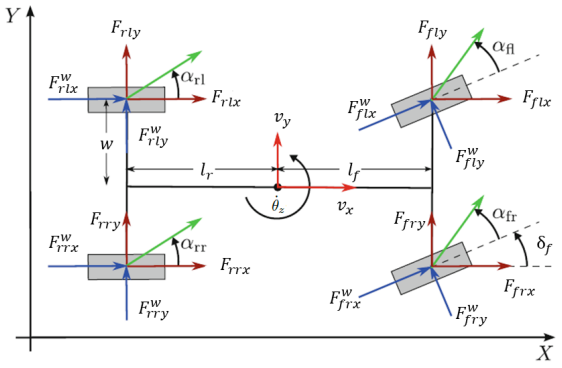

Fig. 1. Two track model of a vehicle [14].

approach for a classical LTV-MPC controller for vehicle path tracking was proposed in [11]. Various tuning parameters were divided into two groups, significant and insignificant, according to whether they had a direct influence on both the control performance and the entailed computational load. Then, extensive simulations and parameter selection were carried out to ensure highest attainable tracking performance under a given available CPU computational capacity.

In this work a torque vectoring and steering system based on LTV-MPC approach is proposed. A non-linear vehicle model without load transfer and with linear tyre models is considered.

II. System description

In this section, the model of the system is introduced. The model is a modification of the one described in [2] and [3]. TMEasy [13] model of the tyres is used for simulation purposes and to obtain a linearized model for prediction. It is assumed that all the states can be measured or estimated. In the following equations markings $\bullet \in \{f, r\}$ and $\star \in \{l, r\}$ represent the values on the front or rear and left or right wheel, respectively.

A. Vehicle model

In this paper, a two track model without load transfer, as shown in Fig. 1. is used. The model is given by

$$m\dot{v_x} = m\dot{\theta}_z v_y + F_{flx} + F_{frx} + F_{rlx} + F_{rrx}, \tag{1}$$

$$m\dot{v_y} = -m\dot{\theta}_z v_x + F_{fly} + F_{fry} + F_{rly} + F_{rry}, \tag{2}$$

$$\begin{aligned} J_z\ddot{\theta}_z = {} & l_f\left(F_{fly} + F_{fry}\right) - l_r\left(F_{rly} + F_{rry}\right) \\ & + w\left(-F_{flx} + F_{frx} - F_{rlx} + F_{rrx}\right), \end{aligned} \tag{3}$$

In (1)-(3) v_x represents longitudinal velocity, v_y lateral velocity and $\dot{\theta}_z$ yaw rate. Parameters are mass m, moment of inertia around yaw axis J_z, longitudinal distance of the front axle from the Centre of Mass (CM) l_f, longitudinal distance of the rear axle from the CM l_r and half of the vehicle's width w. Forces along longitudinal and lateral vehicle axes are calculated using tyre forces as

$$F_{f\star x} = F^w_{f\star x}\cos\delta_f - F^w_{f\star y}\sin\delta_f, \quad F_{r\star x} = F^w_{r\star x}, \tag{4}$$

$$F_{f\star y} = F^w_{f\star x}\sin\delta_f + F^w_{f\star y}\cos\delta_f, \quad F_{r\star y} = F^w_{r\star y}. \tag{5}$$

Steering angle is marked as δ_f. Non-linear tyre force models are, in general, given by

$$F^w_{\bullet\star x} = f_x(\alpha_{\bullet\star}, s_{\bullet\star x}, \mu_{\bullet\star}, F_{\bullet\star z}), \tag{6}$$

$$F^w_{\bullet\star y} = f_y(\alpha_{\bullet\star}, s_{\bullet\star x}, \mu_{\bullet\star}, F_{\bullet\star z}) \tag{7}$$

and tyre slip angles by

$$\alpha_{\bullet\star} = \arctan\left(\frac{v^w_{\bullet\star y}}{v^w_{\bullet\star x}}\right). \tag{8}$$

Wheel velocities are

$$v^w_{f\star x} = v_{f\star x}\cos\delta_f + v_{f\star y}\sin\delta_f, \quad v^w_{r\star x} = v_{r\star x}, \tag{9}$$

$$v^w_{f\star y} = -v_{f\star x}\sin\delta_f + v_{f\star y}\cos\delta_f, \quad v^w_{r\star y} = v_{r\star y}, \tag{10}$$

where

$$v_{flx} = v_x - w\dot{\theta}_z, \quad v_{fly} = v_y + l_f\dot{\theta}_z, \tag{11}$$

$$v_{frx} = v_x + w\dot{\theta}_z, \quad v_{fry} = v_y + l_f\dot{\theta}_z, \tag{12}$$

$$v_{rlx} = v_x - w\dot{\theta}_z, \quad v_{rly} = v_y - l_r\dot{\theta}_z, \tag{13}$$

$$v_{rrx} = v_x + w\dot{\theta}_z, \quad v_{rry} = v_y - l_r\dot{\theta}_z. \tag{14}$$

Since load transfer is neglected, vertical tyre forces can be expressed as

$$F_{f*z} = \frac{mgl_r}{2(l_f + l_r)}, \quad F_{r*z} = \frac{mgl_f}{2(l_f + l_r)}. \tag{15}$$

Longitudinal and lateral forces are assumed to be linear so (6) and (7) become

$$F^w_{\bullet\star x} = C_x(\mu_{\bullet\star}, F_{\bullet\star z})s_{\bullet\star x} = C_x s_{\bullet\star x}, \tag{16}$$

$$F^w_{\bullet\star y} = -C_y(\mu_{\bullet\star}, F_{\bullet\star z})\alpha_{\bullet\star} = -C_y\alpha_{\bullet\star}. \tag{17}$$

Longitudinal tyre stiffness C_x and cornering stiffness C_y have constant values throughout the simulation since the vertical load forces (15) are constant and driving surface is assumed to be equal for all four wheels, i.e. friction coefficients $\mu_{\bullet\star} = \mu$.

The non-linear vehicle dynamics described by (1)-(17) can be compactly written as

$$\dot{\xi}(t) = f(\xi(t), u(t)), \tag{18}$$

$$\eta(t) = h\left(\xi(t)\right), \tag{19}$$

with $\xi = \left[v_y, v_x, \theta_z, \dot{\theta}_z\right]^T$ being the state vector and $u = [\delta_f, s_{flx}, s_{frx}, s_{rlx}, s_{rrx}]^T$ the input vector. The output map is given as

$$h(\xi) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \xi. \tag{20}$$

Remark 1: It is worth noticing that the model (18)-(19) has a steering angle and longitudinal wheel slips as input variables. The existence of a low-level torque controller, which regulates the current slip at each wheel to the desired slip value, is assumed [3].

Remark 2: The model used for simulation testing is the same as (18)-(19), but with longitudinal and lateral load transfer and non-linear tyres included. Static load distribution is assumed, i.e. the pitch and roll rotation along with the vertical motion of the sprung mass of the vehicle is neglected [12]. Non-linear tyre dynamics is described using TMEasy tyre model with coupled longitudinal and lateral forces [13].

B. Reference generation

In accordance with output mapping (20), reference vector equals $\eta^{ref} = \left[v_y^{ref}, v_x^{ref}, \theta_z^{ref}, \dot{\theta}_z^{ref}\right]^T$. In order for yaw angle and yaw rate references to be realistic, an estimation based on a kinematic vehicle model is used. In the model, tyre slip angles at both wheels are assumed to be zero, which is true only for low speed motion. Therefore, the real vehicle will not be able to follow those references while driving at high speeds.

Equation used for yaw rate estimation based on steering angles, vehicle slip angle and vehicle velocity is [1]

$$\dot{\theta}_z^{ref} = \frac{v \cos\alpha}{l_f + l_r} \left(\tan\delta_f - \tan\delta_r\right). \tag{21}$$

The vehicle model uses only front wheel steering so (21) can be written as

$$\dot{\theta}_z^{ref} = \frac{v_x^{ref}}{l_f + l_r} \tan\delta_f. \tag{22}$$

Yaw angle reference θ_z^{ref} is obtained by integrating $\dot{\theta}_z^{ref}$.

III. Controller formulation

A. MPC problem formulation

MPC algorithm uses a discrete-time model of the system (18)-(20) which can be written as follows:

$$\xi(k+1) = f_d(\xi(k), u(k)), \tag{23}$$

$$u(k) = u(k-1) + \Delta u(k), \tag{24}$$

$$\eta(k) = h\left(\xi(k)\right). \tag{25}$$

Using the non-linear model (23)-(25) would result in non-linear and possibly non-convex optimization problem. Therefore, the system is rewritten as a linear time varying (LTV) model. Consider a steady state response of the system starting from the state ξ_0 and the input u_0:

$$\begin{aligned} \hat{\xi}(k+1) &= f_d(\hat{\xi(k)}, u(k)), \\ u(k) &= u_0, \\ \hat{\xi}(0) &= \xi_0. \end{aligned} \tag{26}$$

The system (26) can be approximated using the following LTV model [3]:

$$\delta\xi(k+1) = A_{k,0}\delta\xi(k) + B_{k,0}\delta u(k), \tag{27}$$

with matrices $A_{k,0}$ and $B_{k,0}$ defined as

$$A_{k,0} = \left.\frac{\partial f_d}{\partial \xi}\right|_{\hat{\xi}_0(k), u_0}, \quad B_{k,0} = \left.\frac{\partial f_d}{\partial u}\right|_{\hat{\xi}_0(k), u_0}, \tag{28}$$

$$\delta\xi(k) = \xi(k) - \hat{\xi}_0(k), \quad \delta u(k) = u(k) - u_0(k). \tag{29}$$

The LTV model (27)-(29) describes the deviations of the non-linear system (23) from the state trajectory $\hat{\xi}_0(t)$, when the control input $u(k) = u_0$ is applied. It can be rewritten as

$$\xi(k+1) = A_{k,0}\xi(k) + B_{k,0}u(k) + d_{k,0}(k), \tag{30}$$

with $d_{k,0}$ being the difference between the steady state response of the non-linear and the LTV model:

$$d_{k,0}(k) = \hat{\xi}_0(k+1) - A_{k,0}\hat{\xi}_0(k) - B_{k,0}u_0, \quad k \geq 0. \tag{31}$$

The equation (30) shows the standard linearization approach. However, when designing an RHC, the system is linearized around a predicted trajectory, using state and input predictions from the previous time step. At every time instant t, the LTV model is

$$\xi(k+1) = A_{k|t-1}\xi(k) + B_{k|t-1}u(k) + d_{k|t-1}, \tag{32}$$

where

$$\begin{aligned} A_{k|t-1} &= \left.\frac{\partial f_d}{\partial \xi}\right|_{\xi_{k|t-1}, u_{k|t-1}}, \\ B_{k|t-1} &= \left.\frac{\partial f_d}{\partial u}\right|_{\xi_{k|t-1}, u_{k|t-1}}, \end{aligned} \tag{33}$$

$$d_{k|t-1} = \hat{\xi}_{k+1|t-1} - A_{k|t-1}\hat{\xi}_{k|t-1} - B_{k|t-1}u_{k|t-1}, \tag{34}$$

$$\begin{aligned} \hat{\xi}_{k+1|t-1} &= f_d(\hat{\xi}_{k|t-1}, u_{k|t-1}), \\ \hat{\xi}_{t|t-1} &= \xi(t), \quad k = t, \ldots, t+N-1, \end{aligned} \tag{35}$$

N is the prediction horizon and $\xi_{k|t-1}$ and $u_{k|t-1}$ denote the prediction of the values $\xi(k)$ and $u(k)$ at the time $t-1$, with the exceptions:

$$\xi_{t|t-1} = \xi(t), \quad u_{t+N-1|t-1} = u_{t+N-2|t-1}. \tag{36}$$

The MPC problem is formulated as

$$\begin{aligned} &\min_{U_t, \mathcal{E}_t} J(\xi_t, \eta_t^{ref}, U_t, \mathcal{E}_t) \\ &\text{s.t. } \xi_{k+1} = A_{k|t-1}\xi_k + B_{k|t-1}u_k + d_{k|t-1}, \\ &\quad (\xi_k + \varepsilon_k, u_k) \in \Xi \times \mathbb{U},\ k = t, \ldots, t+N-1, \\ &\quad \xi_{t+N} + \varepsilon_{t+N} \in \Xi_f, \\ &\quad \xi_t = \xi(t), \end{aligned} \tag{37}$$

where $U_t = [u_t, u_{t+1}, ...u_{t+N-1}]$ stands for control input trajectory, ε_t is a vector of slack variables at time t and $\mathcal{E}_t = [\varepsilon_t, \varepsilon_{t+1}, ...\varepsilon_{t+N-1}]$ slack variable sequence throughout the prediction horizon. Polytopes $\Xi \in \mathbb{R}^n$, $\mathbb{U} \in \mathbb{R}^m$ and $\Xi_f \in \mathbb{R}^n$ are state, input and final state constraints, respectively. Optimization objective equals

$$J(\xi_t, \eta_t^{ref}, U_t, \mathcal{E}_t) = \sum_{k=t}^{t+N} \|\eta_k - \eta_t^{ref}\|_Q^2 + p\|\varepsilon_k\|_I^2 + \sum_{k=t}^{t+N_c-1} \|u_k\|_S^2 + \sum_{k=t}^{t+N_c-1} \|\Delta u_k\|_R^2, \tag{38}$$

where N_c is the control horizon, I identity matrix, p scalar weight and $Q = Q^T \succeq 0$, $R = R^T \succeq 0$ and $S = S^T \succeq 0$ weight matrices of corresponding dimensions.

Once the computation is finished and the optimal solution $U_t^* = \left[u_t^*, u_{t+1}^*, ...u_{t+N-1}^*\right]$ to problem (37) is obtained, the first sample of U_t^*

$$u(t, \xi(t)) = u_t^* \tag{39}$$

is applied to the system (18)-(19).

B. Controller parameters

The controller has the following parameters:

- *sample time:* $T = 0.05s$
- *horizons*: $N = 20$, $N_c = 10$
- *weight on slack variables*: $p = 10$
- *weights on tracking errors*: $Q_{v_y} = 1$, $Q_{v_x} = 0.1$, $Q_{\theta_z} = 100$, $Q_{\dot{\theta}_z} = 75$, $Q_{ij} = 0$ for $i \neq j$
- *weights on input*: $S_{\delta_f} = 1 \cdot 10^{-7}$, $S_{s_{flx}} = 1$, $S_{s_{frx}} = 1$, $S_{s_{rlx}} = 1$, $S_{s_{rrx}} = 1$, $S_{ij} = 0$ for $i \neq j$
- *weights on input rates*: $R_{\delta_f} = 5 \cdot 10^3$, $R_{s_{flx}} = 1 \cdot 10^{-3}$, $R_{s_{frx}} = 1 \cdot 10^{-3}$, $R_{s_{rlx}} = 1 \cdot 10^{-3}$, $R_{s_{rrx}} = 1 \cdot 10^{-3}$, $R_{ij} = 0$ for $i \neq j$
- *constraints on inputs and input rates*: $\delta_{f,min} = -8°$, $\delta_{f,max} = 8°$, $\Delta\delta_{f,min} = -2°$, $\Delta\delta_{f,max} = 2°$, $s_{\bullet\star x,min} = -4.4\%$, $s_{\bullet\star x,max} = 4.4\%$, $\Delta s_{\bullet\star x,min} = -0.75\%$, $\Delta s_{\bullet\star x,max} = 0.75\%$
- *constraints on tyre slip angles*: $\alpha_{\bullet\star,min} = -3.4°$, $\alpha_{\bullet\star,max} = 3.4°$

Longitudinal slip and slip angle constraints ensure that the linear tyre models can be applied, as shown in Fig. 2. State constraints are the same along the whole prediction horizon, including the final step. In other words $\Xi_f = \Xi$. For the tyre slip angle constraints to be linear, it is assumed that $\tan\alpha \approx \alpha$ and $\delta_f \approx 0$.

Longitudinal slip rate constraints Δs_x depend on the dynamics of the low-level slip controller. The upper bounds depend on the powertrain dynamics while the lower bounds depend on the braking system dynamics.

Control horizon N_c defines the number of steps used for prediction of the input variables. For all the steps after N_c, control input is held constant, i.e. $\Delta u_{t+k} = 0 \; \forall k \geq N_c$. It is a standard practical scheme, called input blocking, which reduces computational complexity of an MPC problem [15].

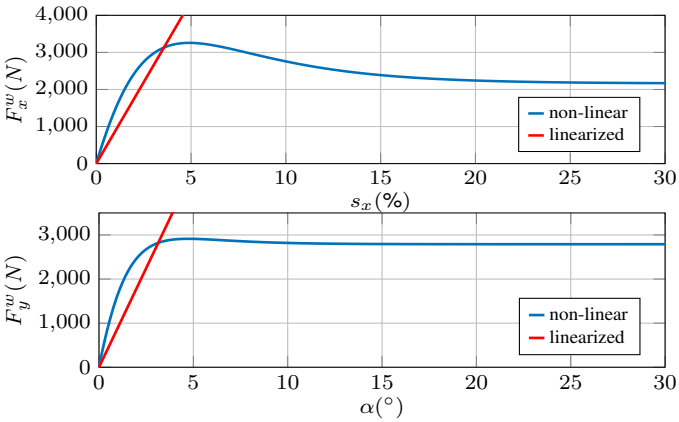

Fig. 2. Linear approximation of longitudinal and lateral tyre force models.

IV. Simulation Results

The control objective is to follow yaw angle and yaw rate references, while maintaining constant longitudinal speed and minimizing drift. Steering manoeuvre used for algorithm testing is based on the sine with dwell manoeuvre [16]. Longitudinal velocity reference is $v_x^{ref} = 80$ km/h, whereas drift minimization is achieved by setting $v_y^{ref} = 0$ km/h. All the tests are performed on a low friction surface with $\mu = 0.6$ (wet asphalt) to better demonstrate advantages and disadvantages of different control approaches. The MPC problem (37) is solved using GUROBI and YALMIP toolbox [17], [18].

A. Prediction and control horizon length variation

Here, the effect of varying the prediction and control horizon is analyzed. In Fig. 3. it can be seen that the nominal controller ($N = 20$ and $N_c = 10$) results in the smallest deviation from the desired v_y and v_x references. This causes yaw angle and yaw rate to have higher deviations from the reference during the transient, but enables the vehicle to eliminate tracking errors fast after the steering manoeuvre is over. Reducing control horizon to $N_c = 3$ only slightly deteriorates vehicle handling. However, reducing both prediction and control horizons to $N = 3$ and $N_c = 3$ causes very poor handling. The comparison shows that, in this case, numerical complexity of the optimization problem can be reduced by lowering control horizon, without a big impact on controller performance.

B. Linearization approach variation

The nominal controller uses a model of the system linearized along the prediction horizon and given by the equations (32)-(36). Model linearized at the first step is defined as

$$\xi(k+1) = A_t\xi(k) + B_t u(k) + d_{k,t}, \tag{40}$$

with

$$A_t = \left.\frac{\partial f_d}{\partial \xi}\right|_{\hat{\xi}_{t,t}, u_{t|t-1}}, \quad B_t = \left.\frac{\partial f_d}{\partial u}\right|_{\hat{\xi}_{t,t}, u_{t|t-1}}, \tag{41}$$

$$d_{k,t} = \hat{\xi}_{k+1,t} - A_t\hat{\xi}_{k,t} - B_t u_{t|t-1}, \tag{42}$$

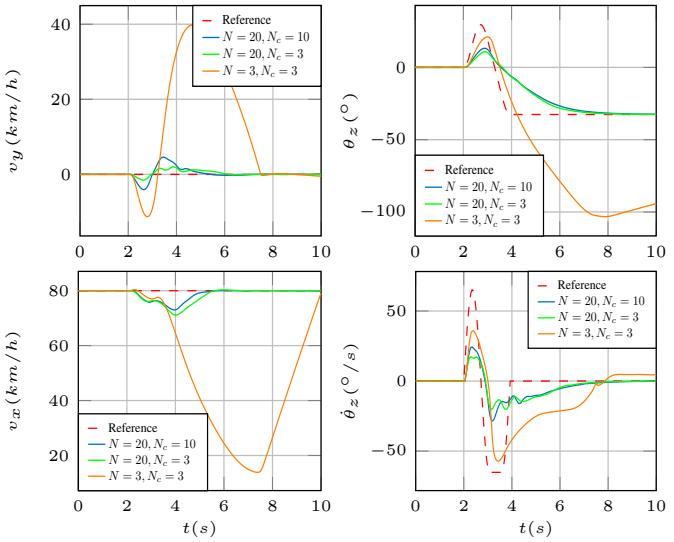

Fig. 3. Lateral velocity v_y, longitudinal velocity v_x, yaw angle θ_z and yaw rate $\dot{\theta}_z$ response for different lengths of prediction and control horizon.

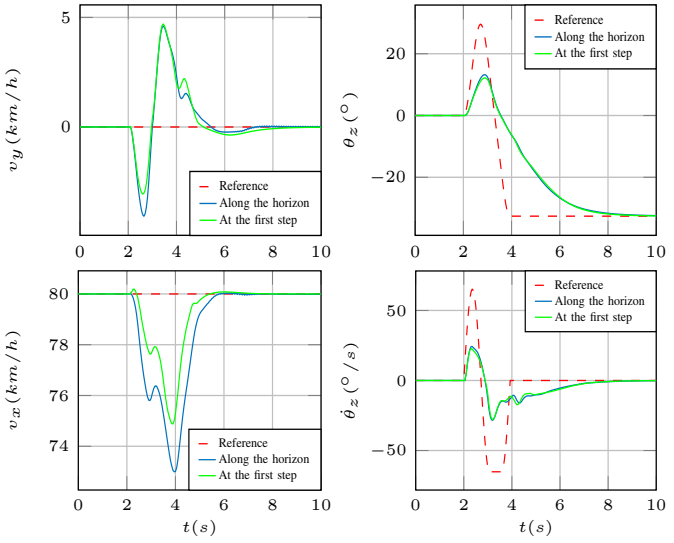

Fig. 4. Lateral velocity v_y, longitudinal velocity v_x, yaw angle θ_z and yaw rate $\dot{\theta}_z$ response for different linearization approaches.

$$\begin{aligned}\hat{\xi}_{k+1,t} &= f_d(\hat{\xi}_{k,t}, u_{t|t-1}),\\ \hat{\xi}_{t,t} &= \xi(t), \quad k = t, \ldots, t+N-1.\end{aligned} \tag{43}$$

Fig. 4. shows the effect of different linearization approaches. Performance of the controller which uses the model linearized along the prediction horizon is slightly better when comparing it to the nominal controller. Tracking deviation is similar for lateral velocity, while it is smaller for longitudinal velocity and almost the same for yaw angle and yaw rate. By comparing closed loop costs in TABLE I, it can be concluded that the change in the linearization approach can reduce computational complexity without a big influence on the performance of the system.

C. Autonomous and manually steered vehicle comparison

In this experiment performance of autonomously and manually steered vehicle, both controlled using the nominal controller settings, is compared. In the autonomous vehicle all the control inputs are determined by the MPC algorithm, whereas in the manually steered vehicle MPC algorithm controls only longitudinal slip ratios at four wheels and the steering angle is determined by the driver. The MPC problem (37) is, in that case, modified by introducing an additional equality constraint:

TABLE I
CLOSED LOOP COST COMPARISON

Controller	Closed loop cost
Linearized along the horizon	1295.023
Linearized at the first step	1315.535
Manually steered vehicle	8353.25

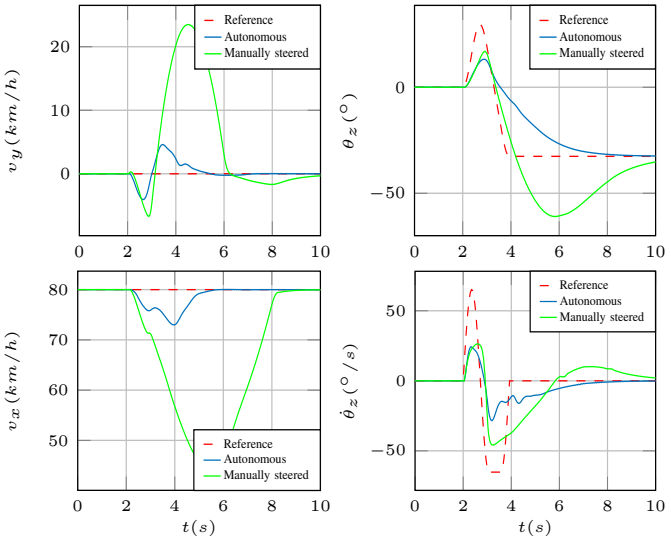

Fig. 5. Lateral velocity v_y, longitudinal velocity v_x, yaw angle θ_z and yaw rate $\dot{\theta}_z$ response for autonomous and manually steered vehicle.

$$u^{(1)}(k) = \delta_f(t), \quad k = t, \ldots, t+N-1, \tag{44}$$

where $u^{(1)}$ represents the first element of a column vector u. To design tyre slip angle constraints for the manually steered vehicle, the real steering angle value δ_f is used, rather than the assumption $\delta_f \approx 0$. References are the same for both simulation scenarios.

In the Fig. 5. it can be seen how, during the steering manoeuvre, the manually steered vehicle tracks all the referent values much worse than the autonomous one. This is mainly due to the fact that, in the autonomous vehicle, the controller predicts future steering angle values, whereas in the manually steered vehicle steering angle values are held constant throughout the prediction horizon and future ones cannot be predicted. Hence, the controller has incorrect information about future actions of a driver. Deteriorated behaviour can also be seen by observing closed loop costs in TABLE I. By observing the Fig. 6. one can see that the autonomous vehicle holds the limit values of steering angle longer than the manually steered one and has, therefore, different slip ratio distribution on all four wheels.

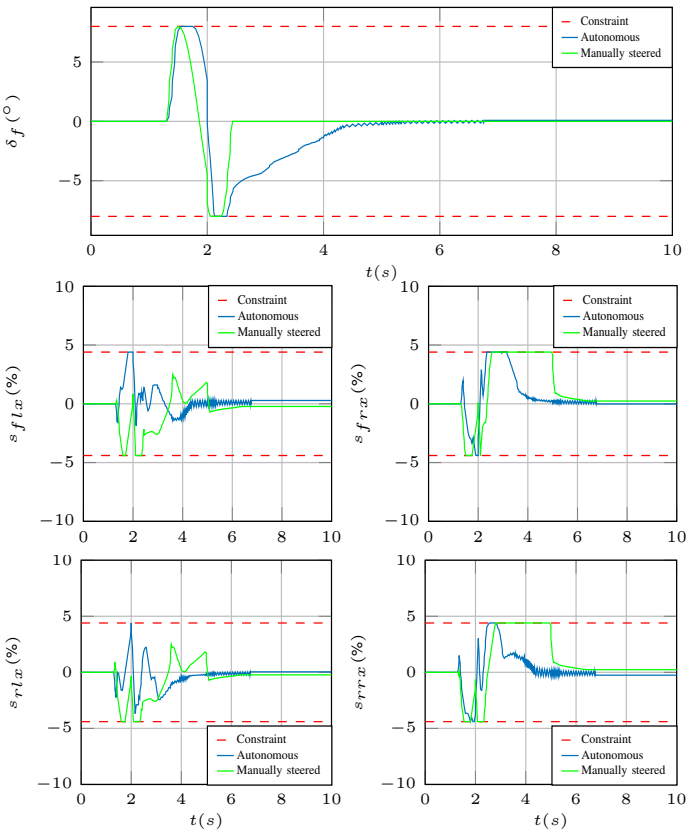

Fig. 6. Steering angle and slip ratios on all four wheels for autonomous and manually steered vehicle.

V. Conclusion

In this paper we presented the model predictive controller for autonomous torque vectoring and steering. The system was tested on a badly conditioned surface using a standard testing manoeuvre and showed the ability to maintain the stability of a vehicle in spite of using approximately linearized tyre model and neglecting the coupling of longitudinal and lateral tyre forces.

Direction of the future work would be to include lateral and longitudinal load transfer into the vehicle model and to replace the linear tyre model with a non-linear model inside the MPC regulator. Additionally, the system should be tested using a high fidelity simulation environment or a real vehicle.

Acknowledgment

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EMBEDDED SYSTEMS AND APPLICATIONS

Bolt65 – performance-optimized HEVC HW/SW suite for Just-in-Time video processing

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***Abstract* – This paper presents Bolt65 HEVC software/hardware suite, consisting of encoder, decoder and transcoder, that is being developed at Faculty of electrical engineering and computing, University of Zagreb. One of the primary focus of Bolt65 is achieving Just-in-Time requirements that would enable video encoding/transcoding on demand. To achieve this goal, Bolt65 tries to maximally utilize all software and hardware components of the system on different architectures, from homogeneous CPU architectures with vector extensions to heterogeneous, accelerator-based architectures that have different types of processing cores. CPU-only implementation of Bolt65 was compared with referent HM HEVC software in three different encoding configurations: All Intra (AI), Low delay (LD) and Random Access (RA). Results show that Bolt65 achieves significant speed-up in all configurations and bitrate savings in AI and RA modes while sacrificing quality in order to achieve just-in-time requirements.**

Keywords - HEVC;video codec;Just-in-Time;Bolt65; heterogeneous accelerator-based architectures

I. INTRODUCTION

Statistics show that Global video IP traffic will be 82 percent of all consumer Internet traffic by 2022, up from 75 percent in 2017. The annual global IP traffic will reach 4.8 ZB (ZB = 1000 Exabytes) by 2022, 3.9 ZB of which will be video content [1]. Handling this enormous amount of data is a very challenging task for the video content providers in years to come. Another factor that highlights this problem is the fact that a range of different devices that can play video content is constantly growing. With such diversity of devices, that have different decoding capabilities, computing resources, network bandwidths, and resolutions, a single copy of the encoded video cannot match requirements of all devices.

Current video providers tackle with this problem usually by pre-encoding and storing multiple copies of the same video on the server and sending the version that best satisfies the requirements of the user. Such an approach has very high storage costs and pre-encoded video streams may still not exactly match end-user requirements. Furthermore, emerging spatial resolutions (4K, 8K...), as well as the long-tail distribution of video content (90 percent of videos are viewed by only 10 percent of users and vice versa) make this concept hardly sustainable. Just-in-Time (JiT) video encoding/transcoding has one of the key roles in resolving these issues. Video transcoding refers to the problem of adapting on-the-fly Internet video content based on user's device features or specific operational conditions. Adaptation involves changing video properties, such as spatial, temporal and amplitude resolution, bitrate and video format. Instead of storing multiple copies on the server, only one version with the highest quality can be stored and transcoded on demand in real-time. Although JiT transcoding increases efficiency while providing the best possible QoE, it is extremely compute and data-intensive operation.

High efficiency video coding (HEVC/H.265) standard is novel video compression standard developed by Joint Collaborative Team on Video Coding (JCT-VC) as a joint activity of ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG) standardization organizations [2][3]. HEVC standard shows a significant advance in compression efficiency compared to its predecessors, such as Advanced Video Coding (AVC). At the same subjective quality, HEVC saves approximately 50 percent bitrate but increases computational complexity and resource requirements by up to 10 times [4].

II. BOLT65 HEVC CODEC

Bolt65 is a codename for an ongoing project on Faculty of Electrical Engineering and Computing in Zagreb. The aim of the project is to develop a "clean room" software/hardware suite consisting of an encoder, decoder, and transcoder. Special focus is set on the performance-efficiency achieved by low-level optimizations and hardware-software co-design by exploiting heterogeneous accelerator-based architectures. Another important focus of Bolt65 is the just-in-time requirement which sets constraints on processing time making Bolt65 suitable for encoding/transcoding on demand. The project is intended for research and development of current and future video processing algorithms and high-performance computing architectures. Bolt65 suite is written from scratch in C++ and is supported on Windows and Linux operating systems. In the following subsections, the main features of Bolt65 are presented.

A. Input and output

Bolt65 encoder supports input video data in YUV and Y4M format with 8-bit pixel samples and 4:2:0 chroma sampling, which corresponds with the Main profile

defined in HEVC standard version 1. Prefetching frames from the input file has been implemented to avoid waiting for the frame data to be loaded after each cycle. The output of the encoder is HEVC bitstream of the Main profile.

Bolt65 decoder supports decoding HEVC bitstreams generated by Bolt65 encoder. In the current version, the decoder is used only in cascade with encoder forming a transcoder. In the future, the decoder will be in conformance with the Main profile defined in HEVC standard.

Bolt65 transcoder supports homogeneous transcoding of HEVC bitstreams. The input to the process is HEVC encoded video bitstream while the output is HEVC encoded video bitstream with modified video properties. Transcoder supports downscaling of the spatial, temporal and amplitude resolutions. The current version of the transcoder is implemented as cascaded pixel-domain transcoding architecture.

B. Block structures

The input video frame is divided into Coding Tree Units (CTU). Each CTU consists of three Coding three blocks (CTB), one luma block and two corresponding chroma blocks and associated syntax elements [5]. Bolt65 supports CTU sizes of NxN, where $N \in \{16,32,64\}$, meaning that luma CTB is NxN, while, due to 4:2:0 color subsampling, chroma CTBs are (N/2xN/2). CTUs can be divided into four smaller units called Coding Units (CU) following a quadtree structure, where CTU represent tree root. Bolt65 supports CU sizes of NxN, where $N_{min} \leq N \leq N_{max}$ and $N \in \{8,16,32\}$. N_{min} and N_{max} are defined in the configuration, if not, default values of $N_{min}=8$ $N_{max}=32$ are used.

Each leaf CU can act as a root for residual quadtree (RQT). The residual quadtree is a tree of transform units (TU) containing transform blocks (TB) that can be created to enable the adaptation of the transform functions to the varying space-frequency characteristics of the residual signal. In Bolt65 luma TB sizes are MxM, while chroma TB sizes are (M/2)x(M/2), where M=N and $M \in \{8,16,32\}$, N being the size of RQT root.

Leaf CUs can also be split to up to four prediction units (PU) that can be used for more precise motion estimation. HEVC standard supports 8 partitioning modes for splitting CU to PU: MxM, Mx(M/2), (M/2)xM, (M/2)x(M/2), Mx(M/4), Mx(3M/4), (M/4)xM and (3M/4)xM. Currently, in Bolt65, only MxM partitioning mode is used.

C. Intra and Inter prediction

Each of the leaf CUs can be partitioned in one or more prediction units (PU) that are predicted by taking advantage of spatial (Intra-prediction) [6] or temporal (Inter-prediction) [7] dependency of video frames. Prediction output represents a block of predicted samples which is then subtracted from the original block to form a residual (i.e. prediction errors) used as an input in following steps of the encoder. Splitting CU to smaller PUs can achieve better coding efficiency, but at the same time increases computational complexity.

Both prediction modes are supported by Bolt65. In intra prediction, all 35 modes, 33 angular and 2 non-directional (DC and planar) are evaluated. Several algorithms for determining distortion are available: Sum of absolute differences (SAD), Sum of absolute transform differences (SATD) and Mean square error (MSE). Determining which of these algorithms will be used as a block matching measurement will affect coding efficiency and computing complexity, which is an important aspect to consider with Just-in-Time requirement.

Motion estimation process in inter prediction is performed by searching the best candidate from the previously encoded frame. Search algorithms that are supported in Bolt65 are Three Step Search (TSS), Diamond Search and Full Search. In HEVC, fractional half- and quarter-pixel motions are possible, but they require additional interpolation filter. Since interpolation is a compute-intensive operation, each of the mentioned search algorithms has an option to exclude fractional motions from a search process.

D. Transformation and quantization

Residual blocks are transformed from spatial to the frequency domain using a discrete cosine transform (DCT) and then quantized with defined quantization parameter (QP). In the decoding loop, dequantization and inverse transformation are used to form a reconstructed frame.

Bolt65 supports HEVC standard integer transform for all transform block sizes of NxN, where $N \in \{4,8,16,32\}$. Since all functions (DCT, IDCT, quantization, and dequantization) are highly parallelizable, advanced vector extensions (AVX, AVX2) on x86 instruction set architectures for Intel processors are used for their optimization.

A high-throughput fully pipelined FPGA-based accelerator for Bolt65 DCT has been designed and implemented. The architecture consists of two cascaded 1D DCT cores with a constant throughput of 32 pixels per cycle in all size modes. The accelerator receives the data through a 512-bit bus which enables fetching 32 16-bit samples in a single clock. The pipeline for worst-case scenario consists of 75 stages which means that for processing a single 32x32 matrix, 106 cycles are necessary. The accelerator was integrated with Bolt65 software encoder/decoder/transcoder in MANGO project [8].

E. In-loop filters

The in-loop filters are applied in the encoding and decoding loops to reduce artifacts that can appear on block boundaries, increasing the quality of reconstructed pictures. There are two types of in-loop filters in HEVC: Deblocking filter [9] and Sample adaptive offset (SAO) [10]. The current version of Bolt65 encoder implements the deblocking filter, which can be enabled or disabled depending on the timing constraints set.

The implementation of SAO filtering is planned and will be available in future version of Bolt65.

F. Parallelization

HEVC standard introduces two novel parallelization concepts, Tile and Wavefront parallel processing, along with the slices, which were also available in previous AVC standard. Tiles, performance-wise, outperform other parallelization concepts in HEVC [11], so this concept was implemented in Bolt65. Tiles are rectangular-shaped groups of CTUs separated by vertical and horizontal boundaries, which can be processed independently and can be split uniformly or non-uniformly. Load balancing algorithms, such as TTLB or Tile-cost balancing algorithm, can be based on historical data, dynamically change tile boundaries to efficiently distribute the workload. In the case when there are more tiles than processing cores, several algorithms for the thread to core assignment which increase the performance of the encoder/transcoder are available.

G. Entropy coding

After quantization, all coefficients, along with other syntax elements are entropy coded using context-adaptive binary arithmetic coding (CABAC) [12]. Bolt65 performs entropy coding on a tile level, forming parts of the bitstream in parallel and then merges them to form a final bitstream.

H. Configurations

As defined in Common Test Conditions [13], three configurations of the encoder are available:

- Intra, main
- Random-Access, main
- Low-delay, main

For each video sequence, four quantization parameter values are to be used: 22, 27, 32 and 37. These values define the QP values used for the I-frames in a sequence (configuration files further define QP values used for other frames).

I. External dynamic control

Both Bolt65 encoder and transcoder execution can be controlled during runtime by an external process that can monitor the current state of the encoding/transcoding. Changing some of the parameters, such as quantization parameter, search algorithm or GOP structure can be used to increase or decrease coding efficiency, power consumption or performance, depending on the current requirements posed by an external factor of the system. Hence, different policies can be implemented and used on the application, without the need for modification of existing source code.

III. Performance evaluation and analysis

Characteristics of Bolt65 were evaluated and compared to the newest version of referent HM encoder [14]. Benchmark was conducted on 9 video sequences shown in Table I. Validation and verification of encoded bitstreams were performed using StreamEye software [15].

TABLE I. Test video sequences

Video sequence	Class	Resolution	Number of frames (frame rate)
Shields	E	1280x720	504 (50fps)
ParkRun	E	1280x720	504 (50 fps)
KristenAndSara	E	1280x720	600 (60 fps)
BasketballDrive	B	1920x1080	500 (50fps)
BQTerrace	B	1920x1080	600 (60fps)
BlueSky	B	1920x1080	217 (25fps)
PedestrianArea	B	1920x1080	375 (25 fps)
RushHour	B	1920x1080	500 (25 fps)
Traffic	A	2560x1600	150 (30 fps)

All experiments were conducted on an environment shown in Table II, using one core of the processor.

TABLE II. Test environment

Processor	Intel i5 4570 (3.2 GHz)
Memory	32 GB
L1 cache	32 kB
L2 cache	256 kB
Compiler	Intel C++ 18.0
Operating system	64-bit Windows 10 Pro

All three encoder configurations, mentioned in Section I.A, are used based on HM default configuration files that are available with the software (*encoder_intra_main.cfg*, *encoder_lowdelay_main.cfg*, *encoder_randomaccess_main.cfg*). Some of the encoding parameters used on both encoders are shown in Table III.

TABLE III. Encoder configuration

Coding option	Parameter
QP	32, fixed
Search algorithm	Fast, search area 64
GOP	All Intra, Low delay, Random Access (every 32. frame is I frame)
In loop filters	Both, deblocking filter and SAO, disabled
CTU size	64x64
QP	32, fixed
Search algorithm	Fast, search area 64
GOP	All Intra, Low delay, Random Access (every 32. frame is I frame)
In loop filters	Both, deblocking filter and SAO, disabled

During the encoding process, three aspects were considered:

TABLE IV. COMPARISON OF HM REFERENCE ENCODER AND BOLT65

Video sequence	All Intra (AI)			Low delay (LD)			Random Access (RA)		
	Speedup	**PSNR**	**Bitrate**	**Speedup**	**PSNR**	**Bitrate**	**Speedup**	**PSNR**	**Bitrate**
Shields	42.34x	-10.69%	8.21%	148.99x	-13.61%	-90.92%	224.42x	-21.72%	63.82%
ParkRun	42.31x	-12.23%	20.40%	176.57x	-13.39%	-55.58%	235.12x	-18.50%	107.67%
KristenAndSara	41.76x	-10.30%	-13.15%	226.82x	-9.91%	-72.91%	234.53x	-17.69%	948.17%
BasketballDrive	41.02x	-5.88%	-0.76%	230.69x	-11.67%	-62.38%	236.78x	-14.52%	274.89%
BQTerrace	42.47x	-8.51%	0.30%	188.20x	-11.27%	-79.21%	268.39x	-15.33%	230.00%
BlueSky	41.01x	-10.22%	8.55%	180.13x	-11.15%	-86.07%	188.77x	-19.48%	70.20%
PedestrianArea	40.40x	-5.89%	9.78%	264.59x	-12.10%	-55.59%	233.00x	-15.50%	524.38%
RushHour	40.27x	-5.05%	9.17%	279.96x	-11.90%	-37.81%	231.28x	-13.17%	776.18%
Traffic	42.79x	-9.08%	10.16%	224.05x	-9.10%	-70.71%	234.17x	-17.63%	293.63%
AVERAGE	**41.6x**	**-8.6%**	**5.8%**	**213.3x**	**-11.5%**	**-67.9%**	**231.83x**	**-17.0%**	**365.4%**

TABLE V. COMPARISON OF HM REFERENCE ENCODER AND BOLT65 – DIFFERENCE IN PSNR (DB) AND BITRATE (BPS)

Video sequence	All Intra (AI)		Low delay (LD)		Random Access (RA)	
	PSNR (Δ dB)	**Bitrate (Δ bps)**	**PSNR (Δ dB)**	**Bitrate (Δ bps)**	**PSNR (Δ dB)**	**Bitrate (Δ bps)**
Shields	-3.30	218.35	-4.05	-2341.96	-6.46	1643.95
ParkRun	-3.50	1055.56	-3.76	-2490.48	-5.29	4710.81
KristenAndSara	-3.66	-147.80	-3.49	-192.70	-6.35	2779.10
BasketballDrive	-2.04	-14.10	-3.80	-1285.80	-4.92	5385.40
BQTerrace	-2.69	14.60	-3.46	-3249.80	-4.82	9039.90
BlueSky	-3.48	181.22	-3.69	-2043.09	-6.52	1634.22
PedestrianArea	-2.17	57.33	-4.18	-255.60	-5.61	2320.20
RushHour	-1.94	802.20	-4.24	-2773.00	-4.97	55520.00
Traffic	-3.06	367.00	-3.04	-1231.40	-5.98	5224.80
AVERAGE	**-2.87**	**281.57**	**-3.74**	**-1762.65**	**-5.66**	**9806.49**

- Speedup as a ratio between performance times
- Peak-Signal-To-Noise (PSNR) for quality assessment (observed for luma component)
- Bitrate for coding efficiency

Results for each of the configuration and for each video sequence are shown in Table IV and Table V. As can be seen from the table IV Bolt65 achieves significant speedup for all three encoder configurations, from 41.6x in All Intra to 231.84x in Random Access on average. In default RA configuration for HM encoder, the focus is set on accomplishing the highest video quality at the cost of bitrate and performance, which is why in RA mode Bolt65 encounters the highest loss in video quality and biggest gains in bitrate and performance time. On the contrary, LD configuration of HM encoder is set to achieve best coding efficiency, i.e. smallest bitrate. Hence, bitrate savings of HM encoder when compared to Bolt65 are highest in LD mode. Since HM encoder includes more encoding tools, such as symmetric and asymmetric prediction units, deeper transform trees, complex Rate Distortion Optimization algorithms, etc., video quality is still higher than for Bolt65 encoder. However, the implementation of these tools in the encoder scheme significantly increases performance time, which makes Just-in-Time encoding hardly feasible.

As can be observed from the presented results speedup gained by Bolt65 encoder comes at the cost of reduced video quality for all video sequences. This can be expected since Bolt65 is designed for fast encoding, aiming to satisfy Just-in-time requirements, where the focus is set on processing time.

IV. CONCLUSION

Bolt65 is a SW/HW suite, consisting of a video encoder, decoder and transcoder and supporting hardware architecture in the form of FPGA accelerators intended for just-in-time processing. The suite was developed at FER, the University of Zagreb as a “clean room” solution based on HEVC standard with special focus set on the

performance-efficiency. It was achieved by low-level optimizations and hardware-software co-design by exploiting heterogeneous accelerator-based architectures. In the paper, we benchmark the encoder and use HM reference encoder 16.2 as a baseline for comparisons. The results show that our encoder achieves significant speed-up and bitrate savings as it sacrifices quality for meeting the just-in-time requirement. In low-delay configuration, HM reference encoder offers better coding efficiency due to basic RDO mode decision algorithm used in Bolt65.

The solution is currently in the early stages, so some advanced features are still missing, however, further development and introduction of new features is planned. More advanced Rate-Distortion Optimization (RDO) mode decision algorithm will be introduced in future versions of the encoder and transcoder which should improve results by better balancing between the coding efficiency, quality, and complexity of the encoder/transcoder. Since SW/HW codesign is an important focus of the research group, more hardware-based accelerator kernels for heterogeneous high-performance computers will be designed and integrated.

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Deep Learning Accelerator on Programmable Heterogeneous System with RISC-V Processor

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***Abstract*—This paper explores a heterogeneous, open source, RISC-V based platform, called PULP (Parallel Ultra-Low-Power Processing Platform) with customizable MAC (multiply and accumulate) accelerator for neural network acceleration on edge computing devices with low power and performance-limited resources. To address the performance and power constraints we propose binarized implementation of a neural network accelerator. We show that binarized implementation is faster than the fixed-point accelerated implementation, albeit with some loss in precision, but still applicable to most of the use cases in edge computing.**

***Index Terms*—deep learning, RISC-V ISA, multilayer perceptron, binarized neural networks, FPGA, accelerator, heterogeneous architecture**

I. Introduction

After the theoretical groundwork on the subject of neural networks was laid down by Bain [1] and James [2] in the late 19th century, there was a lot of progress made in understanding and modeling them on a computer [3]–[8]. However, in 1969 Minsky and Papert [9] encountered two key issues that hindered further progress: single-layer neural networks could not simulate the exclusive-or circuit (later to be solved by backpropagation [10]) and computers at the time did not have enough processing power to handle large neural networks.

To be of practical use and be able to approximate useful functions, neural networks need to be large, requiring considerable computing resources [11]. Simulating such networks on a von Neumann architecture requires storing millions of connections, consuming considerable amounts of memory and storage. Propagating signals through those connections and simulated neurons requires a lot CPU processing. The renaissance of neural network research in the 21st century happened largely because of advances in computing capabilities in the late 20th and early 21st century [12]. For deep learning applications, computing power has increased exponentially, allowing deep network training in a practical amount of time, e.g. days instead of months [11].

The use of dedicated, application-specific chips can further increase neural network training performance and reduce power consumption, when compared to general purpose units such as a CPU and a GPU. The non-von-Neumann architecture of such a chip implements a neural network directly in its digital logic. Google, for example, developed a neural network accelerator in-house, called the Tensor Processing Unit [13]. There are many such neural-network-specific logic designs and a common stepping-stone in developing neural network ASICs is designing them for an FPGAs first [14].

This paper demonstrates our efforts in implementing a neural network accelerator on a heterogeneous, open source, RISC-V based platform, called PULP (Parallel Ultra-Low-Power Processing Platform) which features generic and customizable MAC accelerator. A higly optimized, CPU–only implementation of a neural network is compared to a fixed-point accelerated implementation and a binarized accelerated implementation. Although our preliminary results showed that CPU–based implementation was the fastest one, we demonstrate that accelerated implementation demonstrate higher scalability and are more suitable for low–power and constrained edge computing scenarios with inference phase as the target for optimization. We also demonstrate that the binarized accelerated implementation is faster than the fixed-point accelerated implementation, albeit with some loss in precision, but still good and acceptable generalization for a range of use cases in edge computing.

A. RISC-V and the PULP Platform

The RISC-V ISA started being developed in 2010 at the University of California, Berkley as an academic research project. Since then, many volunteers from industry and academia alike have contributed to the project. The RISC-V ISA is open and, as the name suggests, based on the RISC (Reduced Instruction Set Computing) principles. Unlike other most popular ISAs, RISC-V is BSD-licensed, allowing it to be used, designed, manufactured or sold as physical chips or software without adverse terms or fees [15].

The RISC-V ISA is designed with real-world implementations in mind, while avoiding architecting for a specific purpose or style, thus it is a modular and extensible load/store architecture [15], [16]. The base set for any RISC-V CPU is the Base Integer Instruction Set, denoted as "RVXI", where X is any of 32, 64 or 128, noting the register size in the number of bits. An "E" instead of an "I" denotes a reduced variant for embedded applications. That base is enough to

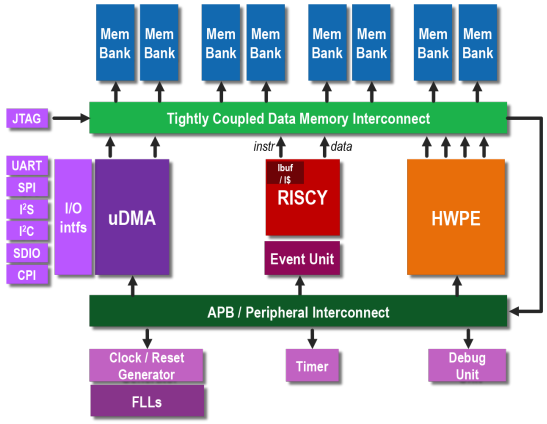

Fig. 1. Architecture of the PULPissimo microcontroller.

make a simplified general purpose computer. Many standard extensions already exist addressing various aspects of modern ISA such as atomic execution, bit manipulation, compressed instruction sets and vector operations. More information on the specific details of the RISC-V ISA is available in the manual [16].

Custom, non-standard RISC-V extensions are also feasible, for various kinds of periphery, accelerators, DSP, ASICs and others, creating a heterogeneous platform, such as the PULP, which was started in 2013 by ETH Zürich and University of Bologna to research new and efficient architectures for ultra-low-power computing. Implementations of the RISC-V cores used in PULP are open source, along with PULP's peripherals [17]. Although not primarily targeted for FPGA implementations, but silicon instead, it has been ported to it. The several RISC-V cores that have been developed for the platform are: RI5CY (4-stage 32–bit operations, optional floating–point suport, integer multiplication, DSP operations, hardware loops, SIMD, bit manipulation and post increment instruction extensions), Zero-riscy (2-stage, area-optimized, 32–bit integer suport, integer multiplication, compressed instructions), Micro-riscy (2-stage, reduced 32–bit integer support, compressed instructions), Ariane (6-stage, 64–bit integer support, integer multiplication, compressed instruction, full Linux support). Developed peripherals include, but are not limited to, custom accelerators, AXI interconnects, DMA engines, GPIO, SPI, and JTAG. The complete, simple microcontroller system is called PULPino and the more advanced one is PULPissimo [18]. Fig. 1 shows the block diagram of PULPissimo heterogeneous system that we used for evaluating our research.

B. Multilayer Perceptron MLP

The perceptron is an algorithm for machine learning of binary classifiers – functions that decide whether an input belongs to a class. Its input is a vector of numbers, representing features of an input sample, which are combined with weights to get the output classification [8], [19]. An important differentiation of perceptrons stems from the number of layers: MLP or Multilayer Perceptron differs from a Single Layer Perceptron SLP by having multiple layers: input, hidden and output layer. The most basic MLP has a single hidden layer, as shown in Fig. 2. One input sample is usually a vector (all the x_is from the Fig. 2), thus multiple inputs – or multiple outputs – can be represented with a matrix $\mathbf{X}^l$. Similarly, biases can be represented with a matrix $\mathbf{B}^l$ and weights with a matrix $\mathbf{W}^l$, where l is the layer corresponding to those biases and weights. Perceptron equation becomes:

$$\mathbf{Y}^l = act(\mathbf{B}^l + \mathbf{W}^l\mathbf{Y}^{l-1}) = act(\mathbf{W'}^l\mathbf{Y'}^{l-1}), \quad (1)$$

where *act()* denotes activation function, and the rightmost equation is a condensed equivalent with $\mathbf{Y}^0 = \mathbf{X}$, and $\mathbf{W'}^l$ and $\mathbf{Y'}^l$ are the matrices which include the bias and the constant 1 input. There are many different activation functions that have been researched, for example identity, sigmoids, binary step, soft step, hyperbolic tangent, inverse tangent, rectified linear unit, sinc, etc. and their many variants [20]. It has been shown that an MLP is a universal function approximator [21], but to approximate a function, the weights $\mathbf{W}$ and biases $\mathbf{B}$ need to be set to certain value, and the process of finding those values is called learning, or training a neural network.

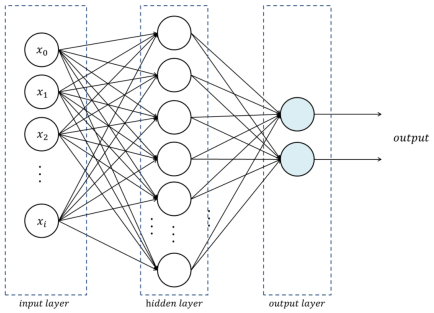

Fig. 2. An example of a multilayer perceptron. [22]

A generalization of the least mean squares algorithm, called backpropagation, is used to teach an MLP. An error in the ith output data point is represneted by $e_i = \hat{y}_i - y_i$, where $\hat{y}_i$ is the achieved output and y_i is the desired output. Therefore, the mean squares error of the entire output is

$$\varepsilon = \frac{1}{N}\sum_N e_i^2. \quad (2)$$

Gradient descent is used to optimize – minimize – the error function of the entire output, thus the change of each weight is given by

$$\Delta w_{ij} = -\eta\frac{\delta\varepsilon}{\delta v_j}\hat{y}_i,$$

where η is the learning rate that ensures convergence without excessive oscillations. The derivative of the error function, which depends on the local field, can be simplified as

$$-\frac{\delta\varepsilon}{\delta v_j} = act'(v_j)\ e_j.$$

In the case of hidden nodes, the derivative is a bit different

$$-\frac{\delta\varepsilon}{\delta v_j} = act'(v_j) \sum_k -\frac{\delta\varepsilon}{\delta v_k} w_{kj},$$

where it is seen that a change in weights of the nth layer depends on the change in weights of the $(n+1)^{th}$ layer, namely the next layer.

The weights, biases and the learning rate is most often a real number, represented by single-precision or double-precision floating-point numbers in a computer. Other representations, without the loss in generalization, are possible and will be used in this paper [23]–[26].

C. Binarized Multilayer Perceptron

Despite the continuous research and progress in neural network theory, there are still many things that are not fully understood about them [27], [28]. For example, the learning rate η is often chosen empirically. Similarly, the idea behind binarization is always the same, but the methods of achieving it differ, as evidenced by some of the previous work [23]–[26]. The core idea of a bitwise/binary neural network is to eliminate the use of floating-point numbers and reduce them to single bits. Each neuron would, instead of outputting a floating-point number, output just a bit, 0 or 1, which represent the values 1 and -1, respectively. In modern computers it is much faster to perform a bitwise operation (such as a XOR) than it is to multiply two floating-point numbers. The required circutry and power consumption is, thus, also reduced. Additionally, a single-precision floating-point number is stored in 32 bits – the same size that can store 32 single-bit numbers, so it is evident that binarized/binary/bitwise neural networks would consume significantly less storage space.

The approach to training a binarized MLP that was used in this paper was to leave the backpropagation algorithm unchanged. During training, all the weights and biases would remain as floats. Actual binarization of the MLP was achieved by augmenting the forward pass with a $sign$ functions, defined as $sign(x) = 1 \ if \ x >= 0, \ else \ -1$. Whenever a weight, a bias or the previous layer's output was accessed during the forward pass, it would be taken through the $sign$ function first, but without actually changing the stored value. That way, multiplication always uses factors of 1 and -1, simplifying the needed arithmatic in a computer. If a -1 is represented with the bit 1, and 1 represented with the bit 0, multiplication can be simplified to bitwise XOR ($\oplus$) operations, which are faster than floating-point multiplication. Evidently, $X \oplus 1 = -X$ and $X \oplus 0 = X$, same as the results achieved when "$\oplus$1" and "$\oplus$0" is replaced with "$\times(-1)$" and "$\times$1", respectively.

Another important matter is the discretization of the input values. A naive idea would be using the binary representation of a fixed-point variant of a real number scaled by a factor, but such discretization failed to produce a meaningful MLP model. The discretization method that did produce a meaningful model was quantifying a real number to a certain number of set bits, leaving other bits unset, for a total of N bits. The more bits were set, the larger the input number, conveying the information of the number's magnitude in a very simple way. Number of bits to set *bc_s* for a real number x was determined by the relation

$$bc_s(x) = \lfloor \frac{x - min}{max' - min} \times (N+1) \rfloor, \qquad (3)$$

where min is the lowest possible value of x and max' is the highest possible value of x, plus a small value δ, such that $\delta << max$. Therefore, $max' = max + \delta$. Using max' in Equation 3, instead of max, is a programmatic detail that enables providing inclusive values of min and max as input to the discretization function, avoiding the impossible case of trying to set $N+1$ bits, out of N bits, when $x = max$.

The binarizing adaptations made to a generic MLP assume that the network will be trained only once, on a more powerful computer than the ones implementing the low-power PULP. Not having the backpropagation algorithm binarized, therefore, is not an issue. In practice, training happens during research and modeling, and once the model is deployed to various devices, only forward propagation is used to achieve the desired application – and that is the part that our binarization method optimizes for.

II. MLP Implmeentation on the PULPissimo

PULPissimo's block diagram is shown on Fig. 1. It can be configured to use either the RI5CY or the zero-riscy core. The system includes autonomous I/O subsystem, called μ–DMA [29], a memory subsystem, and, most relevant to our research, the support for custom Hhardware processing engines or accelerators (HWPEs). In addition, it features a simple interrupt controller, various peripherals and well–developed and usable SDK support [30]. By default, PULPissimo is configured to use zero-riscy as its core, which was used for the purposes of this paper too. It is an in-order, single-issue, 2 pipeline stage core with full RV32I and RV32C support and optional RV32M and RV32E support, targeted for ultra-low-power and ultra-low-area ASIC designs [31].

HWPE block demonstrates the ability to integrate varous accelerators (Fig. 1). An exemplar MAC accelerator operating on a vector of fixed-point values is included and used in this paper. We have modified provided MAC engine for the binarized MLP implementation in our work. The example MAC engine represent initial efforts in demonstrating the inclusion of accelerator engines in heterogeneous systems, and therefore is not meant to be very efficient nor powerful. However, it will fulfill the purpose of demonstrating the points made in this paper. It supports two modes: 32–bit fixed–point vector multiplication, and 32–bit fixed–point dot product combined with vector addition.

HWPE as a building block of heterogeneous PULP–based system with RISC-V ISA cores is meant to provide a specific–purpose, memory-coupled accelerator infrastructure aiming to increase performance and energy efficiency in specific tasks. Unlike in other common accelerator architectures, HWPEs do not need a DMA for I/O handling, but access memory directly, same as the cores, enabling existing and widely accepted

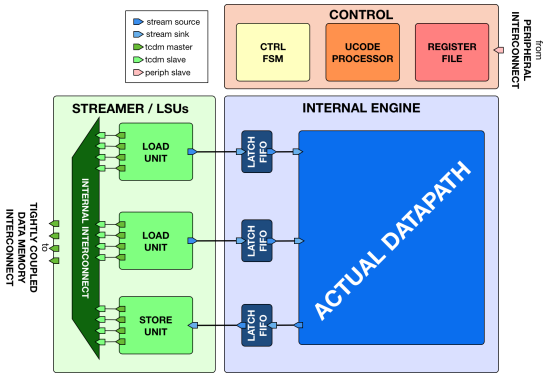

Fig. 3. An example architecture of a HWPE.

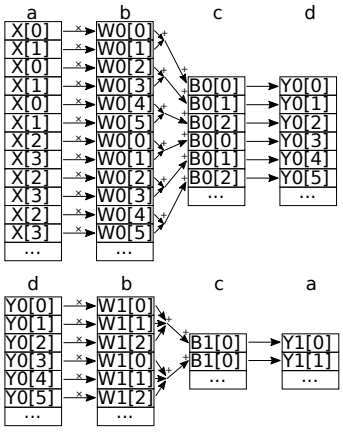

Fig. 4. Compute diagram of the fixed-point MLP implementation. Every rectangle is a 32 bit integer.

programming models. They are designed for simple use, so that only a few pointers and parameters need to be exchanged before HWPE use. An example HWPE architecture is shown in Fig. 3. Memory is accessed using the TCDM (Tightly Coupled Data Memory) protocol, same as the DMA and the cores, and then the data is adapted to the simpler HWPE-Stream protocol, used internally by the accelerator engine. An extension of the TCDM protocol, called PERIPH, is used to control the HWPE, similiar to other peripheral devices in PULPissimo.A microcode processor is included, that can execute the main calculation block of an accelerator in a loop. By default, six static nested loops are supported, and four R/W and twelve R/O registers can be used. In tests and benchmarks for this paper, the default microcode for iterating over the provided vectors is used, as there was no need to change its function, other than setting appropriate registers for the loop count [30].

A. Fixed–Point MLP Implementation

For research purposes, we used a simple MLP with three nodes in the single hidden layer and one output node. Nonetheless, all principles shown apply equally well for much larger networks. Dataset that the network was trained on were two interleaving half-circles, generated by Scikit `make_moons` function [32]. Each datapoint in the generated dataset is a point in a 2D plane that belongs to one of two moons. The input to the network are two real numbers, representing the x and y coordinates in a 2D plane. The output is a real number, indicating which moon the datapoint belongs to through its sign. We used the PyTorch framework [33] to train the model and then use the trained parameters in PULPissimo system used in inference phase. Algorithm 1 shows how the data is arranged in the MAC input arrays. The `w0` array contains three flattened pairs of weights: one pair for each of the three hidden layer nodes and `b0` holds their biases. `w1` and `b1` hold the same kind of information for the output layer. The `X` array contains 300 flattened pairs of coordinates as the dataset and the `Y` array, while not entirely necessary, holds 300 expected signs as the classification output of the MLP. The first loop copies an input coordinate pair into three successive `a` array element pairs because there are three hidden layer nodes that use the same input. The second loop copies the hidden layer's weights into the other MAC input array, `b`. The third loop prepares the hidden layer's biases in array `c`, one bias for each coordinate pair or for each hidden layer's node. Compute diagram of the fixed–point MLP is shown in Figure 4.

Algorithm 1 HWME input array setup.

```
for(int i = 0; i < X_LEN; ++i) {
a[i * W0_DIM * IN_DIM + 0] = X[i * IN_DIM + 0];
a[i * W0_DIM * IN_DIM + 1] = X[i * IN_DIM + 1];
a[i * W0_DIM * IN_DIM + 2] = X[i * IN_DIM + 0];
a[i * W0_DIM * IN_DIM + 3] = X[i * IN_DIM + 1];
a[i * W0_DIM * IN_DIM + 4] = X[i * IN_DIM + 0];
a[i * W0_DIM * IN_DIM + 5] = X[i * IN_DIM + 1];
}
for(int i = 0; i < X_LEN; ++i) {
b[i * W0_DIM * IN_DIM + 0] = w0[0];
b[i * W0_DIM * IN_DIM + 1] = w0[1];
b[i * W0_DIM * IN_DIM + 2] = w0[2];
b[i * W0_DIM * IN_DIM + 3] = w0[3];
b[i * W0_DIM * IN_DIM + 4] = w0[4];
b[i * W0_DIM * IN_DIM + 5] = w0[5];
}
for(int i = 0; i < X_LEN; ++i) {
c[i * W0_DIM + 0] = b0[0];
c[i * W0_DIM + 1] = b0[1];
c[i * W0_DIM + 2] = b0[2];
}
```

B. Binarized MLP Implementation

Several changes were necessary at the RTL level and the HWME client code to implement the binarized MLP. Most notably, we replaced the multiplication with XOR operation. The result of multiplication/exclusive or is latched into a register together with the accumulation part of the MAC engine too, which is the summation part in a linear node. In the binary version, it is performed as bit counting and comparison to an integer to determine whether there is more ones or more zeros in a binary number. Since there is no scaling/shifting in the binary version, the register holding the shift amount is reused to store the threshold value, essentially set to half of the number of total bits that get accumulated. If the count of ones is higher than half of the total number of bits that make it into the count, then the code knows there's more of ones and

sets a one as the accumulation result. Our implementation uses seven bits to represent each coordinate, meaning that a total of four coordinates fit in a single 32 bit value. The remaining four bits can be used for the bias value, which, in this case, adds one count to the number of ones or zeros. There is one bias value for each input pair of coordinates, thus two bits (24 and 8) are ignored in the accumulation block.

The binarized version of the accumulation step packs the results of previous calculations so that the bits are not sparse and are ready for the next MLP layer, same as they were at the start of the current layer's computation. We also merge the bias into the summation/accumulation, so the mode selection is a switch for the final packing, before the results are output.

The most notable difference in the binarized model is that the binary weights and biases are not used directly, but are packed in 32 bit values to better utilize the computational resources of the accelerator. The input values are taken through a discretization function. It is assumed that the input type, input range and bitcount are known ahead of time, thus the minimum and maximum values are hardcoded. Since floating-point arithmetic tends to be slower than integer arithmetic, a fixed-point variant is benchmarked and compared, with the scale factor set to the same value as in the fixed-point MLP implementation.

Compute diagram of the binarized MLP is shown in Fig. 5. For the output layer computation, the `a` array again becomes the output array. Packed weights are set up in array `b` and the packed results from the previous layers are slightly adjusted in `d`. Iteration count, array lengths and stride lengths are all divided by three due to the different count of nodes in the layer. Threshold count is changed to three and no result packing is required.

III. Benchmarking and Results

We benchmarked our MLP implementations for PULPissimo in the Modelsim simulator. The units of the measured time are microseconds. The simulation runs were deterministic and always produced the same numbers. For our MLP implementations, we show two numbers: total runtime and MAC engine runtime (where applicable), as seen in Table I for 300-points dataset, and in Table II. We experiment with both floating–point and fixed–point implementations.

Fixed-point arithmetic is supported in hardware in the zero-riscy core, unlike floating-point arithmetic, thus the fixed-point MLP without HWME showed great results because of the simplistic implementation of the MLP and because of the avoidance of moving data from RISC-V CPU to HWME. The runtime of HWME variant fixed-point MLP is slightly worse to the total runtime of the non-HWME implementation. The difference was dominated by the communication and engine starting/stopping overhead. When the array setup time is taken into account, the HWME variant takes approximately twice as long. Both binarized variants (fixed– and floating–point) show around a quadruple improvement in MAC runtime, but still exhibit the relatively long setup times, especially notable in the floating-point discretization variant. Results in Table II confirm that the runtime increase is roughly linear with the dataset size, as the runtime increases 2 to 3 times for doubling the input size.

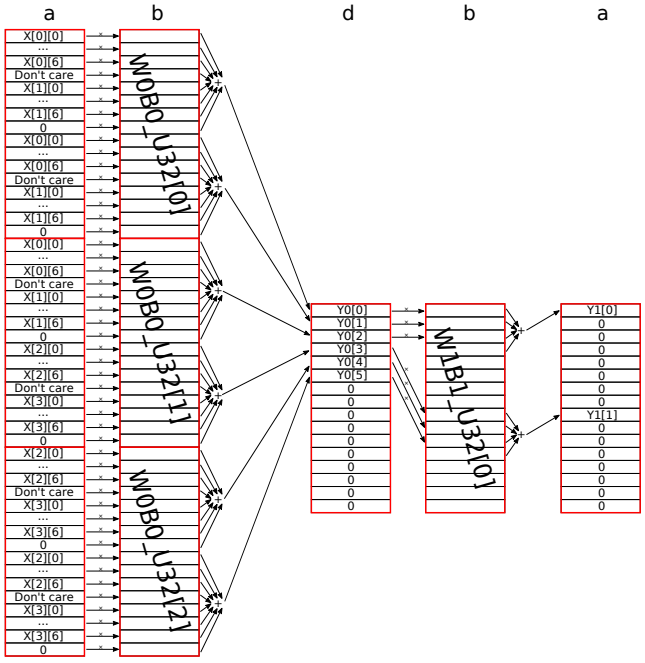

Fig. 5. Compute diagram of the binarized MLP implementation. Every rectangle is a single bit, with the red rectangles denoting 32 bit registers.

IV. Conclusion

This paper presents some of the first results of PULP exploration at the University of Zagreb, using a low-effort, exemplary MAC accelerator with the PULPissimo platform to implement an MLP. The MAC accelerator was then modified to implement a binary MLP that classifies the same dataset. As expected, when the accelerator was used, the computational part of the MLP's forward pass executed in significantly faster time of 62 microseconds versus 244 and 275 when compared to a fixed-point MLP and a fixed-point MLP without the accelerator, respectively. When the dataset was increased from 300 to 600 samples, the advantages were still strong at times of 184, 579 and 488 microseconds respectively. Despite the positive results of the computation-bound benchmarks, using the accelerator incurs an overhead and takes time to setup the data into proper arrays. In this specific case, where a small MLP was accelerated indirectly through the use of a MAC, it was not worth going through the trouble of implemneting it, not due to low returns on time and effort invested, but due to straight up worse performance. A non-accelerated binarized MLP implementation would have shown the best performance in the benchmarks. Some points that would make the investment worth it and would significantly increase performance are: 1) decoupling the accelerator from the memory to avoid the bottleneck where computation is not disproportionately heavier than memory access, 2) the decoupled accelerator could handle a clock boost to increase

TABLE I
RUNTIME FOR THE REGULAR, BINARIZED AND FIXED-POINT DISCRETIZATION MLP VERSION ON A DATASET OF 300 POINTS.

Variant	Total runtime [μs]	MAC runtime [μs]
Fixed-point MLP without HWME	244	N/A
Fixed-point MLP with HWME	549	275
Binarized MLP, floating-point disc.	8667	62
Binarized MLP, fixed-point disc.	488	62

TABLE II
RUNTIME FOR THE REGULAR, BINARIZED AND FIXED-POINT DISCRETIZATION MLP VERSION ON A DATASET OF 600 POINTS.

Variant	Total runtime [μs]	MAC runtime [μs]
Fixed-point MLP without HWME	488	N/A
Fixed-point MLP with HWME	1098	579
Binarized MLP, floating-point disc.	17761	184
Binarized MLP, fixed-point disc.	1251	184

computational performance, 3) implementing more accelerators by duplicating the MAC engines would provide a linear increase in computational performance, 4) offloading more work into hardware, such as the discretization function and array element packing, 5) implementing a bigger MLP that requires more computation, 6) perform other tasks while the HWME is running.

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A New Low-Complexity Cipher Class for Clone-Resistant Identities

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***Abstract* - A new large cipher class based on new two-variable self-inverse-permutation deploying Golden S-Boxes is presented. The mapping has particular properties, in that it is both self-inverse and uses arithmetic over the ring of integers modulo 2^n. The key contribution of such cipher structures is in activating the use of passive hard-core multipliers (Math-Blocks) in modern FPGA devices. Such multipliers are often available for free when not utilized in for the system tasks. Standard ciphers do not usually use multiplications due to their high implementation complexity. The proposed cipher class is reactivating such free multipliers to create good quality ciphers at very low cost. The target application of such ciphers is in creating the so-called Secret Unknown Ciphers (SUCs). Such SUCs can serve as highly-resilient clone-resistant digital-identity-modules in future smart self-reconfiguring non-volatile FPGA devices. The security level of the resulting ciphers is relatively high and scalable. The main future application areas of such structures are expected to be for vehicular security applications. A sample implementation prototype demonstrates the complexity of the resulting physical identity and its performance.**

Keywords - Secret Unknown Ciphers; Physical Unclonable Function; Golden S-Boxes.

I. INTRODUCTION

Since the software-based device identities can be easily cloned and manipulated, several clone-resistant physical approaches were proposed. Unclonable physical properties are much harder to attack and require often very expensive invasive attack techniques. Many physical identification solutions were proposed based on just checking a stored secret key in an embedded non-volatile memory (NVM) [1]. Such technologies has early fallen short against low-complexity physical attacks [2]. Two decades ago, Physical Unclonable Functions (PUFs), often realized as embedded structures in VLSI devices were proposed to serve as better unclonable physical identities [3]. The key idea behind PUFs is to extract unique hard-to clone binary sequences from highly nonlinear unknown born properties of some VLSI physical structures in electronic devices. PUFs exhibit born identification properties which are essentially impossible to clone similar to DNA chains in human beings.

However, due to the varying operation conditions as temperature, supply voltage, and other effects, PUFs suffer from inconsistency/repeatability of their identity response. The PUF's input-output response exhibits therefore high inconsistency resulting with re-identification errors [1]. To counteract inconsistency drawbacks, fuzzy extractors using Helper Data Algorithm (HDA) were proposed as an approach to mitigate this problem. Therefore, most of the proposed PUFs still have the same difficulties in being complex and costly to implement and use in modern technology applications.

Furthermore, PUFs have been proved to be vulnerable to modeling attacks. Such attacks exploit the bias and correlations in PUF's input-output or so-called challenge-response pairs (CRPs) to construct a machine learning algorithm with high prediction rates approaching 99% [4]. Any effort to overcome modeling attacks makes PUFs more expensive and complex.

Various protocols utilizing PUFs has been envisaged to provide a lightweight entity authentication. In [1], nineteen proposals have been studied. The results show that most of the PUFs require multiple communication transactions with the server to attain a stable response, and PUFs also exhibit a small response space that requires expansion to be sufficiently large for the entity authentication.

The Secret Unknown Cipher (SUC) was introduced as a new alternative to PUF initially in [5]. SUC is defined as a randomly self-created crypto-function which is embedded in a post-fabrication process within off-shelf-FPGA devices. Furthermore, the realization of SUC-concept as a pure digital structure essentially ensures the consistency of its input-output pairs. On the other hand, SUC concept satisfies a manufacturer resistant deployment. Furthermore, the SUC-creation concept do not allow producing two equal SUCs/identities.

The main contributions of this paper are first to design a new class of Feistel-like ciphers by replacing the XOR operation by a new powerful self-inverse mapping. The new mapping is based on simple arithmetic using addition and multiplication over $\mathbb{Z}_{2^n}$. The key-idea for using such unusual arithmetic is that it is often available for free (as unused units) in many modern FPGA applications. In other words, the new cipher structure is a novel recycling of dead arithmetic units for creating good ciphers. Multipliers are otherwise usually not-attractive for ciphering operations due to their inherent high-complexity. The resulting new cipher-class is usable for self-creating of Secret Unknown Ciphers SUCs which were proposed to "digitally-mutate" future programmable VLSI devices into physically clone-resistant units at relatively low cost.

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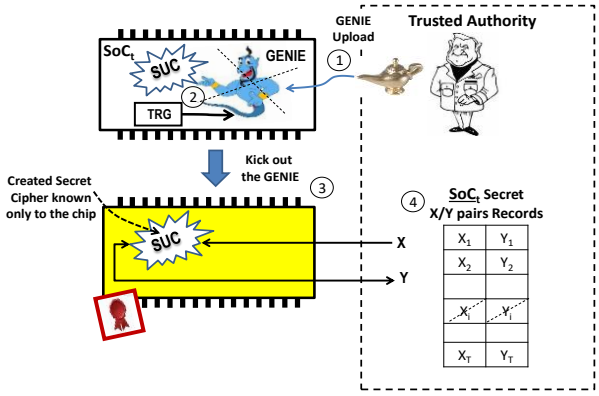

Figure 1. The Concept of Secret Unknown Cipher (SUC).

The rest of this paper is organized as follows. In Section II, a short summary covering several Digital PUFs (D-PUFs) designs and SUC's proposals are presented. Section III introduces the concept of SUC as a D-PUF and points to the target implementation environment. Section IV gives SUC design strategy and a new class of mathematical involutions. In section V, a hardware implementation is provided and evaluated. Section VI shows a security analysis of the proposed SUC.

II. Related Work

Several PUF designs have been introduced in the literature [3] [1]. Within the scope of this paper, D-PUFs are discussed and reviewed. A PUF is called digital when it is silicon-based, and it is extracted from special unique variations of a chip's intrinsic characteristics. This deviation occurs randomly and cannot be controlled during the assembly process. Moreover, the PUF is called strong when it can support a large number of CRPs [1]. Though PUFs are assessed insusceptible to invasive physical attacks because it would destroy the secret through damaging the PUF, they fall short against the side channel analysis which is a non-invasive physical attack. A series of successful attacks has been done on Arbiter PUF [6], SRAM PUF [7], Ring Oscillator PUF [4].

A tremendous amount of research was conducted on PUF as a permutation mapping. For instance, PUF-based block cipher is introduced in [8]. This integrated approach defines a new concept so-called Physical Unclonable Pseudo Random Permutation (PUPRP). Where the integration of PUFs with confusion/diffusion properties of a block cipher enhances the temper-resilience of the overall design [9]. Wu and et al [9] deployed the integrated approach to construct PUPRP, which combines 4x4 PUFs into Feistel cipher. Unfortunately, every 4x4 PUFs require HDA to attain a stable response for every round. That increases the hardware complexity to implement such a proposal. In [10], public D-PUF is presented based on delay PUF that is utilized as a key generator to initialize a Boolean function implanted in FPGA fabric (LUTs). The purpose of the public D-PUF exploits the time gap between the D-PUF execution and its simulation. Moreover, Hardware- Software Digital PUF (HW-SW DPUF) was first proposed in [11] as a cascade of randomly chosen functions from a large class of random cryptographic functions. The random selection of functions is performed by using a bit stream of a True Random Generator (TRG). The authors only utilized Feistel cipher as a function of such cascade. All previous described D-PUFs are reducing the typical disadvantages of analog PUFs against operational effects at relatively high overhead complexity.

Regarding the previous presented issues, SUC is proposed as an alternative to PUFs for lightweight authentication entity. Unlike the conventional PUFs, SUCs use only-digital-mappings making all aging and other operational factors without effect during the whole digital life-cycle of the device. Additionally, it was proved in previous work that the SUCs offer an easy to scale digital response space [12]. Furthermore, several proposals and applications of SUC recently investigated and published. For instance, a classical generalized Feistel network deploying Golden S-boxes is presented in [13] to realize the SUC-concept. In [12], SUC-based "Key Generation Entropy" is modeled and compared with strong traditional PUFs. The key differences between the previous proposals [12] and this work, are that FPGA hard-core multipliers are involved for both confusion and diffusion in this new SUC creation proposal. In addition to that, the golden S-Boxes are additionally used as confusion blocks. The resulting Feistel Network is further optimized in complexity and cryptographic performance compared to [12]. However, SUCs are deployed in [11] as a lightweight cipher to provide an electronic device with an identity. In[14], Adi et al. presented a SUC- based lightweight protocol that enables efficient two-way communications for low-cost physical authentication.

III. SUC Concept and The Targeted Technology

Since "the only secret which can be kept unrevealed is the one which nobody knows", the unknown function concept was introduced in [5]. The concept of Secret Unknown Cipher (SUC) theoretically combines between secret cryptographic key principle and a cascade of unknown symmetric-ciphers. The SUC concept is practically based on randomly self-creating such unknown hard-wired ciphers in a cascade. In other words, the main idea behind SUC is to trigger a random event process that generates a combined Hardware-Software module embedded in a System-on-Chip (SoC) unit[11]. This combination is non-reversible and very hard to predict.

A. Concept of SUC Creation and Personalization

Fig.1 illustrates the creation process of SUC. In step 1. a smart software cipher designer program so-called "GENIE" is uploaded by a trusted authority (TA) into an off-shelf SoC FPGA. In step 2. the GENIE starts a single-non-repeatable event to generate one unknown and unpredictable cipher SUC_t with the help of True random Generator (TRG). In step 3. the GENIE is completely removed from the SoC device. Then, the device with a unique permanent SUC_t is physically locked. Therefore, non-volatile VLSI technology is required. In step 4. TA initializes the device by choosing a set $\{x_1,\dots\ x_T\}$ of clear texts as random challenges and stimulates the device to generate the corresponding ciphertext set $\{y_1, \dots\ y_T\}$. The resulting challenge-response pairs of each individual device are stored in a secret record. Finally, the SoC devices should prohibit reconfiguration after generating SUC by irreversibly setting some last-fuse lock.

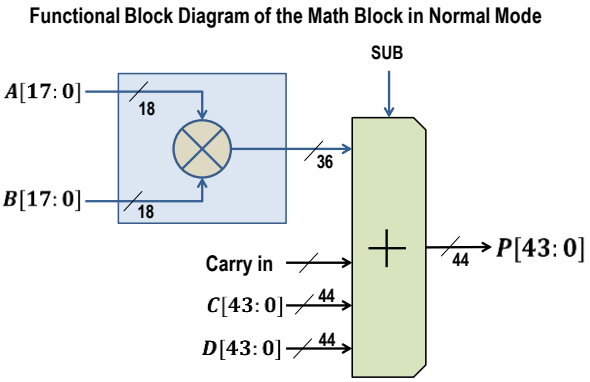

Figure 2. The FPGA math block hard-core MACC as add-multiply unit.

Now, SUC is ready to be used as an identification module to any entity. Note that self-reconfiguration technology is expected to emerge in the flash-based non-volatile technology in the near future.

B. *Target Technology Environment*

The only non-volatile flash-based FPGA with switching fabrics and programmable cells is available by Microsemi Smart-Fusion®2. The FPGA fabric incorporates an integrated ARM Cortex-M3 processor together with powerful/high-performance arithmetic Mathblocks (MACCs), including multipliers, all integrated into this chip.

The integrated MACCs are optimized to efficiently perform 18x18 multiplication with zero hardware cost as shown in Fig.2. To avoid complex modular arithmetic, the ring of integers arithmetic modulo 2^n is adopted as the basic cipher algebra in $\mathbb{Z}_{2^n}$ (that is n=18 in Fig.2).

Fig.3 illustrates a possible functional layout after generating SUC in FPGA which uses MACCs interacting with logic components implemented in FPGA fabric. This combination between MACCs and logic implemented components results with the desired SUC.

To improve the security level of SUC, an FPGA technology, that can be kept the cipher location random and unknown, is required. Note that the random and individual location of each SUC makes physical attack very difficult, even the adversary tries to get some information by probing points inside the chip [15].

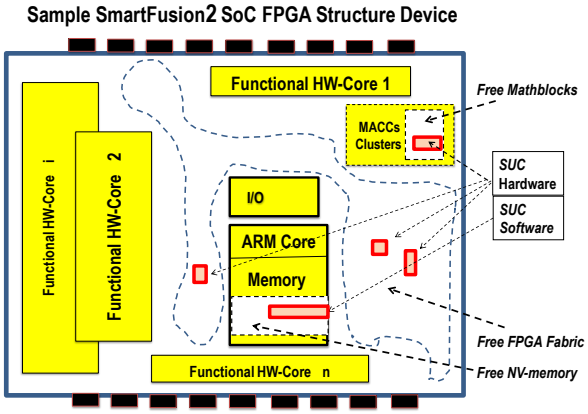

Figure 3. The possible layout of a SoC unit after injecting a SUC.

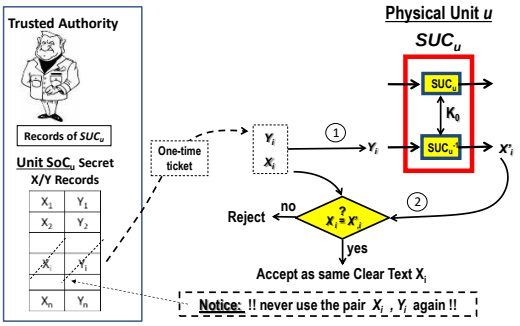

Figure 4. Generic Two-Way Authentication Protocol for a SUC unit.

C. *SUC Basic Use in Physical Identification Protocol*

Fig.4 shows a generic 2-way-protocol for authenticating a SUC_u unit which proceeds as follows:

1) TA randomly selects a pair (x_i ,y_i) from the record of SUC_u. TA then sends cryptogram y_i to SUC_u device.
2) SUC_u responds by sending decrypted clear text x_i'. If x_i' = x_i, then the unit SUC_u is authentic. The pair x_i ,y_i is marked as used and never used again.

IV. Cipher Design Strategy

A huge class of cryptographically-significant mappings is required to select one of them as a randomly selected SUC. Therefore, in the best-case scenario, the cardinality of all possible usable mappings should approach infinity.

A. *Golden 4-bit S-Boxes as Primitive Building Elements*

In [16], Saarinen showed that there are only four classes of 4-bit bijection S-Boxes which can affinely transform the resistance properties against linear cryptanalysis (LC) and Differential Cryptanalysis (DC) to all members of classes that are called golden S-Boxes. TABLE I. shows four 4-bit golden S-Boxes seeds GS_k, where k=0,1,2,3, which generate 4-classes of S-Boxes fulfilling all the ideal and cryptographically significant properties.

TABLE I THE 4 CANONICAL CLASS REPRESENTATIVES OF THE GOLDEN S-BOXES [16]

GS Seed-Classes	4-bit input combinations 0123456789ABCDEF	DC p	LC ε
GS_0: 4-bit outputs	035869C7DAE41FB2	¼	¼
GS_1: 4-bit outputs	03586CB79EADF214	¼	¼
GS_2: 4-bit outputs	03586AF4ED9217CB	¼	¼
GS_3: 4-bit outputs	03586CB7A49EF12D	¼	¼

ε: linear probability bias, ***p***: differential characteristics probability.

The equivalence relation for class-generator is defined based on two binary permutation matrices P_i, P_j, two 4-bit vectors $a, b \in \mathbb{F}_2^4$ and XOR-operations as follows:

$$[S(x)]_{1\times4} = GS_k([x]_{1\times4}\cdot[P_i]_{4\times4} \oplus [a]_{1\times4})[P_j]_{4\times4} \oplus [b]_{1\times4} \quad (1)$$

Fig.5 shows the corresponding block diagram for realizing the mapping described in (1). The number of the resulting S-Boxes is $(4!)^2(24)^2 = 2^{17.1}$ for each GS_k. And the cardinality of Golden S-Box class is $4.2^{17.1}=2^{19.1}$.

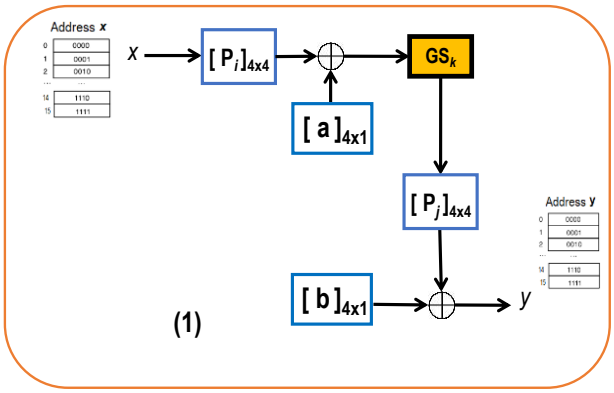

Figure 5. Hardware Sketch of the Golden S-Box Generators [13].

The SUC cipher creator "GENIE" can easily use this formula for creating a class of $2^{19.1}$ possible different golden S-boxes [13].

B. *New Involution-Mapping in Two Variables*

A polynomial $P:\mathbb{Z}_{2^n}\times\mathbb{Z}_{2^n}\to\mathbb{Z}_{2^n}$ in two variables (L,R) is defined as a special mapping having two inputs and one output in $\mathbb{Z}_{2^n}$ as the ring of integers mod 2^n, as follows,

$$P(L,R)=a\cdot L+b\cdot R \tag{2}$$

Where, $a,b\in\mathbb{Z}_2^n$.

The target of this work is to create self-inverse functions with respect to only one variable such as L.

Definition 1. The polynomial P in two variables L and R on the ring $\mathbb{Z}_{2^n}$ is considered as a self-inverse polynomial with respect to L, if the following holds:

$$P(P(L,R),R)\bmod 2^n = L \tag{3}$$

For any L and R.

The following lemma presents the important properties of the modular arithmetic over $\mathbb{Z}_{2^n}$. Note that $x=x_{n-1}\cdots x_1x_0\in\mathbb{Z}_2^n$ is a n-bit vector, where $x_i\in\mathbb{Z}_2$, for every $i\geq 0$ and $\begin{matrix}1\\0\end{matrix}$ denotes 0 or 1.

Lemma 1. Let $a,b\in\mathbb{Z}_2^n$,

- If $a=\begin{matrix}1\\0\end{matrix}1\cdots 1_{n-1}$, then $a^2\bmod 2^n=1$.
- If $u=\begin{matrix}1&1\\0&0\end{matrix}\cdots 0_i$, and $v=\begin{matrix}1&1\\0&0\end{matrix}\cdots 0_j$, then $u\cdot v=\begin{matrix}1&1\\0&0\end{matrix}\cdots 0_{i+j}$, where $i,j\leq n$.
- If $b=\begin{matrix}1&1\\0&0\end{matrix}\cdots 0_r$, then $b^k\bmod 2^n=0$ for $k\cdot r\geq n$.

The proofs are straightforward through the modular arithmetic over $\mathbb{Z}_{2^n}$.

The following theorem determines the conditions required to reach such self-inverse polynomials in two variables (L,R) with respect to L over $\mathbb{Z}_{2^n}$.

Theorem 1. Let $n\geq 2$ and $P(L,R)=aL+bR$ be a polynomial in two variables (L,R) over $\mathbb{Z}_{2^n}$. P is a self-inverse polynomial with respect to L if all the following conditions are satisfied:

1) $a=\begin{matrix}1\\0\end{matrix}1\cdots 1_{n-1}$.
2) $b=\begin{matrix}1&1\\0&0\end{matrix}\cdots 0_r$, where $r\geq n/2$ and n is even.
3) $b=\begin{matrix}1&1\\0&0\end{matrix}\cdots 0_r$, where $r\geq (n-1)/2$ and n is odd.

Proof:

First, let's prove that if n is even and $a=1\cdots 1=2^n-1$, then $P(L,R)=aL+bR$ is a self-inverse polynomial with respect to L over $\mathbb{Z}_{2^n}$. Another case can be proven in a similar fashion.

For $r\geq n/2$,

$$P(P(L,R),R)=a(aL+bR)+bR$$

And,

$$P(P(L,R),R)=a^2L+b(a+1)R$$

Now,

$$P(P(L,R),R)=a^2L+b(2^n-1+1)R$$

Yielding,

$$P(P(L,R),R)=a^2L+2^nbR$$

Applying mod 2^n and from lemma 1 results with,

$$P(P(L,R),R)\bmod 2^n = L$$ □

Note that a self-inverse polynomial in two variables with respect to one variable defines a new n-bit mapping so-called π-mapping as shown in Fig.6, where $\pi(L)=(aL+bR)\bmod 2^n$. It is very simple to prove that the π-mapping is an involution for any R.

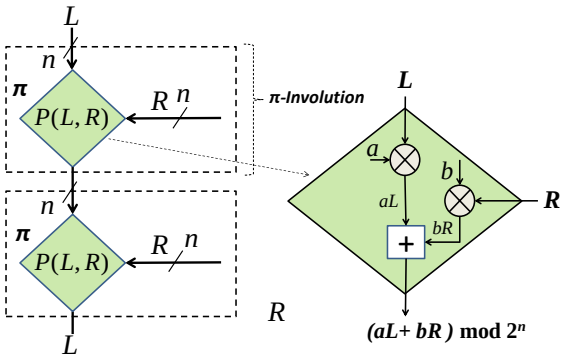

Figure 6. The New π-Involution used as a arithmatic operation.

In [17], Patel et al replaced XOR-operation in Feistel network by the addition $(L+R)\bmod 2^n$ to define a $2n$-bit permutation. The results showed that the three-round variant of such a cipher is a pseudorandom permutation. Therefore, in Fig.7, replacing the XOR-operation in

Feistel network by $\pi(L)$ results with a new mapping $\psi(L,R)=(P(L,F(R)),R)$ which is also an involution.

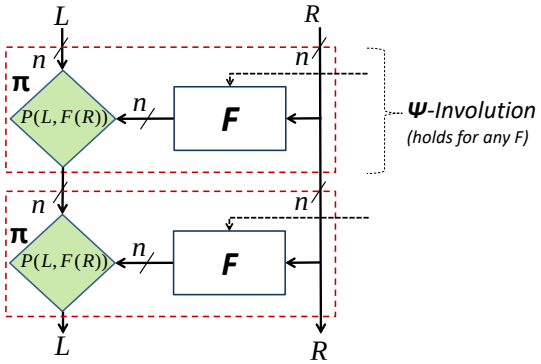

Figure 7. The New ψ-Involution as XOR Replacement

The following corollary determines the number of all district self-inverse polynomials with respect to *L*.

Corollary 1. For $n>3$, the cardinality of the class $\psi(L,R)=(P(L,F(R)),R)$ over $\mathbb{Z}_{2^n}$ is:

$$\left.\begin{aligned} Card[\psi]=Card[P(L,R)]=2^{n/2+1}; \quad n=2k \\ Card[\psi]=Card[P(L,R)]=2^{n-1/2+1}; \quad n=2k+1 \end{aligned}\right\} \quad (4)$$

Where, $k\in\mathbb{N}$.

V. Proposed Ciper-Class and its Complexity

In this section, a new cipher design of SUC and its hardware implementation are presented.

A. Proposed Cipher Structure

Referring to Fig. 8, the proposed 15-rounds cipher as a modified Feistel cipher by deploying the mapping $\pi(L,R)$ to replace the classical XOR-mapping resulting with Feistel-like ψ-Involution.

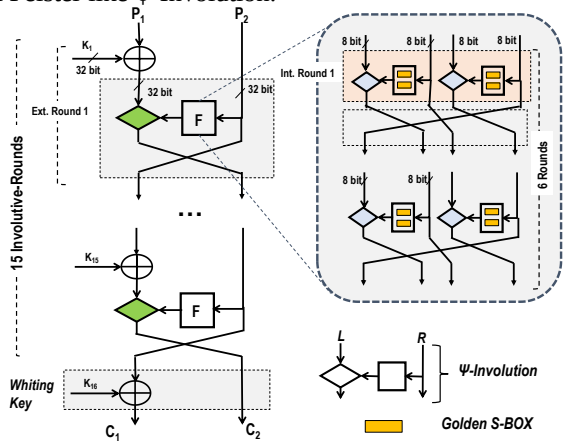

Figure 8. A Sample 64-bit SUC-Cipher Structures.

The mapping's input data is 64 bits that splits into two 32-bit branches (*L*,*R*) in the first round. A 32-bit key is XORed with the left round branch *L*. The involution *π*-mapping as $(aL+b(F(R)))$ is applied on *L* and the output of the inner function *F*. The mapping *F* uses the 32-bit P_2 input and splits it into four 8-bit branches. *F* consists of a nonlinear layer of two-horizontal-blocks using four golden S-Boxes together with a rotation-permutation layer. The involution *π*-mapping is used recursively again in 8-bit size.

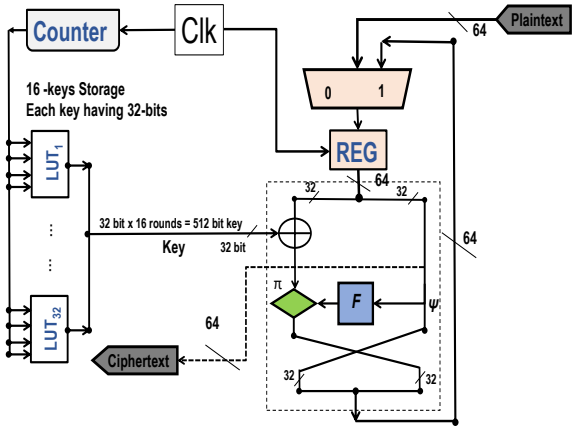

Figure 9. Proposed Hardware Architector of the Round-based SUC.

Moreover, *F* is composed of a recursive *r*-rounds repeating the usage of the same outer Feistel-similar structure. The example of Fig. 8 proposes to take *r*=6 rounds as a minimum-number of rounds required to reach full diffusion in that S-Boxes iteration rounds as shown in [18]. The used golden S-Boxes are randomly selected according to (1)/or Fig.5. The outer round-structure is selected to have 3-involutions namely: XOR with a key followed by *ψ*-involution and terminated by swapping-involution. The 15-outer rounds are using the same 3-involutions each time with a different 32-bit-key.

B. A Possible Hardware Implementation Structure

To implement a possible compact version of the proposed cipher, the architecture of Fig. 9 is proposed as a successive round-based implementation [19]. Iterating one cipher-round (includes the said 3-involutions) is deployed as the core of the hardware design structure. A state register of 64-bit and a 64-bit multiplexer completes the state machine structure to run the 15-cipher rounds, where, each cipher-round is executed in one clock-cycle. In this implementation, additional clock 6-cycles are required for computing of inner function *F*.

Furthermore, a new technique of key scheduling is presented in Fig.9 storing the 16-round-keys in 32 LUTs. The keys are selected fully randomly by the GENIE. The proposed key schedule compared to Khudra and other ciphers [18] differs in that our 16-keys are fully independently and randomly generated. Note that the key entropy in our case is $2^4.32=2^9=512$ bits instead of only 32-bits in the other cipher structure deploying key-schedule generating the sub-keys out of only 32-bit input-key.

Table II. shows the resulting hardware complexity of the sample proposed SUC implementation in a SmartFusion®2 SoC FPGA:

TABLE II HARDWARE COMPLEXITY USING SMARTFUSION®2 M2S025T FPGA

Hardware Resources	# LUTs	# D-FFs	# MACCs
The proposed SUC	208	113	8

VI. Security Analysis and Evaluation

According to Kerckhoffs's principle: "An attacker knows all details of the used cipher structure except the cipher-key which is kept secret". To increase the security of the cipher, the idea of using a block cipher with secret

components is early investigated. For instance, Biryukov and Shamir [20] cryptanalyzed the so-called AES-like cipher that is defined as two and a half rounds of AES-128 with secret 8-bits S-Boxes and secret affine mapping. In such architecture, the attack requires only 2^{16} chosen plaintexts to determine all secret S-Box components.

In SUC- attack model, an attacker theoretically needs to recover the secret key and then to predict the randomly-chosen golden S-Boxes and the coefficients *a*, *b* of each mappings $\pi(L,R)=aL+bR$ of the SUC. The successful attack is possible with a complexity of the order $(2^{71.8} .2^{33} .2^{16.9})= 2^{121.7}$. Where, $2^{71.8}$ is the number of distinct choices for selecting 4 different golden S-Boxes from a class of $2^{19.1}$, 2^{33} is the number of choosing one 32 bits $\pi(L,R)$ out of all possible mappings, and $2^{16.9}$ is the number of choosing two different 8 bits $\pi(L,R)$ out of 2^9 possibilities according to (4). The attack complexity may be reduced by using a novel differential-style attack on a block cipher with secret components as given in [21]. However, this is only possible if the attacker gets access to each output of a round function which is prohibited in SUC structure model.

Furthermore, the selected S-Boxes are golden S-Boxes and their differential behavior is known (see TABLE I). In [13], an exhaustive search algorithm has showed that at least 6 "active S-Boxes" need to be crypto-analyzed in the inner function *F* for both differential and linear cryptoanalysis. These S-boxes have a differential probability of $p = 1/4$ and a linear approximation characteristic probability of $\varepsilon = 1/4$. In this case, the inner function *F* exhibits a differential and linear time complexity of $2^{2\times6}=2^{12}$. Therefore, the proposed SUC with at least 15 rounds has neither differential nor linear characteristics whose complexities are less than $2^{12\times14} =2^{168}$. This discussion proves that even if the GENIE is published or somehow found, then the proposed SUC has an acceptable level of security. Otherwise, an attacker is only able to collect the input combinations and save the corresponding outputs in the term of the generic attacks with respect to a black-box attack model, where, the probability of guessing/predicting the secret parameters and then recovering the secret key approaches the products of both previous complexities, that is 2^{168}. $2^{121.7} =2^{289.7}$. Therefore, ongoing research is conducted to answer the following open question: whether the three-round variant of such a cipher behaves like a pseudorandom permutation [17].

VII. Conlusion

A new self-creatable large cipher class based on multiplicative two-variables self-inverse mappings together with golden S-Box mappings is presented. The resulting ciphers can serve as low-complexity Secret Unknown Ciphers (SUCs) as a clone-resistant digital PUFs. The low-complexity results from recycling dead math-blocks in some FPGA applications. As a result, highly-resilient digital PUF may be created for possibly negligible-costs in existing applications using the unused MACCs (math-blocks) in their FPGA units. The resulting digital-PUF's security level is scalable and can even cope with post-quantum security requirements.

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PROFESSIONAL PAPERS IN CROATIAN

Automatizacija proizvodne linije u mesnoj industriji

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***Sažetak* - Automatizacija proizvodne linije u mesnoj industriji izvedena na način da je uklonjeno zastarjelo relejno upravljanje te razvijeno potpuno novo upravljanje na bazi programibilnog logičkog kontrolera. Na osnovu mehaničke konstrukcije stroja i tehnološkog opisa rada linije, odabrano je optimalno tehničko rješenje automatizacije linije. Tehničko rješenje obuhvaća principe pneumatike i hidraulike koji se koriste na liniji, odabir sklopne opreme i programibilnog logičkog kontrolera, senzora i njihove karakteristike. Prema odabranoj opremi nacrtana je električna shema, naveden princip rada pojedinih dijelova sheme te izveden upravljački razdjelnik. Prema izvedenom stanju elektro upravljačkog razdjelnika i tehničko tehnološkom opisu napravljen je upravljački program tehnikom programiranja ljestvičastog dijagrama i proizvodna linija je puštena u pogon.**

I. OPIS TEHNIČKO - TEHNOLOŠKOG PROBLEMA

Strojevi za rad u mesnoj industriji izrađeni su većinom od nehrđajućeg čelika i robusne su konstrukcije .Zbog toga ostaju u dobrom stanju nakon dugog niza godina pouzdanog rada. Većina cijene stroja otpada na mehaničke dijelove koji su u dobrom stanju, dok manji dio cijene otpada na električni dio stroja. Zbog toga je isplativo remontirati i modernizirati stare proizvodne linije.

Jedan od najvećih problema u mesnoj industriji predstavlja vlaga koja je uzrokovana redovnim pranjem strojeva. Zbog zahtjeva čistoće strojevi se peru određenim kemijskim sredstvima koja se doziraju u vodu za pranje. Pranje se vrši mlaznicama pod visokim tlakom, tako da usprkos visokom stupnju zaštite od polijevanja, voda i deterdžent ulaze u električne dijelove strojeva i time dolazi do problema u radu strojeva.

Dio problema se odnosi i na starost elemenata (a zbog uvjeta u kojima rade često dolazi do ubrzanog starenja materijala) pa tako u kombinaciji s vlagom može doći do kompleksnih kvarova i problema u radu strojeva. Automatizacija strojeva prije 30-ak godina bila je bazirana na relejnoj tehnici i mehaničkim krajnjim sklopkama. Tako je konkretna proizvodna linija imala većinom mehaničke krajnje sklopke i relejno upravljanje. Zbog njihovih dotrajalosti često je dolazilo do zastoja u proizvodnji i dugotrajnih traženja kvarova.

II. OPIS RADA LINIJE

Kompletna proizvodna linija za punjenje šunke u kalupe sastoji se od dvije nezavisne cjeline koje rade zasebno. Te dvije cjeline podijeljene su tako da prva cjelina *LW80* i *V170* služi za punjenje šunke u kalupe, dok druga cjelina *D115*, *S220* i *D116* služi za vakuumiranje i zatvaranje kalupa. Na slici 1 prikazan dio proizvodne linije.

III. RJEŠENJE

A. Pneumatika

Pneumatski elementi su zajednički naziv za sve funkcionalne jedinične cjeline koje rade pod stlačenim zrakom [2]. Opskrba stlačenim zrakom mora biti konstantna i ne smije varirati. Svaki od elemenata radi pod određenim tlakom zraka, a koji ne smije biti iznad dopuštene razine da ne dođe do oštećenja elemenata. Za regulaciju stlačenog zraka koriste se regulatori kojima reguliramo tlak zraka za pogon pneumatskih elemenata. Također za ispravan rad pneumatskih elemenata bitno je odvojiti kondenzat iz stlačenog zraka te po potrebi zrak nauljiti, a za to služe odvajači kondenzata i nauljivači. Regulatori tlaka, odvajači kondenzata i nauljivači izvode se u različitim kombinacijama, a skupa se nazivaju pripravnom grupom.

Najčešći pneumatski izvršni elementi su pneumatski cilindri, a koji mogu biti jednoradni, dvoradni ili specijalni.



Slika 1 D115 transportna linija

Elektromagnetski ventili omogućuju povezivanje električnog upravljanja s pneumatskim izvršnim elementima. Njihov način rada je takav da uzbuda u svitku stvorena protokom struje stvara magnetsko polje koje pomiče kotvu i otvara prolaz stlačenom zraku od ulaza na izlaz, a ujedno zatvara odzračivanje na priključku. Možemo ih podijeliti u dvije grupe:

- Monostabili – razvodnici kod kojih se aktiviranje razvodnika ostvaruje električkom uzbudom u svitku, a povratak u nulti položaj oprugom. Imaju samo jedno stabilno stanje i to ono u nultom položaju. Dok djeluje struja, razvodnik mijenja položaj a nestankom njenog djelovanja vraća se u nulti položaj.
- Bistabili – razvodnici koji se aktiviraju i vraćaju u početni položaj uzbudom u svicima. Kod njih su oba položaja stabilna. U tom položaju ostaju i kada prestane djelovanje električne struje.

Pneumatika je uglavnom ostala u originalnom stanju, jedino što je kroz godine zamijenjena pripravna grupa adekvatnom novije generacije.

B. Hidraulika

U osnovi su hidraulički elementi, simboli i način upravljanja isti kao pneumatski elementi, samo što je u hidraulici medij ulje i hidraulika postiže veće sile od pneumatike. Uvjet za rad hidraulike je uključen motor hidrauličke pumpe, a tlak ulja se kontrolira presostatom. Kad je motor uključen i presostat je zatvorio svoj kontakt tj. postignut tlak ulja, mogu se uključiti špule hidrauličkog razvodnika koji ovisno o svojoj poziciji upravlja radom hidrauličkog cilindra. U nekim primjenama također se ugrađuje plovak u spremnik s hidrauličkim uljem kako bi se osigurala dovoljna količina ulja, i u slučaju propuštanja indicirao nedostatak ulja. Hidraulički dio linije ostao je u originalnom stanju jer uredno funkcionira.

C. PLC oprema

Odabran je programibilni logički kontroler (engl. *Programmable Logic Controler*, PLC) od renomiranog proizvođača *SIEMENS* i to iz serije *S7-200* koja zadovoljava potrebe za nižom razinom automatizacije, a pokazala se pouzdanom u pogonu.

Osnovne karakteristike serije *S7 – 200* : Mali modularni upravljački sustav za nižu razinu automatizacije, *"Micro PLC"* s ugrađenim funkcijama, vlastita programska podrška, centralna veza s programiralicom s mogućnošću pristupa svim modulima, opseg koji obuhvaća gradaciju procesora različite razine zahtjeva, širok izbor dodatnih modula, mogućnost proširenja do 7 modula, sabirnički sustav koji podržavaju moduli i mogućnost povezivanja u mrežu pomoću RS485 komunikacijskog sučelja, PROFIBUS-a i industrijskog ETHERNET-a [4].

Za izvedbu automatizacije proizvodne linije za punjenje šunke u kalupe odabran procesor *CPU224XP* oznake *6ES7-214-2AD23-0XB0*.

Njegove osnovne karakteristike su: napajanje 24VDC, 14 digitalnih ulaza 24VDC, 10 tranzistorskih digitalnih izlaza 24VDC, 2 COM priključka, 2 analogna ulaza (±10V), 1 analogni izlaz (0 - 10V ili 0 - 20mA) i disipacija snage 8W.

Za potrebe ove aplikacije odabrani su dodatni moduli digitalnih ulaza i izlaza. Odabrane su dvije vrste modula: s digitalnim ulazima i tranzistorskim izlazima te s digitalnim ulazima i relejnim izlazima:

EM223 6ES7223-1BM22-0XA0 modul: 32 digitalna ulaza 24 VDC, 32 tranzistorska izlaza 24 VDC – 0.75A i disipacija snage 9W.

EM223 6ES7223-1PL22-0XA0 modul: 16 digitalnih ulaza 24VDC, 16 relejnih izlaza 2A i disipacija snage 6W.

Za obradu analognih vrijednosti iz procesa te za postavljanje analognih referenci služe moduli analognih ulaza i izlaza.

EM231 6ES7 231-0HC22-0XA0 modul: napajanje 24VDC, 4 analogna ulaza 12bit, disipacija snage 2W i ulazi se mogu konfigurirati za željene veličine napona do 10 V, struje do 20mA.

EM 235 6ES7 235-0KD22-0XA0 modul: napajanje 24VDC, 4 analogna ulaza/ 1 analogni izlaz, disipacija snage 2W, ulazi se mogu konfigurirati, naponski izlaz ±10V i strujni izlaz 0 – 20mA

Ethernet modul *CP 243-1 6GK7243-1EX00-0XE0* služi za komunikacijske veze sustava automatizacije preko etherneta i to za komunikaciju prema programu *STEP 7 MicroWin*, komunikaciju prema udaljenim komponentama porodice *STEP 7* i komunikaciju prema OPC (eng. *OLE for Process Control*) baziranim aplikacijama.

Operatorski zaslon *TP177 micro 6AV6640-0CA11-0AX11* služi za nadzor i kontrolu manjih strojeva ili sustava automatizacije. Jednostavno se programira pomoću programa *WinCC flexible*. Podržava razne funkcije potrebne za automatizaciju, kao što su ulazno izlazna polja za prikazivanje i mijenjanje procesnih parametara, prikaz grafike procesa i prikaz dinamičkih parametara procesa. Njegove osnovne tehničke karakteristike su: monokromatski LCD zaslon (engl. *Liquid Crystal Display* , LCD) ekran osjetljiv na dodir, RS485 priključak, napajanje 24VDC (20.4V – 28.8V), disipacija snage 6W, uvjeti rada 0 do +40°C s 85% relativne vlage, podržava do 250 ekrana i konfigurirati se može do 250 oznaka(imena dodijeljena adresama uređaja ili PLC-a) i20 oznaka po ekranu.

D. Sklopna oprema

- Glavna sklopka – proizvođača Telemecanique koja se odlikuje robusnošću, izdržljivošću i jednostavnom montažom [7]. Postoje razne vrste grebenastih sklopki koje se koriste u razne svrhe. Kada se grebenasta sklopka koristi u svrhu glavne sklopke stroja, mora biti žuto crvene boje s jasno istaknutim natpisom GLAVNA SKLOPKA i mogućnošću zaključavanja lokotom u isključenom položaju. Ovo je bitno zbog pravila zaštite na radu. U slučaju radova na stroju glavna sklopka mora biti isključena i spriječena mogućnost slučajnog uključivanja sklopke a koja radnja bi mogla dovesti u opasnost po život osobu koja izvodi radove.

- Automatski osigurači – za zaštitu uređaja na liniji odabrani su automatski osigurači *Merlin Gerin* koji su se pokazali iznimno pouzdanim i trajnima. Važna odlika im je da pouzdano mogu prekinuti struje kratkog spoja više puta uzastopno bez ikakvih oštećenja, a što je bitno za primjenu u industrijskim pogonima [8]. Loši osigurači često stradavaju nakon prekida kratkog spoja i time donose dodatne zastoje i probleme u industrijskom pogonu.
- Sklopnici – za uklapanje motora odabrani su sklopnici *Telemecanique* [7]. Pri odabiru sklopnika bitno je obratiti pažnju na snagu kontakata i na napon svitka. Postoje gotove varijante za pokretanje motora zvijezda – trokut, ali to u ovome radu nije korišteno već je primijenjena klasična kombinacija sa spajanjem pojedinih elemenata. Naime to je u ovom slučaju praktičnija varijanta jer je potrebno imati manje rezervnih dijelova, tj. upotrjebljeni sklopnici su jednostavno zamjenjivi s bilo kojima drugima u slučaju kvara.
- Pomoćni releji – od proizvođača *Schrack* s pripadajućim podnožjima korišteni su kao izlazni releji PLC uređaja tj. preko njih se uklapa teret kako bi se štitili izlazi. Ukoliko dođe do kvara, potrebno je jednostavno zamijeniti utični relej, dok je zamjena kartice PLC uređaja puno kompliciranija i skuplja te se zbog toga odabire ovo rješenje gdje god je to moguće.
- Termomagnetski motorski prekidači – Za zaštitu motora odabrani su termomagnetski prekidači *Telemecanique* koji štite motore od pregrijavanja i kratkih spojeva. Na prekidače se jednostavno prigrađuju pomoćni kontakti koji su galvanski odvojeni od dijelova pod naponom. Koriste se za indikaciju stanja prekidača u upravljačkim krugovima [7].
- Tipkala – tipkala u kućištu *Telemecanique* serije *XB5* su korištena za stop u nuždi i upravljanje transportnom linijom. Tipkala su modularna, jednostavna za montažu i pouzdana u dužem periodu rada [7].

E. Pretvarač napona i frekvencije OPTIDRIVE

Za pogon motora transportne linije *D115* odabran je pretvarač napona i frekvencije *OPTIDRIVE ODE-2-14150-3K012* koji je jednostavan za montažu, konfiguraciju i puštanje u pogon. Svi parametri Izravno se mogu konfigurirati na njegovom operacijskom zaslonu ili putem kabela i sučelja za konfiguraciju preko računala. Konfiguracija preko računala je jednostavnija jer je cijeli set parametara pregledniji može spremiti, a konfigurirani podaci isprintati i priložiti tehničkoj dokumentaciji [9].

F. Senzori

U ovom radu korišteno je više vrsta senzora koji služe za pretvorbu mjernih veličina u standardne električne signale (tlak, vakuum, struja), presostati za indikaciju postignutih uvjeta rada te optički i induktivni senzori koji služe za inicijalizaciju pozicija mehaničkih elemenata proizvodne linije.

- Strujni transformator *LEM AP50 B10* – s razdvojenom jezgrom za mjerenje izmjeničnih struja, s galvanskom izolacijom između primara (visoke struje) i sekundara (elektroničkog kruga). Osnovne karakteristike su mu: jednostavna montaža, nazivna struja primara do 50 A, naponski izlaz 0 – 5 V ili 0 – 10 V, napon napajanja 24VDC, linearni izlaz, radna temperatura - 20°C do +60°C.
- Mjerni pretvornici tlaka *E+H PMC131* – koriste se za mjerenje tlaka plinova, para i tekućina. U konkretnoj aplikaciji koriste se za mjerenje tlaka zraka, hidraulike i vakuuma. Osnovne karakteristike: strujni izlaz 4-20 mA, procesni priključak ½ cola, širok izbor mjernih područja ovisno o modelu, temperatura medija -20°C do +100°C, radna temperatura -20°C do +85°C
- Napajanje *E+H RNS221* – je dvokanalno napajanje za dvožične senzore ili odašiljaće. Osnovne karakteristike: širok opseg napona napajanja 20 do 250VDC/VAC, galvanska izolacija između oba kanala, stabilno napajanje 24VDC struje 30mA, zaštita od kratkog spoja, radna temperatura -20°C do +60°C.
- Induktivni senzori – senzori *Osiprox* su iz serije univerzalnih senzora za općenitu primjenu, ističu se mogućnošću ugradnje u metal i izvan metala. Za ovu aplikaciju odabrani su senzori promjera 18mm. Za njih su napravljeni nosači kako bi odgovarali na pozicije starih mehaničkih krajnjih sklopki bez potrebe za bilo kakvim preinakama. Ovisno o potrebi određene pozicije korištena su dva tipa senzora i to: *XS618B1NAL2* i *XS618B1NBL2*. Oba tipa senzora odlikuju se istim karakteristikama, samo obrnutom funkcijom izlaza: NPN tip izlaza, preožičeni s 2m kabela, nazivna osjetna duljina 8 mm, radna temperatura -25°C do +70°C, napajanje 10 – 58VDC, uklopna struja 200mA, prekostrujna i kratkospojna zaštita.
- Optički senzor *Banner T18SP6DQ* – u ovoj aplikaciji korišten je za kontrolu prisutnosti kalupa na poziciji za zatvaranje. Senzor je difuznog tipa i ima mogućnost podešavanja osjetljivosti, što ga čini prikladnim za detekciju prisutnosti proizvoda na zadanoj poziciji. Upravo zbog tih karakteristika pogodan je za razne aplikacije jer se ne mora montirati na određenoj poziciji, već se montira na najpogodniju poziciju i naknadno podesi. Također mu je jedna od bitnih karakteristika da se slobodno pere i nakon pranja pouzdano radi čak i ako ostane kapljica vode na optici ili sloj nečistoće. Osnovne karakteristike: napajanje 10 do 30 VDC, zaštita od krivog priključka na napon i prijelaznih pojava, PNP tranzistorski izlaz, zaštita od preopterećenja ili kratkog spoja na izlazu, mogućnost podešavanja osjetljivosti do 500 mm, radna temperatura -40°C do +70°C i vodootporan.
- Presostati – uređaji za mjerenje tlaka koji, ovisno kako je podešen, pri postignutom tlaku preklapa

stanje svojih kontakata. U ovom radu se koriste presostati Danfoss serije *RT* za opće namjene.

IV. UPRAVLJAČKA SHEMA

Električna shema izrađena je pomoću programa *EPLAN Electric P8 V1.9*, koji je namijenjen za izradu električnih shema razvodnih ormara i kompletnih postrojenja. Shema je izrađena prema odabranim elementima. Elementi su prvo nabavljeni nakon toga se pristupilo izradi sheme prema konkretnim stvarima i oznakama. Bitno je imati elemente prije crtanja tako da se odmah mogu provjeriti sve oznake kako bi shema bila jasnija i zahtijevala kasnije što manje preinaka. Prema nacrtanim shemama napravljeni su upravljački razdjelnici.

A. Glavni motori

Motor hidrauličke pumpe u *LW80* pokreće se grupom zvijezda – trokut. Grupa je spojena u standardnoj konfiguraciji. Njom upravlja program u PLC uređaju koji određuje vrijeme zalijetanja i redoslijed preklapanja sklopnika. U seriju sa sklopnicima spojeni su pomoćni kontakti koji služe za zaštitu, pošto program u PLC uređaju samo vodi grupu bez povratne informacije o stanju sklopnika. Kao povratna informacija o stanju motora na ulaze PLC uređaja spojeni su pomoćni kontakti termomagnetskih motorskih prekidača. Ugrađeni su strujni transformatori za kontrolu struje motora. Vrijednosti struje motora nisu vidljive na zaslonimama za operatere, već samo pomoću *MicroWina- a* na servisnom računalu i one su vidljive samo ako pratimo analogne ulaze. To je izvedeno tako da operateri na liniji ne bi dobivali njima nepotrebne podatke. Dok s druge strane u slučaju problema na liniji (propuštanja ulja, raznih blokadi u sistemu) u smjenama kada rade samo operateri, tehničko osoblje može pomoći od kuće spajanjem na servisno računalo. Uvidom u struju motora pumpe iskusni tehničari mogu procijeniti da li je došlo do nekog kvara koji mogu riješiti sami operateri (nedostaje ulja, preopterećenje) ili je potrebno da netko od tehničkog osoblja dođe osposobiti liniju.

Upravljanje transportnom trakom *D115* izvezeno je pomoću pretvarača napona i frekvencije. On je konfiguriran na način da starta motor kada je zatvoren kontakt na njegovom digitalnom ulazu. Referenca za brzinu zadaje se preko operacijskog zaslona a PLC uređaj zadanu vrijednost pretvara u standardni naponski signal 0–10 V na svojem analognom izlazu. Analogni izlaz PLC uređaja spojen je na analogni ulaz pretvarača napona i frekvencije koji je konfiguriran tako da mu je analogni ulaz referenca brzine.

B. Pomoćni razvod

Pomoćni razvod upravljačkog razdjelnika sastoji se od servisne utičnice i grijača ormara. Utičnica se najčešće koristi kada se obavljaju neki radovi na liniji. Grijač unutar ormara služi za sprečavanje kondenzacije vlage s obzirom da se ormar nalazi u dosta hladnim i vlažnim radnim uvjetima. Termostat ga uključuje po potrebi kada komponente unutar ormara ne odvode dovoljno topline, da bi se izbjegla kondenzacija.

C. Napajanje 24VAC

Napajanje 24VAC izvedeno je klasičnim transformatorom 380/24VAC i služi za napajane komponenata koje rade na 24VAC . Zaštita transformatora izvedena je automatskim osiguračima.

D. Napajanje 24VDC

Veći dio komponenata na liniji napaja se s 24VDC. U svrhu napajanja 24VDC korišten je transformator i punovalni mosni ispravljač. Takav izvor istosmjernog napajanja jednostavan je i jeftin, te ne zahtjeva nikakve posebne rezervne dijelove, što ga čini najboljim izborom. Ovakva izvedba napajanja može se koristiti za komponenate koje toleriraju varijacije napona izazvane uslijed varijacija napona mreže, pošto ovakva izvedba nema stabilizaciju napona. Zbog potrebe stabilnog napona na mjernim pretvornicima odabrani su elektronički stabilizirani izvori napona.

E. Grijači za varenje vrećica

Jedna od važnijih stvari bitnih za kvalitetu je varenje vrećica. Ono se izvodi električnim grijačima. Grijači su oblika termoletvice od teflona na kojoj je otporna žica. Varenje se podešava namještanjem vremena kroz koje struja zagrijava otpornu žicu. Zbog kontrole ispravnosti žice grijača ugrađen je strujni transformator koji služi za kontrolu struje koja kroz njega protječe. S vremenom zbog dotrajalosti se struja smanjuje pa grijači više ne griju dovoljno dobro i var nije kvalitetan. Za vrijeme varenja operater na zaslonu vidi struju grijača i tako može kontrolirati kvalitetu vara. Ako se struja smanji ispod dozvoljene potrebno je zamijeniti otpornu žicu grijača.

F. Stop u nuždi

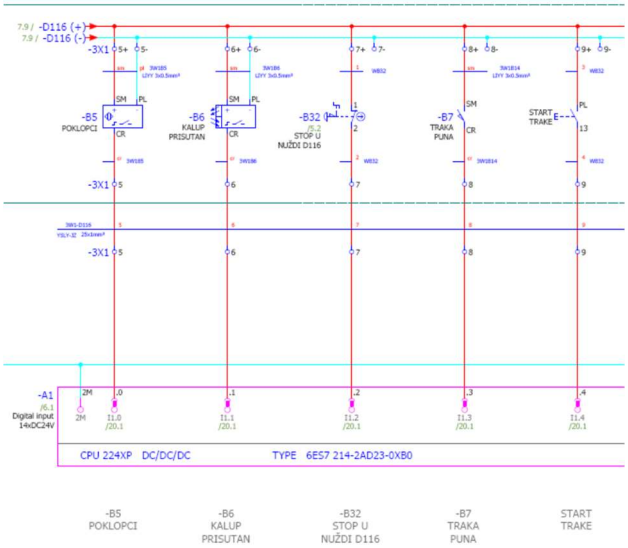
Na svakom dijelu stroja nadohvat ruke operateru nalaze se gljivasta tipkala za stop u nuždi. U slučaju pritiska tipkala za stop u nuždi cijela linija treba stati. To je izvedeno serijskim spajanjem tipkala koja upravljaju glavnim sklopnikom K0 za pomoćni napon. Sklopnik K0 služi za uključivanje i isključivanje napajanja aktuatora. Kada je pritisnuto tipkalo za stop u nuždi svi aktuatori ostaju bez napajanja. Napajanje ostaje na senzorima i PLC uređaju kako bi se moglo imati uvid u problem zbog čega je pritisnuto tipkalo za stop u nuždi. Svako tipkalo za stop u nuždi ima dodatne kontakte koji su spojenu na digitalne ulaze PLC uređaja koje služi za indikaciju stanja. Na temelju praćenja stanja tih ulaza ispisuju se poruke na operatorskom zaslonu.

G. Povezivanje senzora na digitalne ulaze PLC uređaja

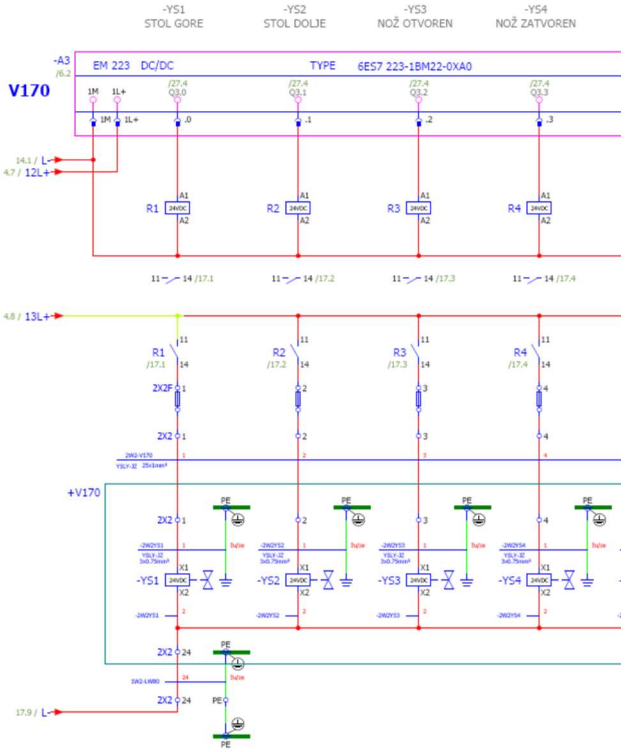
Svaki senzor ima predviđene stezaljke za napajanje i stezaljku za povrat signala na ulaz PLC uređaja. U slučaju da se umjesto senzora koristi tipkalo ili neki senzor s kontaktima (presostat) spaja se samo između + stezaljke i stezaljke za povrat signala.

H. Povezivanje aktuatora na digitalne izlaze PLC uređaja

Zbog zaštite izlaza PLC uređaja na izlaze su spojeni mali utični pomoćni releji koji služe za uklapanje aktuatora. Ovaj način zaštite izlaza odabran je zato što je u slučaju kvara puno jednostavnije i jeftinije zamijeniti samo



Slika 2 Povezivanje senzora na digitalne ulaze PLC uređaja

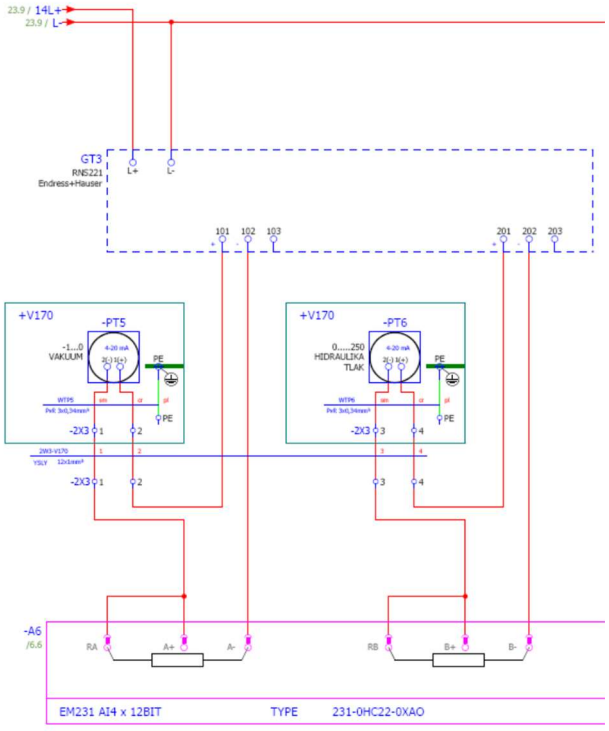


Slika 3 Povezivanje aktuatora na digitalne izlaze PLC uređaja

pomoćni relej nego cijelu karticu PLC uređaja. Ova metoda se često koristi. U startu je skuplja i kompliciranija za izvođenje, ali zato s vremenom smanjuje troškove održavanja i skraćuje vrijeme popravka.

I. Povezivanje mjernih pretvornika na analogne ulaze PLC uređaja

Za napajanje mjernih pretvornika korišteni su elektronički izvori napajanja koji daju stabilan napon i galvanski su odvojeni pojedini izvori. Mjerni pretvornici tlaka daju strujni signal 4 – 20mA. S obzirom da analogno-digitalni pretvornik (engl. *Analog to Digital Converter,* ADC) u kartici mjeri napon a ne struju, senzori su spojeni u seriju s otpornikom u kartici, tako da ADC mjeri napon



Slika 4 Povezivanje mjernih pretvornika na analogne ulaze PLC uređaja

na tom otporniku, a koji je proporcionalan sa strujom u mjernom krugu. Elektronika strujnih transformatora koji se koriste za kontrolu struje daje na svom izlazu naponski signal 0 – 10V, tako da su oni spojeni na analogne ulaze direktno bez otpornika.

V. UPRAVLJAČKI PROGRAM

A. STEP 7-MicroWin

Upravljački program izrađen je pomoću programskog paketa *SIEMENS STEP7 – MicroWin*

Program *STEP 7 – MicroWin* namijenjen je programiranju PLC uređaja serije *S7-200* i njihovih dodatnih modula. Program podržava ljestvičasti dijagram (engl. *Ladder logic,* LAD), funkcijski blok dijagram (engl. *Function Block Diagram,* FBD) i popis izjava (engl. *Statement List,* STL) način programiranja [3]. U ovom radu korišten je LAD način programiranja. Ovaj način odabran je zato što je najbliži relejnoj logici na koju je osoblje održavanja naviknuto tako da razumije način na koji je izvedeno upravljanje linijom .

B. WinCC flexible

Operatorski zasloni programirani su pomoću programskog paketa *SIEMENS WinCC flexible*

WinCC flexible služi za konfiguriranje sučelje čovjek-stroj (engl. *Human Machine Interface*, HMI) na operatorskim zaslonima. Svojstva *WinCC-a* su definiranje i manipulacija oznakama, stvaranje grafičkog sučelja, definiranje alarma, receptura, trendova, stupičastih grafova, te prebacivanje konfiguracije na operatorski zaslon pomoću komunikacijskog kabela [5].

U ovom radu konfigurirani su zasloni *TP177 micro* koji služe za upravljanje i kontrolu linije. Zasloni koji su

definirani za upravljanje linijom, poslužili su i kao osnova za izradu uputa za uporabu.

VI. OPIS RADA PROGRAMA

S obzirom da se linija sastoji od dvije nezavisne cjeline kojima upravljaju zasebni PLC uređaji razvijena su dva potpuno nezavisna programa za upravljanje, a koji će biti ukratko opisani u narednim poglavljima.

A. Opis programskog dijela za upravljanje LW80 i V170

Program kontrolira uvjete za uključenje linije LW80 i V170. U slučaju neispunjenja uvjeta za rad ili pritiska tipkala za stop u nuždi postavljaju se bitovi zaštite i ispisuju greške na operatorskom zaslonu. Resetiranje se vrši potvrdom greške na operatorskom zaslonu, čime se resetiraju pomoćni bitovi zaštite. Kada su zadovoljeni svi uvjeti za uključivanje i linija pokrenuta, uključuju se motori hidrauličkih pumpi LW80 i V170. Motor hidrauličke pumpe LW80 pokreće se grupom zvijezda-trokut. Kada se uključuje motor pumpe prvo se uključuje kombinacija spoja u zvijezdu. Nakon isteka perioda zalijetanja motora preklapa se u kombinaciju trokut i tako nastavlja raditi. Motor hidrauličke pumpe V170 se starta direktno preko sklopnika i za njegovo pokretanje dovoljni su samo zadovoljeni uvjeti. Nakon što su ispunjeni svi uvjeti za početak rada linije u automatskom modu rada, umetanjem kalupa s vrećicom na poziciju za punjenje i zatvaranjem vrata komore počinje složeni proces punjenja. Analogne vrijednosti pohranjuju se na memorijske lokacije koje se koriste u programu na više mjesta za kontrolu ili ispis vrijednosti na operatorskom zaslonu. Brojači proizvodnje broja kalupa izvedeni su uzastopnim dodavanjem broja 1 za svaki napunjeni kalup na njihove memorijske lokacije. Ukupna težina računa se tako da se ukupni broj napunjenih kalupa pomnoži s težinom kalupa. Resetiranje brojača izvodi se tako da se na njihove memorijske lokacije upiše 0.

B. Opis programskog dijela za upravljanje D115, S220, D116

Pritiskom na tipkalo stop u nuždi resetiraju se svi izlazi i zaustavlja linija. Ukoliko su prisutni uvjeti da tipkala za stop u nuždi nisu pritisnuta, tj. aktivni su njihovi ulazi, aktivan je i memorijski bit STOP_UVJETI koji se koristi dalje u programu kao uvjet da bi se dio programa uopće izvodio. Kao i u prethodnom programu analogne vrijednosti pohranjuju se na memorijske lokacije koje se koriste u programu na više mjesta za kontrolu ili ispis vrijednosti na operatorskom zaslonu. Također se koristi usporedba analogne vrijednosti sa zadanom vrijednošću za kontrolu uvjeta prisustva zraka. Brzina trake se podešava na operatorskom zaslonu i sprema na memorijsku lokaciju, a čija se vrijednost seli na analogni izlaz kao referenca za brzinu trake. Transportna traka pokreće se automatski pritiskom na tipkalo Start trake ukoliko su zadovoljeni svi uvjeti za pokretanje. Definirana je i minimalna zadana brzina kojom se traka može kretati te neće krenuti ako je postavljena na manju brzinu od minimalne. U procesu rada, ukoliko dođe do zagušenja linije, tj. traka se napuni, automatski staje i automatski kreće kad se raščisti. Nakon što su zadovoljeni svi uvjeti za početak vakuumiranja, zatvaranjem vrata komore za vakuumiranje u automatskom modu rada počinje proces vakuumiranja i zatvaranja proizvoda. Zatvarač *S220* se sastoji od dvije identične komore te je stoga za svaku komoru identičan i program. Zadnja radnja u procesu punjenja šunke u kalupe je postavljanje poklopaca na kalupe. To se odvija u automatskom modu rada kada kalup dođe na poziciju za zatvaranje. Spušta se vodilica poklopca, cilindar pritišće poklopac na kalup, vraća se u početnu poziciju i čeka sljedeći kalup kada se radnja ponovno odvija.

VII. ZAKLJUČAK

Kako bi se poboljšale performanse linije i smanjio trošak održavanja te skratilo vrijeme mogućih zastoja u proizvodnji razvijeno je potpuno novo upravljanje linijom na bazi PLC uređaja. Takvo rješenje je optimalno jer je upravljanje bazirano na provjerenom PLC uređaju tvrtke *SIEMNS S7-200* koji je cjenovno pristupačan i pouzdan u radu te je odabrana provjerena standardna sklopna i mjerna oprema koja ne zahtjeva skladištenje veće količine rezervnih dijelova te time pridonosi smanjenju troškova pošto se isti dijelovi koriste na različitim dijelovima linije. Zbog korištenja standardne opreme serviseri su već upoznati s njenim prednostima i nedostacima te puno lakše uočavaju i otklanjaju greške naspram stare dotrajale opreme za koju nije bilo sigurno dali će uspjeti odraditi do kraja smjene. Dodavanjem HMI sučelja ostvareno je jednostavnije rukovanje a i mogućnost prikaza okvirnih lokacija greška prilikom nastupanja kvara što značajno olakšava njen pronalazak naspram prijašnjeg sustava gdje se pojavom kvara morao ispitati svaki kontakt dok se nije došlo do pronalaska greške. Nikada nisu bili mjereni konkretni podaci za koliko su smanjeni troškovi, ali dobar pokazatelj uštede i poboljšana cijele linije je smanjeni interval između grešaka i vrijeme potrebno za njeno otklanjanje. Red dešavanja grešaka na liniji se smanjio sa od prilike jednom tjedno na jednom mjesečno a trajanje tog servisa se smanjilo sa par sati rada gdje je bila potrebna prisutnost minimalno dvaju servisera na od prilike jedan sat rada jednoga. Shema linije je napravljena modernim programom za crtanje shema, kojim se jednostavno radi te je u slučaju izmjena na liniji jednostavno ažuriranje tehničke dokumentacije. S obzirom da je upravljanje bazirano na PLC uređaju, otvorene su mogućnosti: poboljšanja sustava upravljanja ako se pokaže potrebnim, jednostavne nadogradnja novih komponenata u sustav i eventualno povezivanje s ostalim sustavima unutar tvornice. Linija je puštena u pogon u tvrtki PIK-Vrbovec.

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Realizacija sustava za kontrolu pristupa temeljenog na Raspberry platformi

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***Sažetak* – Suvremeni elektronički sustavi omogućili su brzu i jednostavnu kontrolu pristupa određenim objektima. Komercijalni sustavi za kontrolu pristupa često imaju relativno visoku cijenu te su najčešće zatvorenog tipa, što otežava jednostavnu nadogradnju i prilagodbu potrebama korisnika. U radu je prikazana realizacija jeftinog i modularnog sustava za kontrolu pristupa temeljenog na Raspberry Pi 2 računalu. Sustav koristi pasivno infracrveno osjetilo, radiofrekvencijski čitač identifikacijskih čipova, alfanumerički zaslon za prikaz poruka namijenjenih korisniku, te kameru koja se koristi za arhiviranje i dodatnu kontrolu pristupa. Sustav kombinira module za realizaciju jednostavnog i efikasnog sustava kontrole pristupa. Infracrveno osjetilo detektira korisnika u blizinu uređaja, nakon čega se na alfanumeričkom zaslonu ispisuje poruka da korisnik treba približiti svoj identifikacijski čip. Provodi se očitanje identifikacijskog čipa, obrada podataka, te donosi odluka o propuštanju ili blokadi korisnika. Pri tome se dodatno koristi kamera za fotografiranje korisnika. Za evidenciju pristupa i pohranu fotografija koristi se standardni sustav za pohranu na memorijske kartice, integriran u Raspberry Pi 2 računalo. Obradu prikupljenih podataka moguće je obaviti uobičajenim alatima na računalu, jer su podaci snimljeni u standardnim zapisima koji se koriste za spremanje teksta i fotografija.**

Ključne riječi – kontrola pristupa, Raspberry Pi 2, RFID, identifikacija korisnika

I. UVOD

Svrha sustava za kontrolu pristupa je omogućiti ovlaštenim korisnicima brz i jednostavan pristup kontroliranim objektima. Osim brzog i jednostavnog pristupa, suvremeni sustavi za kontrolu pristupa omogućavaju automatsko prikupljanje i spremanje podataka o pokušajima pristupa osoba, što se najčešće koristi prilikom evidencije radnog vremena zaposlenika. Podaci o pokušajima pristupa se koriste i u svrhu povećanja sigurnosti objekta, te bolje zaštite imovine. Zbog navedenih razloga, upotreba sustava za kontrolu pristupa je u porastu. Suvremeni sustavi za kontrolu pristupa mogu koristiti razna tehničkih sredstava, no najčešće koriste identifikacijske kartice s radiofrekvencijskim identifikacijskim (RFID) čipom. Osnovni razlozi popularnosti ove metode kontrole pristupa su jednostavnost upotrebe i relativno niska cijena opreme [1]. Jednostavnost upotrebe se očituje u brzom očitavanju podataka s identifikacijske kartice koju je dovoljno približiti čitaču sustava za kontrolu pristupa. Također, postupak dodjele identifikacijske kartice za novog korisnika je brz i jednostavan. Prilikom gubitka identifikacijske kartice, promjenom statusa kartice u datoteci korisnika, jednostavno je onemogućiti pristup korištenjem izgubljene kartice. Ovakav način kontrole pristupa je mnogo učinkovitiji nego korištenje mehaničkih brava, gdje je nakon gubitka ključa, zbog sigurnosti potrebno promijeniti i bravu. Sljedeća prednost naspram klasičnih mehaničkih brava je jedinstvenost identifikacijske kartice koju posjeduje korisnik, zbog čega se sustav osim za kontrolu pristupa može koristiti i za evidenciju pristupa.

Komercijalni sustavi za kontrolu pristupa često imaju relativno visoku cijenu i zatvorenu strukturu koja otežava nadogradnju i prilagodbu sustava korisnikovim potrebama. Zbog toga će u radu biti prikazana realizacija modularnog sustava za kontrolu pristupa koja koristi jeftino Raspberry Pi 2 računalo i standardne elektroničke module [2], [3], [4], [5], [6]. Standardni elektronički moduli i gotove programske biblioteke omogućiti će brzu realizaciju i jednostavnu prilagodbu prikazanog sustava.

U drugom poglavlju opisano je Raspberry Pi 2 računalo i standardni elektronički moduli kojima će se realizirati sustav za kontrolu pristupa. U trećem poglavlju se prikazuje i objašnjava elektronička shema sustava. Četvrto poglavlju sadrži objašnjenje principa rada sustava za kontrolu pristupa. Zaključak o radu realiziranog sustava i mogućnostima njegovog poboljšanja iznosi se u petom poglavlju.

II. MODULI SUSTAVA ZA KONTROLU PRISTUPA

Sustav za kontrolu pristupa realiziran je modularno, a temeljni modul koji povezuje sve ostale module sadrži Raspberry Pi 2 računalo, model B [2]. Raspberry Pi 2 je računalo temeljeno na Raspberry platformi jeftinih računala, koje je razvila tzv. Raspberry Pi fondacija. Spomenuta fondacija osnovana je u Velikoj Britaniji s ciljem da popularizira informatiku i računarstvo među djecom i mladima. Razvojem Raspberry platforme računala dobivena su jeftina računala, malih dimenzija, temeljena na SoC integriranim sklopovima i besplatnoj programskoj podršci. SoC integrirani sklopovi koje koriste Raspberry računala sadrže mikroprocesor ARM

arhitekture i grafički koprocesor za obradu slike. Ovi sklopovi dobro su poznati iz mobilnih uređaja, a osnovne karakteristike su im veliki stupanj integracije, mala potrošnja energije i relativno niska cijena.

Za računala temeljena na Raspberry platformi razvijena je posebna verzija Linux operacijskog sustava nazvana Raspbian [7]. Raspbian operacijski sustav temelji se na Debian Linux distribuciji, zbog čega je za Raspberry računala dostupno mnogo besplatnih softverskih alata. Osim Raspbian operacijskog sustava, danas su za Raspberry računala dostupni i drugi operacijski sustavi, npr. posebne verzije Windows ili Android operacijskih sustava.

Standardna Raspberry računala se ne prodaju s tvrdim diskom. Zbog toga korisnik treba najprije instalirati Raspbian, ili drugi prikladni operacijski sustav, na mikro SD memorijsku karticu, koju zatim stavlja u odgovarajući priključak Raspberry računala. Opisani postupak instalacije operacijskog sustava na memorijsku karticu vrši se korištenjem klasičnog osobnog računala.

Raspberry Pi 2 računalo, model B, sadrži Broadcom SoC integrirani sklop oznake BCM2836, 1GB radne memorije, četiri USB2 priključka, 10/100 Mbps Ethernet mrežni priključak, priključak sa 40 ulazno-izlaznih pinova opće namjene (40pin GPIO), mikro USB priključak za priključivanje istosmjernog napajanja, HDMI priključak, izlazni audio priključak, kompozitni video priključak, CSI video priključak za Raspberry Pi kameru, DSI priključak za Raspberry Pi zaslon osjetljiv na dodir te mikro SD priključak za smještaj kartice koja sadrži operativni sustav. SD kartica se koristi i za spremanje korisnikovih podataka i programa [2]. BCM2836 sadrži ARM Cortex-A7 mikroprocesor s četiri procesorske jezgre koji radi na 900 MHz i grafički koprocesor s dvije grafičke VideoCore IV 3D procesorske jezgre.

Sustav za kontrolu pristupa koristi Raspberry Pi kameru oznake Rev 1.3 [3], koja se direktno spaja na poseban, tzv. CSI priključak Raspberry Pi računala. Navedenu kameru podržava Raspbian operacijski sustav i grafički koprocesor ugrađen u BCM2836 SoC, čime je omogućen njezin brz rad i jednostavno korištenje.

Identifikacija korisnika u sustavu za kontrolu pristupa obavljati će se čitanjem podataka pohranjenih u identifikacijske čipove koji se nalaze u RFID karticama. Za čitanje podataka s kartica koristi se modul čitača radiofrekvencijskih kartica, čija je tvornička oznaka SL031 [4]. SL031 modul ima UART sučelje putem kojeg Raspberry računalu šalje pročitane podatke.

Za prikaz poruka namijenjenih korisniku koristiti će se monokromatski alfanumerički zaslon s tekućim kristalima, tvorničke oznake LCD2004 [5]. Zaslon se sastoji od 4 retka, a u svakom retku se može prikazati maksimalno 20 alfanumeričkih znakova. Integrirani sklop koji upravlja radom zaslona ima tvorničku oznaku HD44780, a proizvod je tvrtke Hitachi.

Za detekciju prisutnosti korisnika ispred uređaja za kontrolu pristupa koristiti će se pasivno infracrveno (PIR) osjetilo pokreta tvorničke oznake HC-SR501 [6]. Na stražnjoj strani osjetila nalazi se promjenjivi otpornik koji služi za namještanje osjetljivosti razine pokreta pri kojoj se aktivira digitalni izlaz.

III. ELEKTRONIČKA SHEMA SUSTAVA

Međusobnim spajanjem svih opisanih modula dobivena je elektronička shema sustava za kontrolu pristupa prikazana na slici 1. Zbog bolje preglednosti, na elektroničkoj shemi nije prikazano direktno spajanje Raspberry Pi kamere na CSI priključak računala. U središtu sheme nalazi se Raspberry Pi 2 računalo na kojem je dio ulazno-izlaznih pinova opće namjene spojen na pinove ostalih modula sustava za kontrolu pristupa. Ulazno-izlazni pinovi GPIO18, GPIO15 te GPIO14 računala spojeni su na pinove OUT, TXD i RXD UART sučelja radiofrekvencijskog čitača kartica SL031.

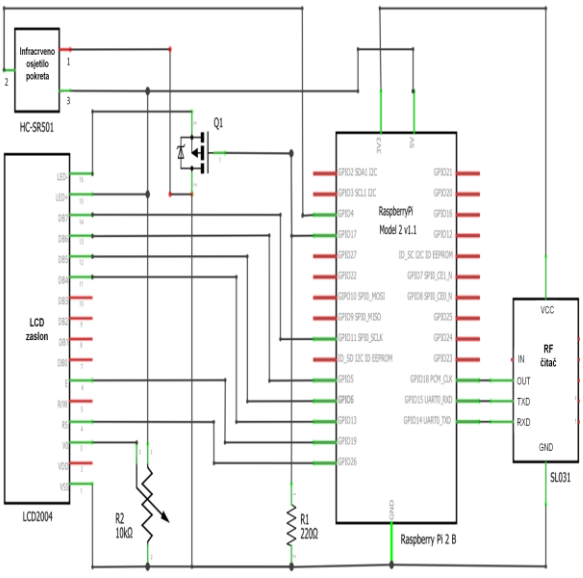
GPIO17 pin Raspberry računala spojen je na unipolarni tranzistor Q1 koji uključuje prikaz monokromatskog zaslona s tekućim kristalima. Promjenom iznosa otpora R2 mijenja se napon na VD priključku zaslona, što uzrokuje promjenu zatamnjenja.

Izlazni pin 2 infracrvenog osjetila pokreta, spojen je na ulazni GPIO4 pin Raspberry računala. Aktiviranjem ovog pina računalu se šalje signal da se sustavu za kontrolu pristupa približila osoba.

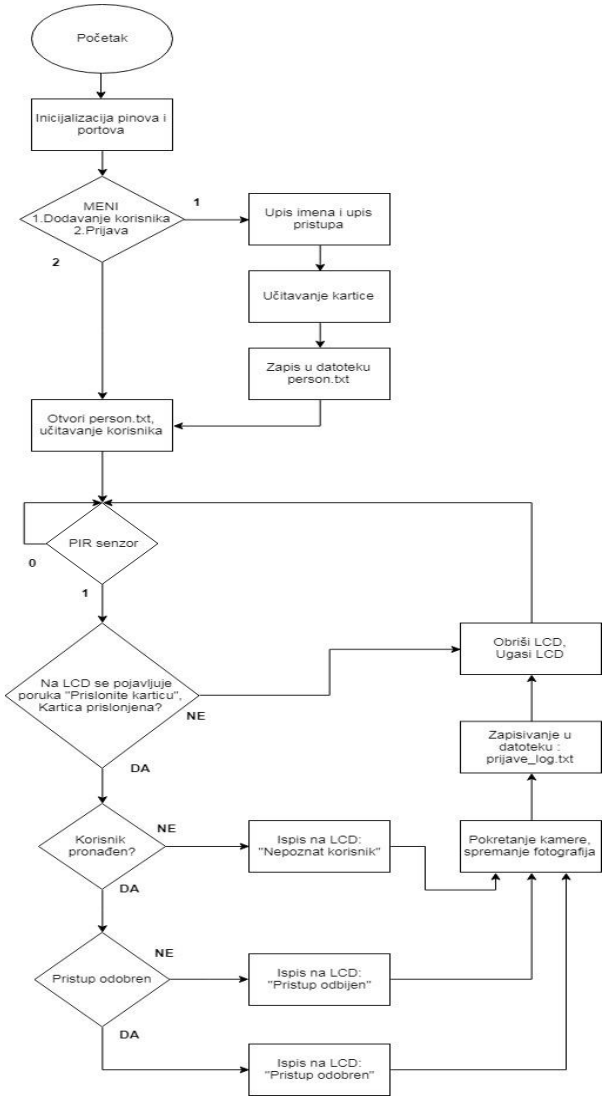
Na neki od slobodnih izlaznih pinova Raspberry računala jednostavno se može spojiti tranzistorska sklopka koja će uključiti električnu bravu i omogućiti pristup unutar kontroliranog objekta.

IV. PRINCIP RADA SUSTAVA ZA KONTROLU PRISTUPA

Princip rada sustava za kontrolu pristupa može se objasniti blok dijagramom prikazanim na slici 2. Blok dijagram opisuje izvršavanje glavnog programa koji upravlja radom sustava. Program je pisan u Python programskom jeziku. Python je viši programski jezik, jednostavan za učenje, za kojeg postoje mnoge gotove programske knjižnice [8]. Komunikacija s elektroničkim modulima se ostvaruje pozivom odgovarajućih



Slika 1. Elektronička shema sustava za kontrolu pristupa



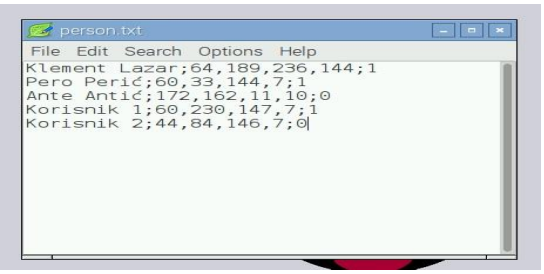
Slika 2. Blok dijagram rada sustava za kontrolu pristupa [9]

programskih knjižnica unutar glavnog programa sustava. Ovakav način izrade glavnog programa omogućava brz i jednostavan razvoj sustava.

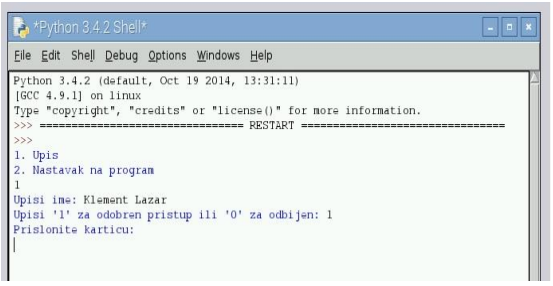
Izvršavanje glavnog programa započinje uključenjem i inicijalizacijom pojedinih elektroničkih modula, nakon čega administrator može pristupiti upisu podataka novog korisnika. Izgled administratorovog zaslona prilikom upisa podataka novog korisnika prikazan je na slici 3. Za upis podataka novog korisnika potrebno je odabrati izbornik „Upis“, nakon čega administrator upisuje ime i prezime korisnika te mu odobrava pristup. Upis podataka administrator završava prislanjanjem RFID kartice novog korisnika na radiofrekvencijski čitač. Čitač očita broj identifikacijske kartice pridijeljene korisniku te taj broj šalje računalu. Podaci o novom korisniku snimaju se u datoteku „person.txt“ na memorijskoj kartici računala. Svaki redak datoteke redom sadrži ime i prezime novog korisnika, broj identifikacijske kartice pridijeljene korisniku, te da li mu se pristup dozvoljava ili zabranjuje. Primjer datoteke „person.txt“, koja sadrži nekoliko upisanih korisnika, nalazi se na slici 4. Posljednji broj u svakom retku datoteke označava da li je pristup korisniku omogućen. Ako je taj broj jedan, pristup korisniku je omogućen. Nula na posljednjem mjestu u retku označava da je pristup korisniku zabranjen.

Postupak kontrole pristupa započinje nakon što pasivno infracrveno osjetilo (PIR senzor) detektira približavanje osobe. Detekcijom približavanja osobe, na zaslonu s tekućim kristalima ispisuje se poruka da je potrebno prisloniti RFID karticu. RFID čitač pročita broj identifikacijske kartice te u datoteci „person.txt“ traži taj broj i podatke o korisniku kojem kartica pripada. Ako je broj kartice pronađen i ako je pristup korisniku omogućen, na zaslonu se ispisuje poruka da je pristup korisniku odobren te se uključuje tranzistorska sklopka koja otvara električnu bravu kontroliranog objekta. Istovremeno se vrši fotografiranje osobe koja je tražila pristup te se na memorijsku karticu Raspberry računala spremaju podaci o pristupu. Nakon spremanja podataka, glavni program sustava ponovno čeka da PIR osjetilo detektira osobu i time pokrene novi postupak kontrole pristupa. Primjer prikaza poruke u slučaju odobrenog pristupa poznatom korisniku nalazi se na slici 5.

Podaci o pokušaju pristupa spremaju se u datoteku „prijave_log.txt“. Datoteka sadrži datum i vrijeme pokušaja pristupa, informaciju da li je pristup odobren, informaciju da li je osoba koja je pokušala pristupiti poznata, te ime i prezime, ako se radi o poznatom korisniku. Primjer datoteke „prijave_log.txt“ nalazi se na slici 6.



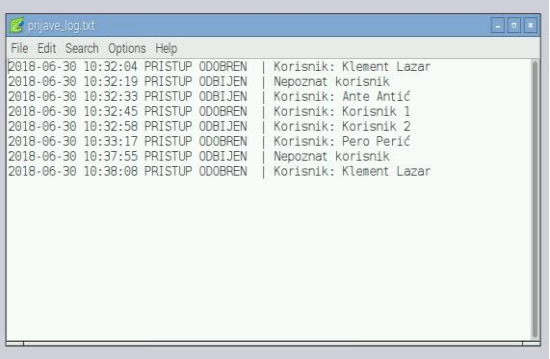
Slika 4. Primjer datoteke koja sadrži podatke o korisnicima [9]



Slika 3. Upis podataka novog korisnika [9]

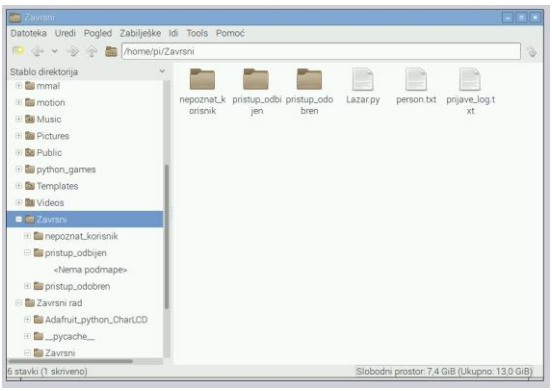


Slika 5. Poruka prilikom odobrenog pristupa poznatom korisniku [9]

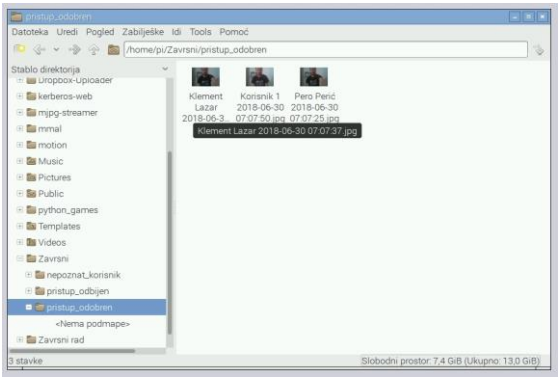


Slika 6. Primjer datoteke o pokušajima pristupa [9]

Mape s fotografijama osoba koje su tražile pristup, te datoteke s evidencijom pristupa korisnika, prikazane su na slici 7. Fotografije osoba kojima je odobren pristup, prikazane su na slici 8. Fotografije su snimljene u mapu koja je nazvana „pristup_odobren“.



Slika 7. Mape i datoteke koje sadrže podatke o pristupu osoba [9]



Slika 8. Fotografije osoba kojima je odobren pristup [9]

V. ZAKLJUČAK

U radu je prikazana realizacija sustava za kontrolu pristupa temeljena na Raspberry Pi 2 računalu i komercijalnim elektroničkim modulima. Sustav koristi pasivno infracrveno osjetilo za detekciju osoba, modul za čitanje RFID kartica, alfanumerički zaslonu s tekućim kristalima i kameru koja služi za fotografiranje osoba.

Nakon što ovlašteni korisnik sustavu približi RFID karticu, sustav za kontrolu pristupa mu odobrava pristup, o čemu ispisuje poruku na zaslonu s tekućim kristalima. Ako se sustavu približi identifikacijska kartica korisnika kojem je pristup zabranjen, ili nepoznata identifikacijska kartica, sustav ne odobrava pristup. Sustav bilježi vrijeme zahtjeva za pristup, podatke o osobi i fotografiju osobe koja traži pristup. Navedene podatke i fotografiju sustav snima na memorijsku karticu Raspberry računala.

Korištenjem Raspberry računala, te komercijalnih modula i besplatnih programskih alata, omogućen je brz i jeftin razvoj modularnog sustava za kontrolu pristupa.

Preduvjet primjene predloženog prototipa u stvarnim sustavima svakako jest razmatranje i realizacija dodatnih funkcionalnosti – implementacije naprednog administratorskog pristupa, analize i moguće izvedbe određenih sigurnosnih mehanizama za zaštitu lokalnih podataka (kodiranje), izvedba (kad za to postoje preduvjeti) mrežne komunikacije za potrebe udaljenog pristupa ili dijeljenje podataka i slično. Umrežavanje sustava je nužno kako bi se mogla realizirati kontrola pristupa u velikim objektima i veza prema nadređenim računalima za daljinski nadzor i upravljanje. Isto tako, obzirom da i takvi zahtjevi ponekad postoje u profesionalnim sustavima, mogla bi se provesti analiza mogućnosti korištenja alternativnih mrežnih tehnologija za izvedbu redundantnih veza.

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Regulator sustava centralnog grijanja s kompenzacijom po vanjskoj temperaturi

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***Sažetak* - Centralno grijanje u modernim društvima opče je prihvaćen pojam za komfor življenja. Regulacija centralnog grijanja može se ostvariti na razne načine. Bez obzira koji tip regulacije primjenjujemo u sustavu svima je zajednički cilj da osiguraju željenu temperaturu u prostoru u kojem se boravi. Jedan od efikasnih načina regulacije temperature prostorija u kojima se boravi je regulacija preko temperature polaznoga voda. Kada se takvoj regulaciji pridoda i kompenzacija po vanjskoj temperaturi dobivamo regulator koji smo razvili. Ovaj tip regulatora namijenjen je prvenstveno zahtjevnijim korisnicima kao što su industrijski kompleksi i veći stambeni kompleksi. Kod projektiranja ovog regulatora iskorištene su sve prednosti prošle verzije analognog regulatora centralnog grijanja, ali se novim regulatorom postigla univerzalnost i mogućnost rješavanja regulacija u sustavima u kojima je to s starim regulatorom nije bilo moguće. Posebna briga vodila se je na polju pristupačnosti regulatora krajnjem korisniku i monteru. Tako je razvijen mod rada „čarobnjak" u kojem se u par jednostavnih koraka regulator prilagođava sustavu centralnog grijanja bez ikakvog manualnog podešavanja.**

I. UVOD

Današnji život modernog čovjeka nezamisliv je bez centralnog grijanja i komfora kojeg takav sustav pruža. U Hrvatskoj 42,3% ukupne potrošnje energije otpada na grijanje prostora u kojem boravimo[5]. Zbog te činjenice i zbog činjenice da je energija svakim danom postaje sve skuplja prilikom projektiranja sustava grijanja vodi se velika briga o uštedi energije, a s namjerom da se zadrži i poveća komfor življenja. Pravilna regulacija centralnog grijanja donosi uštedu energije i do 30%, a da se time nimalo ne narušava udobnost boravljenja u prostoru[6]. Upravo suprotno, udobnost se povećava jer se vremenski ovisnom regulacijom dobiva da temperatura prostorija u svakom trenutku bude jednaka temperaturi koju korisnik želi. Iako su početna ulaganja u kvalitetan sustav regulacije velika ona se u vrlo kratko roku isplate zbog velike uštede energije, a samim time i novca.

A. Princip rada reguliranog centralnog grijanja

Osnovni elementi sustava za grijanje su [2](Slika 1):

- Kotao -1
- Regulator centralnog grijanja -2
- Miješajući ventil-3
- Cirkulaciona pumpa -4
- Ekspanziona posuda -5

Sustav radi na načina da u kotlu zagrijava se voda i takva zagrijana voda cirkulira u sustavu prenoseći toplinu u razne dijelove zgrade gdje se ta toplina oslobađa na radijatorima i tako zagrijava prostorije objekta. Nakon što se toplina oslobodi na radijatorima hladna voda vraća se u kotao gdje se ponovo zagrijava. Cirkulacija vode vrši se upotrebom centrifugalne pumpe.

Da bi se osigurala konstantna temperatura vode koja odlazi u radijatore koristi se miješajući ventil. Taj izvršni element regulacije ima dva ulaza i jedan izlaz. Na njegove ulaze dolazi topla voda iz kotla i hladna voda iz radijatora. Ventilom upravlja regulator i postavlja ga u položaj da omjer hladne vode i tople vode zadovoljava željenu vrijednost temperature polaznoga voda. Postoje i slučajevi u kojima ne postoji miješajući ventil. U tim slučajevima izvršni član regulacije je centrifugalna pumpa.

Cilj ovog projekta je razviti regulator centralnog grijanja koji će podržavati sve zahtjeve raznih sustava centralnog grijanja, a uz to biti pristupačan korisniku, jednostavan za upotrebu i konkurentan na tržištu.



Slika 1 Kotlovnica manjeg stambenog objekta

B. *Opis zahtjeva regulatora*

Kako bismo postigli da uređaj bude univerzalan i primjenjiv u raznim sustavima grijanja mora zadovoljavati neke opće karakteristike:

- Podržavati više regulacijskih krugova te imati mogućnost alarmiranja u slučaju greške na bilo kojoj mjernoj sondi
- Korisničko sučelje treba unaprijediti postavljenjem tastature i LCD (engl. *Liquid Crystal Display*) zaslona .
- Biti jednostavan za montažu
- Voditi regulaciju neovisno o tipu sustava grijanja
- Imati jednostavnost unosa parametra kako monteru i serviseru tako i krajnjem korisniku
- Jednostavnost sklapanja i ugađanja
- Zadržati se ispod određene granice cijene, a da se ne naruši kvaliteta

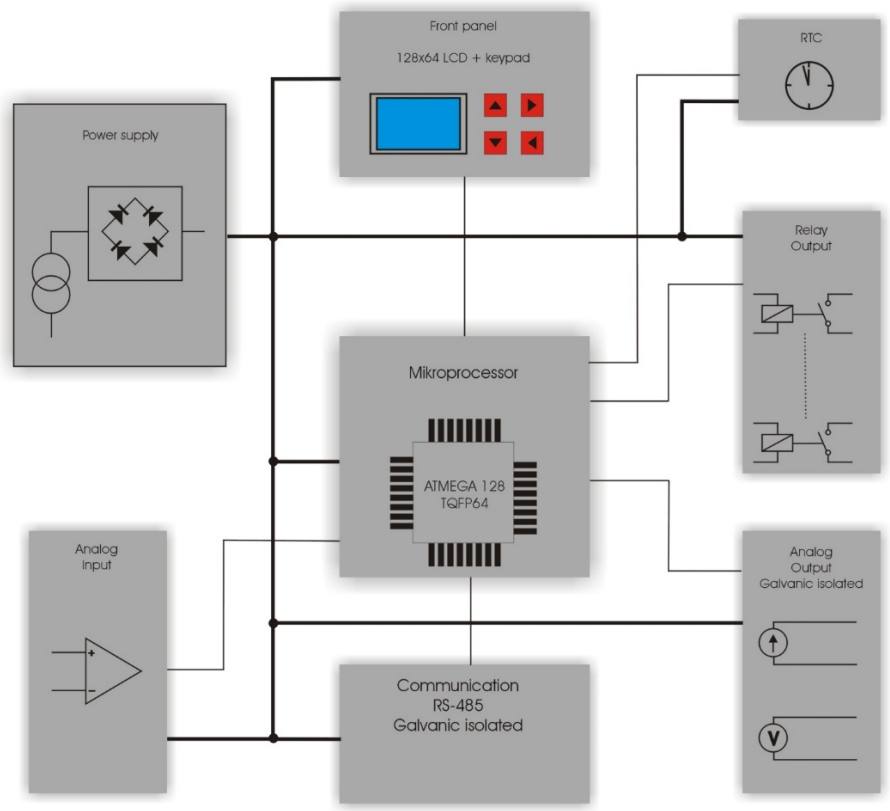
Uz ove opće karakteristike potrebno je zadovoljiti i neke tehničke karakteristike:

- napon napajanja uređaja 230V/AC
- omogućiti priključak do 6 temperaturnih sondi različitih tipova (*Pt1000*, *Pt500*, *Ni1000*, *Ni 500*, 0-4-20mA i 0-2-10V)
- do 8 izlaznih releja sposobnih za direktno upravljanje pumpe i miješajućeg ventila (5A /230VAC)
- MODBUS komunikacija preko serijske RS485 veze
- Zbog teških uvjeta rada u industriji izvesti uređaj s IP65 zaštitom
- Omogućiti modularnost uređaja (priključak relejne kartice po potrebi)
- Omogućiti rad s dva analogna izlaza zbog ventila koji imaju upravljanje s analognim signalima (0-4-20mA ili 0-2-10V)
- Smanjiti utjecaj elektromagnetske indukcije kvalitetnom izvedbom sklopovlja-a jer uređaj mora pouzdano raditi i u industrijskom okruženju
- Omogućiti priključak dodatnog panela za zadavanje temperature

II. TEHNIČKO RJEŠENJE

Na slici 2 prikazana je blok shema regulatora sa njegovih osam osnovnih dijelova:

- Napajanje
- Analogni ulaz
- Prednja ploča HMI(engl. *Human Machine Interface*)
- Upravljački dio (*procesor ATMEGA 128*)
- RTC (engl. *Real Time Clock*) sat realnoga vremena
- Relejni izlaz
- Analogni izlaz
- Komunikacija RS-485



Slika 2 Blok shema regulatora

A. Napajanje

Napajanje uređaja izvedeno je s transformatorom koji transformira napon sa 230 V na 24V. prije transformatora postavljeni su otpornici R1 i R2 za zaštitu od mogućeg kratkog spoja te kondenzator Cu koji služi za elimininiranje smetnji koje dolaze iz mreže. Greatz-ov spoj služi za pretvaranje izmjeničnog napona u istosmjerni te se zatim taj napon pomoću stabilizatora stabilizira na željene vrijednosti. Transformator je proračunat za najgori slučaj tj. kada je potrošnja regulatora najveća.

B. Analogni ulaz

Analogni ulaz može podržavati otporne termoelemente *Pt1000*, *Pt500*, *Ni1000* i *Ni500*, a dva posljednja analogna ulaza mogu primiti standardni strujni ili naponski signal.

Analogni ulaz sastoji se od tri glavna dijela, a to su strujni izvor, analogni demultiplekser i pojačalo.

Osnovni dio strujnog izvora je PNP tranzistor i temperaturno stabilna zener dioda. Napon između baze tranzistora i Avcc napajanja je konstantan i temperaturno nepromjenjiv zahvaljujući zener diodi. Zbog toga je i struja strujnog izvora temperaturno nepromjenjiva. To je bitno jer se struja kroz termoelement ne smije mijenjati. Iako se napon baza-emiter mijenja on se podjednako mijenja na svim tranzistorima zbog uparenosti te struja izvora ne ovisi o toj promjeni. Struja koja protječe kroz otporni termoelement *Pt1000* ne smije biti veća od 150 uA kako se senzor ne bi samo zagrijavao. Identična je situacija i za druge vrste otpornih termoelemenata.

Protjecanje struje kroz temperaturno ovisan otpor stvara pad napona koji je neposredno ovisan o otporu. Taj se napon se filtrira na jednostavnom nisko propusnom RC filtru te zatim dolazi na ulaze analognog multipleksera. Odabran je demultiplekser *HC 4051*, to je integrirani krug koji je procesorski upravljiv sa 3 adresna pina (A0,A1,A2). Ima osam ulaza i jedan izlaz. Ovisno o postavljenoj adresi na pinovima A0,A1,A2 ovaj sklop preklapa jedan od ulaza na izlaz. U ovom slučaju on preklapa napone sa temperaturnih senzora na ulaz pojačala .

Za pojačanje signala korišteno je operacijsko pojačalo u ne invertirajućem spoju s malim ulaznim pomacima (10uV), malim temperaturnim pomakom (0.2uV/°C), i malom strujom (0.7nA).

C. Prednja ploča HMI

Za prikaz je korišten grafički LCD zaslon rezolucije 128x64 točke proizvođača *WINSTAR* i sastoji se od dvije strane. Strane su identične i svaka ima rezoluciju 64x64 točke. Svaka strana zaslona je pokretana sa zasebnim kontrolerom.

Tipke i LED(engl. *Light Emitting Diode*)diode pokretane su preko 16-bitog serijskog posmičnog registra s izlazima koji su tipa otvoreni kolektor. LED diode služe za signalizaciju upaljenosti izlaznih releja dok tipke služe za unos parametara uređaja.

D. Upravljački dio

Za upravljanje se koristi mikrokontroler *ATMEGA 128* to je 8-bitni mikrokontroler proizvođača *ATMEL*. Radi na 16MHz taktu s mogućnošću obrade 16MIPS(engl. *Million Instructions Per Second*). Programska memorija je „flash“ tipa i ima mogućnost programiranja do 128kb. Ima 4kb EEPROM(engl. *Electrically Erasable Programmable Read-Only Memory*) memorije i 4kb RAM (engl. *Random Access Memory*) memorije.

Također ima 8 kanalni AD(*engl. Analog to Digital*) pretvornik s rezolucijom 10 bita i programibilne PWM (engl. *Pulse Width Modulation*) module do16 bita. Dolazi u dvije varijante kućišta *TQFP* (engl. *Thin Quad Flat Pack*) i *MLF* (engl. *Micro Lead Frame*). Odabran je *TQFP* koji ma ukupno 53 ulazno/izlazna pina što nije dovoljno za upravljanje regulatorom pa se u svrhu proširenja koriste serijski upravljivi posmični registri.

Programiranje mikrokontrolera vrši se preko JTAG (engl. *Joint Test Action Group*) sučelja. JTAG sučelje je sučelje koje je standardizirano od strane međunarodne komisije IEEE(engl. *Institute of Electrical and Electronics Engineers Inc*.) Std.-1149.1, a služi za ISP (engl. *In-System Programming)* i za ICE (engl. *In Circuit Emulat*ion). Za programiranje se koristi *AVR JTAGICE mk II emulator*.

E. RTC sat realnoga vremena

RTC(engl. *Real Time Clock*) sat realnoga vremena izveden je s integriranim krugom *PCF8583.* Integrirani krug ima 8 pinova i vrlo široko područje napajanja od 1V do 6V.

Komunikacija se vrši preko SDA(engl. *System Data*) i SCL(engl. *System Clock*) linija (I2C komunikacija). Prije početka rada potrebno je od strane mikrokontrolera konfigurirati registre unutar satnoga čipa kako bi integrirani krug funkcionirao na željeni način.

Također potrebno je postaviti i početno vrijeme te omogućiti korisniku da zadaje željeno vrijeme.

Točnost ovoga integriranog kruga najviše ovisi o kristalu kvarca. U ovom slučaju koristi se kristal koji ima grešku izlazne frekvencije 10ppm(engl. *Parts Per Million*). Ta se greška povećava uslijed varijacija temperature okoline u kojoj kvarc radi te se uslijed promjene temperature od 50°C može popeti i do 26ppm.Točnost se povećava dodavanjem kondenzatora od 22pF prema preporukama proizvođača kristala. Mjerenjem smo ustvrdili da greška vremena iznosi nekoliko desetaka sekundi (20-30) na 30 dana što je prihvatljivo za sustave centralnog grijanja.

F. Relejni izlaz

Korišteni releji su od proizvođača *Schrack*. Osnovne karakteristike releja su sljedeće: struja preklapanja 5A, napon preklapanja 230V/AC, struja potrošnje 42mA i napon napajanja 4.3-6.8V.

Na zavojnice releja su paralelno spojene diode a služe za kratko spajanje napona koji se generira prilikom isklapanja releja na zavojnici.

Važno je napomenuti da se uklapanje pumpi i miješajućih ventila vrši direktno bez pomoćnih releja pa maksimalna struja preklapanja mora biti velika kako bi se mogle uklapati pumpe i ventili većih snaga.

U praksi kod manjih stambenih objekata ne susreću se cirkulacione pumpe snaga većih od 500W ali u industriji to je čest slučaj. Tamo se za cirkulaciju koriste pumpe snage i nekoliko kilovata. U tom je slučaju potrebno ugraditi snažnije sklopke za uključenje pumpi.

Upravljanje relejima vrši se preko tranzistora *BRC533* koji ima u baznom krugu otpornike pa nije potrebno dodavati otpornik za ograničenje bazne struje izvana.

Tranzistori se koristiti jer je maksimalna izlazna struja po pinu procesora 20mA što je premalo za pokretanje releja.

G. Analogni izlaz

Analogni izlaz služi za upravljanje motornim miješajućim ventilima koji za koji za upravljanje koriste standardne strujne ili naponske signale (0-4-20mA ili 0-2-10V).

Analogni izlaz upravljan je preko PWM izlaza na mikrokontroleru. PWM je svima poznata pulsno širinska modulacija koja mijenjanjem širine impulsa mijenja srednju vrijednost izlaznog napona.

Galvanski je odvojen od samoga uređaja kako bi se izbjegli mogući problemi proboja uslijed razlike potencijala između samoga uređaja i linija analognog izlaza koje se kablovima odvode do miješajućih ventila. Deklarirana maksimalna razlika potencijala između analognog izlaza i samoga uređaja je 500V. Odvajanje signala realizirano je optičkim sprežnikom (engl. *optocoupler*) dok je odvajanje napajanja realizirano DC/DC pretvaračem. Probojni napon optičkog sprežnika iznosi 3500V/DC dok DC/DC pretvarač ima deklarirani probojni napon od 1000V/DC.

H. Komunikacija RS-485

Odabrana je serijska RS-485 komunikacija koja je vrlo česta u industrijskim sustavima. Komunikacijske linije galvanski su odvojene od ostatka uređaja kako bi se izbjegli mogući nepoželjni efekti uslijed razlike potencijala između linija i samoga uređaja.

III. PID REGULACIJA

PID algoritam danas se primjenjuje u 95% regulacijskih krugova [4]. Primjena mu traje već više od 60 godina. Prvi sistemi s PID algoritmom bili su u pneumatici i mehanici, a zatim u elektronici posredstvom prvo vakuumskih cijevi, a zatim sklopova s tranzistorima i operacijskim pojačalima. Takve PID regulatore nazivamo analognim PID regulatorima. Tek razvojem procesora razvili su se danas poznati PID regulatori. Izraz

A. Diskretizacija PID algoritma

Kako u mikrokontrolerima ne možemo postići beskonačno malo vrijeme uzorkovanja, a time i računanje integrala i derivacija možemo obaviti samo u diskretiziranom obliku. Prilikom diskretizacija PID algoritma koristimo sljedeće supstitucije za integraciju izraz 1 i derivaciju izraz 2.

$$\int_0^t e(t)dt = \sum_{i=0}^{k} e(t_i)\Delta t \tag{1}$$

$$\frac{de(t_k)}{dt} = \frac{e(t_k) - e(t_{k-1})}{\Delta t} \tag{2}$$

Uvrštavanjem prethodnih izraza u klasični PID algoritam (izraz 3) dobivamo pozicijski diskretni PID algoritam koji glasi(izraz 4)

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{3}$$

$$u(t) = Ke(t) + \frac{K \cdot \Delta t}{T_i} \cdot \sum_{l=0}^{t} e(t) + \frac{K \cdot K_d \cdot (e(t) - e(t-1))}{\Delta t} + u(0) \tag{4}$$

Slika 3 Klasični PID algoritam sa uvrštenim supstitucijama

U praksi se često koristi i tzv. Prirasni diskretizirani PID algoritam. Pomakom jedan disktetan trenutak unazad dobivamo sljedeću jednadžbu diskretizirane PID funkcije (izraz 5).

$$u(t-1) = Ke(t-1) + \frac{K \cdot \Delta t}{T_i} \cdot \sum_{i=0}^{t-1} e(t-1) + \frac{K \cdot K_d \cdot (e(t-1) - e(t-2))}{\Delta t} + u(0) \tag{5}$$

Sređivanje gornje (izraz 4) i donje (izraz 5) jednadžbe dobivamo prirasni PID algoritam (izraz 6) (prirast upravljanja od trenutka t-1 do trenutka t)

$$u(t) = u(t-1) + K\big(e(t) - e(t-1)\big) + \frac{K \cdot \Delta t}{T_i} e(t) + \frac{K \cdot \mathrm{T_d}}{\Delta t}(e(t) - 2(e(t-1) + e(t-2)) \tag{6}$$

Prednost ovog algoritma je u tome što nije potrebno poznavati stanje u(0).

B. Određivanje P, I i D člana

Uređaj svakih 100ms uzorkuje (mjeri) vrijednosti temperature te se pozivaju funkcije za izračun pojedinih članova. Funkcije su pisane u programskom jeziku C u *CodeVision AVR* prevoditelju koji ima i svoje integrirano razvojno okruženje IDE(engl. *Integrated Developement Envirement*).Kroz godine programiranja u C-u razvijene su mnoge standardne funkcije osobito za rad s grafičkim i 8 segmentnim displejima , tipkovnicama i PID regulacijom koje olakšavaju izradu potrebnog programa[3].

C. Upravljačka veličina i ulaz

Pošto je regulator univerzalan uz glavnu namjenu reguliranja centralnih grijanja ima i mogućnost regulacije u drugačijim regulacijskim krugovima.

Kako bi se postigla univerzalnost uređaj je tako izveden da prilikom izračuna upravljačke veličine u izračun može uči bilo koja mjerena vrijednost s bilo kojeg ulaza. Samo u slučaju da se izračunu upravljačkog signala

vrši preko odnosne regulacije onda u izračun ulaze vrijednosti s prva četiri analogna ulaza.

D. Potrebna vrijednost polaznoga voda i kotla

Korisnik u ovom uređaju ne zadaje direktno željenu vrijednost temperature regulacijskog kruga nego zadaje željenu vrijednost noćne i dnevne temperature. Prema tim zadanim vrijednostima izračunava se potrebna vrijednost temperature polaznoga voda i temperature kotla prema sljedećim izrazima (7).

$$PT(t) = F_1 * F_2(SV_z - VT(t)) + (SV_z - ST(t)) * F_3 + SV_z \quad (7)$$

Gdje su: PT(t) željena (potrebna) temperatura polaznoga voda, SV_z zadana vrijednost od strane korisnika (setpoint (dnevna ili noćna temperatura)), VT(t) vanjska temperatura (mjerena u vremenu t), ST(t) - sobna temperatura (mjerena u vremenu t), F_1 -težinski faktor vanjske temperature (PV1(t)) - postavlja se najčešće na vrijednost 1.0, F_2 težinski faktor polaznog voda (PV2(t)) - postavlja se u granicama od 0.2 do 2.0, F_3 težinski faktor sobne temperature (PV3(t)) - postavlja se u granicama od 0.0 do 2.0.

Temperatura kotla ovisna je o potrebnoj temperaturi polaznoga voda i to na način da se temperaturi polaznoga voda dodaje određeni ofset prema željama korisnika kako bi kotao radio u najnižem, a opet dovoljno visokom režimu te tako trošio najmanje energije za rad. Temperatura kotla računa se tada prema izrazu (8).

$$TK(t) = PT(t) + OFSET \quad (8)$$

Kod ovog regulatora upravljački signal ne djeluje direktno na pojedini izlazni relej tj. upravljački signal dobiven izračunom PID funkcije nije fiksno pri dodijeljen jednom od izlaza već korisnik prema potrebi pri dodjeljuje izračunati upravljački signal releju ili kontinuiranom analognom signalu.

IV. MJERENJE TEMPERATURE

Mjerenje temperature vrši se na ukupno 6 analognih ulaza s time da su 4 analogna ulaza Pt1000 dok dva analogna ulaza podržavaju standardne strujne i naponske signale te Pt1000 temperaturne sonde.

Mjerenje se vrši tako da se preko analognog demultipleksera svaki od ulaza dovodi na jedan A/D ulazni kanal mikrokontrolera.

Pošto je prikaz mjerenja 0.1 °C, a uređaj mjeri od -50.0 do 250.0 °C vidljivo je da 10bitni A/D pretvarač ima premalu rezoluciju da bi kvalitetno mjerio i prikazivao u takvoj rezoluciji. Mjerenjem s 10-bitnim A/D pretvaračem omogućava rezoluciju od minimalno 0.3 °C u ovom mjernom području. Na LCD pokazivaču prikazuje se mjerena veličina u desetim dijelovima stupnja ali se primjećuje da prilikom promjene temperature uređaj ne reagira na promjene ulazne vrijednosti od 0.1 °C. Tek kada se ulazna vrijednost promjeni za 0.3°C promjeni se i prikaz na pokazivaču.

A. Mjerenje temperature na Pt1000 ulazu

Pt1000 je temperaturno ovisan element tj. otpor mu se mijenja s promjenom temperature. Ima pozitivan temperaturni koeficijent.

Kako je karakteristika mjernog elementa nelinearna potrebno je matematičkim algoritmom dobiti pravilni odnos temperature i otpora na mjernom elementu

B. Mjerenje temperature na strujnim i naponskim ulazima

Strujni i naponski signali visokih razina imaju prednost u odnosu na Pt1000 signal što su puno otporniji na elektromagnetske smetnje koje se induciraju u industrijskim uvjetima. Kada se koristi strujni ili naponski signal s pretvarača važno je definirati donju i gornju granicu pokazivanja za taj signal. To se vrši u SYSTEM izborniku za svaki mjerni kanal posebno.

C. Filtriranje ulaznog signala

Zbog šumova koji se nalaze u mjernom signalu prilikom mjerenja potrebno je mjerni signal filtrirati. Filtriranje ima dvije razine. Uzorkovanjem signala na A/D pretvorniku mikrokontrolera u istom se trenutku provjerava dali je uzorak unutar nekih unaprijed zadanih granica. Ako to nije uzorak se odbacuje kao nevažeći. Ako je uzorak važeći njegova se vrijednost upisuje u privremeni među spremnik. Kada se izvrši deset mjerenja izračuna se srednja vrijednost među spremnika te se ta vrijednost uzima kao važeća. Nakon toga dolazi druga razina filtra. Ona se sastoji od oduzimanja djela od prave vrijednosti koja se trenutno prikazuje na zaslonu i dodaje dio od nove mjerene vrijednosti. Koliki dio se dodaje i oduzima definira se preko parametra filtra kojeg može podešavati korisnik, a ovisi o stupnju smetnji.

V. KORISNIČKO SUČELJE

A. Izbornici

Uređaj posjeduje 8 izbornika u kojima se namještaju parametri. Pritiskom Tipke ENTER/EXIT pristupa se izbornicima uređaja:

- BASIC izbornik - Namještanje osnovnih parametara regulatora kao što su zadana vrijednost, vrijednosti alarma., filtar mjerenja itd.
- SYSTEM izbornik-namještanje parametara regulacije, konfiguracija ulaza i izlaza itd.
- PROG izbornik - postavljanje programa
- RELAY izbornik - konfiguracija releja
- ALARM izbornik - konfiguracija alarma i regulacijskih alarma
- PERIOD izborni - namještanje 12 perioda kroz godinu
- CAL izbornik- kalibracija ulaza i izlaza
- TIME izbornik - namještanje realnoga vremena (sata)
- EXIT- izlaz u normalni način rada

B. Programi u realnom vremenu

Uređaj ima mogućnost programiranja do 10 programa sa po 10 segmenata. Programi i segmenti su vremenski intervali u kojima se odvija regulacija po nekim unaprijed zadanim parametrima. U jednom danu može biti aktivno više programa. Ukoliko je više programa vezano

(aktivno) u jednom danu uređaj ima tendenciju da izabere prvi program koji zadovoljava uvjete.

C. Komunikacija s računalom

Paket MODBUS protokola kupljeni su od austrijske firme *Embedded Solutions*. Ako je prilikom uključenja uređaja omogućena komunikacija u parametrima se inicijalizira serijski otvor uređaja. Unutar uređaja u SYSTEM meniju potrebno je definirati parametre komunikacije kako bi prilikom inicijalizacije serijskog porta mikrokontroler imao potrebne informacije. Pomoću uspostavljene komunikacije s mogu pratiti vrijednosti registra i mogu se upisivati u holding registre vrijednosti koje želimo na određenoj adresi na računalu uz pomoć besplatnih programa koji se lako mogu pronaći na internetu. Jedan od takvih besplatnih programa je *Modbus Tester*.

VI. PUŠTANJE U POGON

Prije same prodaje uređaj je potrebno kalibrirati. Naime svaki od analognih ulaza i izlaza zbog nesavršenosti komponenata nije identičan tj. napon na ulazu A/D pretvarača različit je za različiti analogni ulaz. Jednaka je situacija i s analognim izlazima koji se isporučuju s ovim uređajem. Baždarenje se radi u izborniku CAL i pristup mu je zaštićen šifrom kako se ne bi dogodio nepoželjan ulaz u taj izbornik, a samim time narušio rad samoga uređaja.

A. Mod rada „čarobnjak“

Kako bismo olakšali rad korisniku ali prije svega monteru uređaja osmišljen je tzv. čarobnjački način rada. U ovom modu rada uređaj se montira, a zatim se podešava u tri vrlo jednostavna koraka. Razvijeno je 20 shema i 10 vrsta programa koje monter pozove i uređaj se postavlja prema odabranoj shemi odnosno programu koji je pozvan. U ovom slučaju čovjeku koji montira uređaj i pušta ga u rad znatno je olakšan rad s uređajem.

Kako je navedeno postoji 20 shema i 10 programa koje korisnik može odabrati. Sheme se kreču od onih najjednostavnijih (shema 1) koje imaju npr. regulaciju samo čvrste vrijednosti temperature kotla do onih najsloženijih (shema 20) s regulacijom dva potpuno odvojena kruga regulacije, vođenjem regulacije preko programa, alarmnim vrijednostima, itd.

Kada niti jedna shema ne odgovara sustavu centralnog grijanja koji korisnik posjeduje potrebno je odabrati shemu koja je funkcijski najbliža takvom sustavu i dodatno podesiti parametre unutar uređaja.

Sve sheme i programi nalaze se u trajnoj programskoj memoriji. Nakon što korisnik odabere shemu i program svi podaci vezani uz tu shemu prenose se u EEPROM memoriju, a zatim se učitavaju u radnu memoriju.

B. Mod rada „Ručno“

Mod rada ručno omogućava serviseru i monteru upravljanje s izlaznim članovima (relejima i analognim izlazima) direktno. Ovaj način služi da se prilikom puštanja u pogon uređaja sustav centralnog grijanja može lako ispitati. Također ovaj način služi da ukoliko dođe do lošeg mjerenja (npr. otkaza sonde) direktno preko izlaznih članova može se djelovati na izvršne elemente u sustavu i postaviti ih u položaj da grijanje funkcionira bez obzira na kvar.

C. Brzi odabir programa i režima rada

Kako bi se dodatno pojednostavio rad s uređajem krajnjem korisniku izrađen je mod rada koji nazivamo brzi unos programa. U tom modu korisnik jednostavnim pritiskom samo jedne tipke poziva mod u kojem za svaki danu u tjednu može pri dodijeliti već isprogramiran program.

D. Mod rada „Stop“

U ovom modu zaustavlja se regulacija. Svi releji se gase, a analogni izlazi postavljaju se u nulti položaj tj. bez djelovanja na izvršne članove. Uređaj može uči u stop mod automatski ili na zahtjev korisnika pritiskom tipke START/STOP.

Automatski uređaj ulazi u stop mod rada ako je došao do kraja programa te ako mu je to od strane korisnika to omogućeno. Izlazak iz stop moda rada događa se kada uređaj ima ponovo programe koji zadovoljavaju vremenske uvjete.

Ako je pak uređaj ušao u stop mod rada na zahtjev korisnika ponovno vračanje u normalan mod rada moguć je samo od stran korisnika tj. pritiskom tipke START/STOP.

VII. ZAKLJUČAK

Razvoj novog regulatora centralnog grijanja uspješno je priveden kraju. Regulator zadovoljava unaprijed postavljene kriterije koji su u potpunosti ostvareni. Novi regulator ima mnogobrojne prednosti u odnosu na stari analogni. Kao glavnu prednost treba istaknuti njegovu univerzalnost i primjenjivost u različitim sustavima centralnih grijanja s jednim ili više regulacijskih krugova.

Zbog svoje univerzalnosti uređaj je primjenjiv ne samo u sustavima centralnih grijanja već i u drugim sustavima gdje je potrebna vremenski vođena regulacija.

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PAPERS

An overview and comparison of free Python libraries for data mining and big data analysis

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***Abstract* - The popularity of Python is growing, especially in the field of data science. Consequently, there is an increasing number of free libraries available for usage. The aim of this review paper is to describe and compare the characteristics of different data mining and big data analysis libraries in Python. There is currently no paper dealing with the subject and describing pros and cons of all these libraries. Here we consider more than 20 libraries and separate them into six groups: core libraries, data preparation, data visualization, machine learning, deep learning and big data. Beside functionalities of a certain library, important factors for comparison are the number of contributors developing and maintaining the library and the size of the community. Bigger communities mean larger chances for easily finding solution to a certain problem. We currently recommend: pandas for data preparation; Matplotlib, seaborn or Plotly for data visualization; scikit-learn for machine leraning; TensorFlow, Keras and PyTorch for deep learning; and Hadoop Streaming and PySpark for big data.**

Keywords - data science, python, data mining, machine learning library, big data analysis, framework

I. INTRODUCTION

Data mining (DM) deals with preparation of data obtained from various information sources (e.g. databases, text files, streams) as well as data modeling using a variety of techniques, depending on the goal that one wants to achieve (e.g. classification, clustering, regression, association rule mining, etc.). DM uses machine learning (ML) techniques to discover new knowledge from the existing information. DM is, nowadays, mostly considered within the wider scope of data science, which also encompasses statistics, big data techniques and data visualization. Data preparation is a vital step in the process of data analysis, and it includes data preprocessing and data manipulation (sometimes also called wrangling). Preprocessing aims at cleaning, integrating, transforming and reducing the original raw data so that it can become usable for data analysis, while wrangling transforms the preprocessed dataset into a data format that can be easily manipulated by the data modeling algorithms.

The use of Python in the area of data science has reached unprecedented levels, especially in the area of freely available tools and libraries. In a poll published in May 2018 by the authoritative portal KDNuggets [1], under the category "Top Analytics, Data Science, Machine Learning Tools", it was found that Python is used by 65.2% of roughly 2000 participants, compared to 52.7% for RapidMiner and 48.5% for R, its two major competitors. In practical perspective, in the last three years, Python has become the programming language of choice for the data science community, with R being the second choice. The Python's popularity probably stems from its relative ease of use (even for non-computer scientists), huge ecosystem consisting of a number of libraries for every aspect of data science and its reliance via *NumPy* and *SciPy* wrappers on the fast implementations of a large number of scientific algorithms written in C and Fortran.

In our previous work from 2014, we have provided a comparison of freely available tools for general DM [2]. At the time, Python based tools were still not mature enough, while R, RapidMiner, Weka and Knime were at the forefront of the most popular tools. In contrast, the aim of this work is to provide an overview and comparison of various existing Python based libraries for data science. Specifically, we focus on six groups of libraries: Python core, data preparation, data visualization, machine learning, deep learning and big data. We estimate the libraries' significance based on a detailed analysis of their capabilities, the number of contributors and the community size. Since deep learning is a rather recent development in data science, but already with a steady and growing tools' support in Python, we include these libraries, too.

II. AN OVERVIEW AND COMARISON OF LIBRARIES

A. Core libraries

Many DM and ML tasks in Python are based on fast and efficient numerical and vectorized computing with *NumPy* [3] and *SciPy* [4] libraries. Many functionalities from these libraries are actually wrappers around the *Netlib* [5], secure and robust scientific implementations of algorithms. Main advantage of *NumPy* and *SciPy* is their ability of performing efficient vectorized computing and broadcasting over *n*-dimensional arrays.

The other advantage of using Python in this field is the fact that it is relatively easy to connect third party code into the Python interpreter. Probably the most commonly used library for that purpose in the of DM is *Cython* [6]. *Cython* is a language built on top of Python that also supports calling C functions and having C type of variables and classes. The usage of *Cython* can make some critical parts of code several times faster.

All three aforementioned libraries have a stable code and are in constant maintaining and development. Table 1 shows useful information about libraries' "reputation" on GitHub, a web-based hosting service for version control [7], using the number of stars, forks, contributors and activity on the library repository. Activity is shown through the number of contributing authors and the number of commits in the last month.

B. Data preparation

Since everything in the field of data science is based on data, there is a need for data preparation libraries. Currently the best and most used Python library in this field is *pandas* [8]. *pandas* has a wide range of capabilities for input/output data formats, like Excel, csv, Python/*NumPy*, HTML, SQL and more. Furthermore, *pandas* has powerful querying possibilities, statistic calculations and basic visualizations. It has a rich documentation, but a bit confusing syntax, which is often pointed out as its most significant flaw.

Every other library in this field has much bigger issues than *pandas*. *PyTables* [9] and *h5py* [10] accept only HDF5 data type, which is a huge limitation for general usage. There are several more similar libraries (e.g. *Tabel* [11]), but none of them can be competitive to *pandas*, for now.

C. Data visualization

Table 3 shows a comparison of data visualization libraries. *Plotly* [12] has support for most of the standard plots that are used in DM and ML. *seaborn* [13] has a few capabilities less than *Plotly*, and *Matplotlib* [14] has a few less than *seaborn*. Although there are differences between these three libraries, they all have the main plotting capabilities. *Bokeh* [15] and *ggplot* [16] have the fewest options and are the least used libraries.

Matplotlib is a Python implementation of the MATLAB-like plots and is written on a low level, with a lot of possibilities for customization. Its syntax can be a bit confusing at first, but once one masters its main concepts, it is easy to draw pretty much any graph. *seaborn* is built on top of *Matplotlib* and is easier for usage and learning for beginners than *Matplotlib*. Although it is easier to use, in the cases of some complex graphs with a need for a lot of customization, it is possible that *seaborn* would be an infeasible option.

Plotly seems to be the most powerful library in data visualization field. Its main flaw is a relatively unintuitive syntax, making it harder to learn for beginners. However, the flaw is compensated with a very rich documentation providing a lot of examples. It is possible to integrate *Plotly* graphs into webpages with *Dash* [17]. *Bokeh* is intended for integration of interactive plots into webpages, where a user can explore data himself. g*gplot* is the Python's implementation of R's way of plotting. It has a limited documentation and sacrifices customization in order to have a simple and straightforward code.

Although all of the libraries in this group are relatively popular based on the data presented in Table 1, we must mention that *ggplot* has not been maintained or developed in the last two years.

Table 1. Information about libraries from GitHub

Library	Stars	Forked	Contributors	Activity
NumPy	9621	3318	726	28 (103)
SciPy	5418	2690	685	21 (101)
Cython	3833	799	275	10 (85)
pandas	18134	7233	1407	65 (217)
PyTables	801	164	60	0 (0)
h5py	1042	288	98	3 (6)
Tabel	11	0	1	1 (1)
Matplotlib	8688	3966	787	20 (218)
seaborn	5722	905	87	0 (0)
Plotly	4569	1068	68	5 (38)
Bokeh	8969	2398	346	11 (52)
ggplot	3429	539	13	0 (0)
scikit-learn	33337	16358	1253	38 (94)
mlpy	5	2	1	0 (0)
Shogun	2312	891	153	8 (57)
mlxtend	2033	475	46	3 (17)
TensorFlow	120547	72008	1834	194 (1888)
Keras	38196	14584	773	20 (53)
PyTorch	24781	5878	934	152 (913)
Caffe	27016	16335	267	0 (0)
Caffe2	8407	2130	196	0 (0)
mrjob	2367	570	82	3 (143)
Dumbo	1037	161	6	0 (0)
Hadoopy	245	62	3	0 (0)
Pydoop	168	53	11	1 (18)
Spark (PySpark)	20576	18057	1330	78 (246)
Hadoop (Streaming)	8567	5360	155	58 (456)

Note: 1) activity represents: number of contributing authors (number of commits) in the last month; 2) data is from February 14th, 2019

D. Machine Learning

scikit-learn [18] is the most popular Python library for machine learning. Beside it, there are also *mlxtend* [19], a new and small library that includes only a few basic algorithms, and *Shogun* [20], which is primarily written in C++, but there is an available Python wrapper for all of its functionalities. *Shogun* has more algorithms than *mlxtend*, but far less than *scikit-learn*. There are only a handful of algorithms that *Shogun* has implemented and *scikit-learn* does not, which can be seen in Table 2. There is also a library called *mlpy* [21], which is not listed in Table 2. The reason for its absence is that it is a small library, similarly to *mlxtend*, but it does not have any well known algorithm implemented that other libraries do not have.

scikit-learn has an advantage in the number of algorithms implemented in most categories in Table 2. *Shogun's* advantage over the other libraries is in the number of algorithms that implement different kinds of trees. Although *mlxtend* is a small library, it is the only library with implemented association rule algorithms and stacking ensemble learning. The lack of these algorithms can be considered a huge omission by *scikit-learn* and *Shogun*. The same goes for inductive rule learners, full Bayesian network, rotational forest and fuzzy c-means clustering, which are not implemented in any of the listed libraries.

Table 2. Comparison of machine learning libraries

Category	Supported algorithms	scikit-learn	mlxtend	Shogun
Feature selection	Filters	+ (many methods)	+ (one method)	-
	Wrappers	+ (many methods)	+ (two methods)	-
Feature transformation	Discretization	+	-	-
	Normalization	+	-	+
	PCA	+ (several methods)	+	+
	ICA	+ (several methods)	+	+ (various)
	MDS	+	-	+
	Manifold learning	+	-	+
	SVD	+	-	-
	Random projections	+	-	-
	LDA (for dimensionality reduction)	+	+	+
	GDA (Kernel Fisher Discriminant Analysis, for dimensionality reduction	+	-	-
	Factor analysis	+	-	+
	tSNE	+	-	-
	others	+	-	+
Decision tree learner	ID3	-	-	+
	C4.5	-	-	+
	CART	+ (optimized)	-	+
	CHAID	-	-	+
	RelaxedTree	-	-	+
	others	-	-	+ (Conditional probability tree, Nobody tree)
Bayesian classifiers	Naïve Bayes	+ (various distribution assumtions)	-	+
	others	+ (ComplementNB)	-	-
Function based classification	LDA classifier	+	-	-
	Logistic regression	+	+	-
	GDA classifier	+	-	-
	Elastic net	+	-	-
	Others	+	+ (Softmax regression)	-
Instance based learning	kNN	+ (several)	-	+ (several)
	Nearest centroid classifier	+	-	+
Regression analysis	Ordinary least squares linear regression	+	+	-
	Ridge regression	+	-	-
	Kernel ridge regression	+	-	+
	PLS regression	+	-	-
	Lasso (and variations)	+	-	-
	Least angle regression	+	-	-
	Polynomial regression	+	-	-
	others	+ (Bayesian regr. Robustness regr., Isotonic regr. …)	-	-
ANN	Perceptron	+	+	+
	MLP classification and/or regression	+	-	+
	Restricted Bolzman Machine	+	-	-
	Building your own NN	-	-	+
	others	-	+ (Adaline, Multilayer perceptron)	+ (Averaged perceptron)
SVM	SVC (or NuSVC)	+	-	+
	SVR (or NuSVR)	+	-	+
	OneClassSVM	+	-	+
	LaRankSVM	-	-	+
	others	+ (RBF kernel SVM)	-	+ (NewtonSVM, SVMSGD, LPBoost, MKLRegression)
Ensemble learning	Bagging	+	-	+
	AdaBoost	+	-	-
	Random forest	+	-	+
	Extremely randomized trees	+	-	-
	Totally randomized trees	+	-	-
	Gradient boosting	+	-	+
	stacking	-	+	-
	Majority voting	+	+	+
	others	+ (IsolationForest, weighted average voting)	+ (stacking regressor,	+ (MeanRule, Combination Rule)

Hierarchical clustering	AgglomerativeClustering	+ (Ward; single, average and complete linkage strategies)	-	+ (single linkage)
	BIRCH	+	-	-
Centroid (partition) clustering	k-means	+	+	-
	Mean Shift	+	-	-
Distribution based clustering	EM clustering	+ (Gaussian mixture model)	-	+ (Gaussian micture model)
	Affinity propagation	+	-	-
	Spectral clustering	+	-	-
Density based clustering	DBSCAN	+	-	-
Association rules (unsupervised)	Apriori	-	+	-
	Association rules	-	+	-
Evaluation methods and metrics	Holdout	+	+	-
	Cross-validation	+	-	+
	Regression evaluation: MSE, MAE, Pearson's correlation coefficient	+	-	-
	Classification evaluation: TP, FP, FN, TN, confusion matrix, accuracy, precision, recall, F1…	+	+	+
	Clustering evaluation: Adjusted rand index, Normalized mutual information, Silhouette Coefficient, Calinski-Harabasz index…	+	-	+ (Normalizer mutual information)
	ROC, PRC, Lift chart, Cost-benefit	+ (ROC, PRC), liftchart and cost-benefit in scikit-plot	-	+ (ROC, PRC)
	other	+ (OVO, OVR, GridSearchCV, RepeatedKFold, …)	+ (bootstrap, lift score, …)	+ (ECOCStrategy, OVO, OVR, GridSearch, …)

From popularity shown in Table 1, we can see that *scikit-learn* has a huge community, while *mlpy* has a very small community. It should also be mentioned that s*cikit-learn* has the best documentation, which is intuitive for usage.

E. Deep learning

Table 4 shows functionalities that certain deep learning library have implemented. Basic functionalities are implemented in all four available libraries. *Caffe* [22] does not have much more than these basic functionalities and its documentation is not intuitively structured. *Caffe* has its new version – *Caffe2* [23], but it has a similar number of functionalities. *TensorFlow* [24] (*TF*) is developed by Google Brain, it has a good documentation, a lot of functionalities beside the basics and it is possible to make code very customable. Since it is written as a low level library, it is bit harder to master. TensorBoard is a visualization tool that comes with all the standard installations of TF. It allows users to monitor their models, parameters, losses, and much more.

Keras [25] is built on top of *TF*. Coding in *Keras* is therefore on a higher level. The cost for that is a harder customization of code. It is well known that customization and tweaking of code is much easier when coding at a low level. *PyTorch* [26] (*PT*) is developed and used by Facebook. It was developed more recent than *TF*, but its community is growing fast. *PT* is dynamic and it runs code in a more procedural fashion, while in *TF*, one first needs to design the whole model and then run it within a *Session*. Because of this, it is much easier to debug code in *PT*. *PT* has more "pythonic" codes, it is easier to learn and easier to use for quick prototyping. *PT* and *Keras* also have good documentations.

Table 3. Comparison of data visualization libraries

Plot type	Matplotlib	seaborn	Plotly	Bokeh	ggplot
Line chart	+	+	+	+	+
Histograms	+	+	+	-	+
Bar	+	+	+	+	+
Scatterplots	+	+	+	+	+
Boxplot	+	+	+	-	-
Contures	+	+	+	-	-
Filled polygons	+	-	+	+	-
Spectrogram	+	-	+	-	-
Violin plot	+	+	+	-	-
Pairplot	-	+	-	-	-
Heatmap	-	+	+	+	-
Matrix clustermap (dendogram)	-	+	+	-	-
Regression plot	-	+	-	-	+
Joint plot	-	+	+	-	-
Polar plot	+	-	+	-	-
3D	+	-	+	-	-
Interactive graphs and animations	+	-	+	+	-
Others	+	+	+	+	-

NOTE: If there is minus in some column, it does not necessarily mean that it is not possible to do it, but that there is no direct function for a wanted plot (for example, pairplot is possible to create with Matplotlib with several lines of code and a scatterplot)

Table 4. Comparison of deep learning libraries

Category	Supported method	TensorFlow	Kearas	PyTorch	Caffe
Layers	Conv1D, Conv2D, Conv3D	+	+	+	+
	ConvTranspose1D, ConvTranspose2D, ConvTranspose3D,	+	+	+	+
	SeparableConv1D, SeparableConv2D	+	+	-	-
	MaxPool1D, MaxPool2D, MaxPool3D	+	+	+	+
	AvgPool1D, AvgPool2D, AvgPool3D	+	+	+	+
	AdaptivePool (all combinations)	-	-	+	-
	GlobalPool	-	+	-	-
	Dense	+	+	+	+
	Dropout	+	+	+	+
	Flatten	+	+	-	+
	Padding	+	+	+	+
	RNN	+	+	+	+
	LSTM	+	+	+	+
	GRU	+	+	+	-
	Normalization	+	+	+	+
	Noise	-	+	-	-
	others	+	+	+	+
Activation functions	ReLu	+	+	+	+
	ReLu6	+	-	+	-
	PReLu	-	+	+	+
	LeakyReLu	-	+	+	-
	CReLu	+	-	-	-
	ThresholdedReLu	-	+	+	-
	Elu	+	+	+	+
	Selu	+	+	+	-
	Softplus	+	+	+	-
	Softsign	+	+	+	-
	Bias_add	+	-	-	-
	Sigmoid	+	+	+	+
	Hard_sigmoid	-	+	-	-
	Exponential	-	+	-	+
	Linear	-	+	-	-
	Softmax	+	+	+	+
	Tanh	+	+	+	+
	others	+	+	+	+
Losses	MSE	+	+	+	+
	Log_loss	+	-	-	-
	Hinge_loss	+	+	+	+
	Logcosh	-	+	-	-
	Cross_entropy	+	+	+	+
	Poisson	+	+	-	-
	Cosine_distance	+	-	-	-
	Huber	+	-	-	-
	NLLLoss	+	-	+	-
	CTCLoss	+	-	+	-
	KLDivLoss	-	+	+	-
	NCELoss	+	-	-	-
	BCELoss	-	+	+	-
	SoftMarginLoss	-	-	+	-
	CosineEmbeddingLoss	-	-	+	-
	MultiMarginLoss	-	-	+	-
	others	+	+	+	+
Optimizers	GradientDescent (GD)	+	-	-	-
	Proximal GD	+	-	-	-
	StohasticGradientDescent (SGD)	-	+	+	+
	Averaged SGD	-	-	+	-
	RMSprop	+	+	+	+
	Rprop	-	-	+	-
	Adadelta	+	+	+	+
	Adagrad	+	+	+	+
	AdagradDualAveraging	+	-	-	-
	ProximalAdagrad	+	-	-	-
	Adam	+	+	+	+
	AdaMax	-	+	+	-
	Nadam	-	+	-	+
	SparseAdam	-	-	+	-
	L-BFGS	-	-	+	-
	FTRL	+	-	-	-
	Momentum	+	-	-	-
GPU acceleration		+	+	+	+

F. Big data

Currently, the most popular tools for big data are Spark and Hadoop MapReduce. Both are scalable, flexible and fault tolerant tools. They have their own specialized storage system, which allows them to work on clusters of computers. Spark uses the Resilient Distributed Datasets (RDDs), while Hadoop uses the Hadoop distributed file system (HDFS). The main difference between Spark and Hadoop MapReduce is the fact that Spark can work within the RAM memory, while Hadoop always writes on the file system. Hadoop is a good choice in the cases of very large amount of data (larger than the available RAM) and when there is no need for immediate results. In all other cases, Spark is probably a better choice. Although both are written in Java, many big data engineers prefer to use them in combination with Python.

Hadoop Streaming [27] is an interface that allows the usage of any language for MapReduce jobs on Hadoop. The other possibility is to use *mrjob* [28], an open source wrapper around *Hadoop Streaming*. It is actively developed by Yelp and it has a good documentation. A disadvantage of *mrjob* is that it is a simplified framework that does not provide some advanced functionalities and does not have available support for typedbytes, so it is a bit slow in some cases. In contrast, *Dumbo* [29] provides more advanced functionalities. It is also a wrapper around *Hadoop Streaming*, but its documentation is not that rich, which makes it harder to use. It is very similar to *Hadoopy* [30], which also has support for typedbytes serialization of data and is a *Hadoop Streaming* wrapper. *Hadoopy* has a relatively good documentation. *Pydoop* [31] is a wrapper around *Hadoop pipes* (C++ API for Hadoop). There are a few additional Python libraries for Hadoop, but we find that those mentioned above are currently the best options. *Dumbo* and *Hadoopy* have not been maintained or developed for the last 5 years.

Regarding Spark, we are not aware of any other Python library other than *PySpark* [32]. *PySpark* is an API that exposes Spark data processing model to Python.

III. Conclusion

For data preprocessing and manipulation, we recommend the usage of *pandas*. It has a strong community support, a rich offer of functionalities and no serious competition. In the field of data visualization, things are not so clear-cut and the choice of library largely depends on the project. *Plotly* has the most capabilities, *seaborn* is very intuitive and easy to use, while *Matplotlib* offers many possibilities for customization. All three have strong communities.

scikit-learn is the best library in the field of machine learning. It has a very good and intuitive documentation with many examples. It has a large scope of implemented algorithms. Deep learning is a relatively recent field, but with three very good libraries. We recommend the usage of *PyTorch* or *Keras* for quick prototyping and *TensorFlow* for projects which demand a lot of customization.

Hadoop Streaming and *PySpark* are the best libraries to use in the field of big data. Both are APIs for native libraries (Hadoop and Spark), so they have a large community support.

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Web tool for graph embeddings representation techniques evaluation

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***Abstract* - Graphs are important structures used in wide range of applications techniques for graph analysis proposed in the literature. At recent time, graph embeddings can be found as one of the most popular techniques used for graph analysis. There are plenty graph embedding techniques, but the choice of the most appropriate one is a challenging task which depends on the type of the graph and the intended application. The aim of this paper is to present a web-based tool with a simple user interface that enables performance comparison of different models for graph transformation. The system allows graph embeddings models comparison for three different tasks – node classification, edge prediction and graph reconstruction. Additionally, the users can compare specific algorithms performance for different values of their hyperparameters. This supports and accelerates the process of selecting the most appropriate model for graph transformation and enables the use of these models by a larger number of people in different scientific disciplines.**

Keywords – graph embeddings; data mining; software tools

I. INTRODUCTION

Graphs are important structures for data representation used in a wide range of real-life applications. A graph G can be defined as an ordered set $G = \{V, E\}$, where V is a set of nodes, and E is a set of edges. Graph nodes are discrete objects, while edges are associations between two node objects. Many problems covering a wide range of scientific areas can be defined using the concept of networks of interconnected objects, thus, a problem representation using graphs is very versatile. In biology, examples of using graph representations can be seen in protein interaction networks [1] and the connections between brain regions [2]. In linguistics, graphs are used in the semantic networks construction [3] and in machine translation in languages [4]. In sociology, graphs are basis for representing social networks [5] and collaborative networks between people in a profession [6]. In computer science, they are used in a wide range of problems, from modeling and analysis of communication networks [7] to data mining [8]. These examples cover only part of the problems in the given areas, and only scientific areas that make use of graphs more prominently.

The development of effective approaches and algorithms for graph understanding is of great interest. In general, these algorithms fall into one of the following four categories: node classification, edge prediction, graph clustering and graph visualization [9]. Node classification methods are divided in two different approaches - methods that use random walks through graphs for label propagation [10] and methods that extract node characteristics and apply classifiers to these characteristics [11]. Edge prediction methods consist of node-based methods [12], models with maximum probability [13], and probabilistic models [14]. Clustering models include model-based models [15] and models that try to maximize the distance of different groups [16].

Graph analysis methods commonly use an adjacency matrix or a derived vector space [9]. The nodes from a graph can be represented as vectors from a certain vector space, and this is called a vector representation of graphs or graph embedding.

Vector spaces are more amenable to data science than graphs. Graphs contain edges and nodes, and those network relationships can only use a specific subset of mathematics, statistics, and machine learning methods. Vector spaces have a richer toolset from those domains, moreover, vector operations are often simpler and faster than the equivalent graph operations. In many real-world graphs after a couple of hops (e.q. in finding nearest neighbors), there is little meaningful information (e.g. recommendations from friends of friends of friends). However, in vector spaces, distance metrics to get quantitative results (e.g., Euclidean distance or Cosine Similarity) can be used. Quantitative distance metrics in a meaningful vector space can make the problem of finding nearest neighbors to be straightforward.

Obtaining a vector nodes representation from a given graph is a difficult task that imposes more challenges. One of the main problems is to choose the property of the graph that the vector representation should preserve. When transforming the graph, the structure and nodes edges in the graph should be retained. There are many metrics and properties of the graph that can be selected for conservation, so the choice usually depends on the application of the vector representation as well as the desired performance. The acquired vectors are used as inputs in graph analysis models and the corresponding parameters are learned with the help of training data. In this way, the efficiency and number of models that can be used in the graph analysis is increasing.

Nowadays, we deal with the graphs that reach up to millions of nodes, thus, vector representations should be sufficiently adjustable to work with large-size graphs. This is extremely difficult if concurrently it is necessary to retain some global graph properties. The dimension of

vector representations is also an important choice that needs to be made when creating models. Increasing the number of dimensions can lead to greater accuracy, but the execution time gets slower, while the memory requirements are getting expanded.

Many of the graph transformation models have their own implementations in various programming languages which are open-source. Thus, the needed knowledge of the programming language in which the appropriate model is implemented can be found as obstacle for some of the users. These models often apply several different parameters that should be adapted to the graph of interest, as well as the planned use of the vector representation. Testing different parameter values requires manual setup of each parameter individually or writing program scripts that would do the process automatically. Additionally, the performance comparison of different transformation models applied to a single graph is often problematic by nonuniform input types, as well as by different types of the outputs. All of the above mentioned, complicates the process of selecting the most appropriate transformation model for a given graph and an application of interest.

In this paper, we present a web-based system with a simple user interface used for comparison of the performance of different models for transformation of a given graph of interest. The system allows multiple parameter comparison of models of three different tasks – nodes classification, edges prediction and graphs reconstruction. Firstly, the users can compare the performances of the models for various dimensions of the vector representations. In addition, the system also enables performance comparison of individual algorithms for different values of their parameters.

The choice of models and test parameters is done through the web forms and does not require any technical knowledge. This overcomes the need of specific programming language knowledge. The comparisons results are displayed as interactive graphs. After comparing the performance of different models to different parameters, the users can make a more informed decision on the model and the parameters to use for their application. The system offers a tool in which users can specify the selected model and its parameters and obtain the vector representation generated by these parameters for future use in their applications. In this way, the graph embeddings algorithms are made accessible for bigger number of users, and the process of choosing the most appropriate technique becomes much easier. The system offers the opportunity to simply expand the number of transformation models, test parameters, and model comparison tasks.

This paper is structured as follows: in section II we review the graph embeddings methods that are applied in our system, together with the used evaluation metrics and evaluation methods (graph reconstruction, edges prediction and nodes classification). Section III presents some implementation details of the web system, while the section IV explains the conducted experiments with some discussion. Finally, the section V concludes the paper.

II. MATERIALS AND METHODS

A. Methods for graph transformation in vector space

1) Locally Linear Embedding (LLE)

LLE is a technique that assumes that each node of a graph is a linear combination of its neighbors [17]. LLE assumes that the edge weight between two nodes $W_{i,j}$ represents the weight of the node j in the vector representation of node i. Mathematically, the vector representation of node i is defined as follows:

$$X_i \approx \Sigma_j W_{i,j} X_j , \quad \forall_i \in V \tag{1}$$

A vector representation of graph nodes is obtained by using (1), but the dimension of this representation is equal to the number of the graph nodes ($D = V$). LLE assumes that the nodes in this vector space lie on a smooth nonlinear manifold with much smaller dimension $d << D$. In this case, a linear transformation which consists of translations, rotations, and scalings, exists. It transforms the high-dimensional coordinates of each neighborhood of nodes in global internal coordinates of the manifold. Since the graph's weights can characterize the local geometry in the high-dimensional space, they can characterize the geometry of the local parts of the manifold. In particular, the same weights $W_{i,j}$ can be used to represent nodes in the d-dimensional vector space. Based on this idea, LLE constructs a vector representation that preserves the neighborhoods between the nodes. Each high-dimensional vector X_i is mapped into a low-dimensional vector Y_i, which represents the global internal coordinates of the manifold. This is done by choosing d-dimensional vectors Y_i that minimize the function:

$$\varphi(Y) = \Sigma_i \left| Y_i - \Sigma_j W_{i,j} X_j \right|^2 \tag{2}$$

2) Laplacian Eigenmaps (LE)

LE is a method for transforming graphs, which also tries to preserve the neighborhoods between nodes [18]. In the same manner as LLE, this method assumes that points lie on a nonlinear manifold with smaller dimensionality than that of the original vector space. LE tries to keep the vector transformations of two nodes, similar to each other, if the weight of the edge between them $W_{i,j}$ is large enough.

3) Graph Factorization (GF)

GF is the first algorithm that manages to achieve an execution time that is linearly dependent on the number of edges in the graph, O(|E|). This is a significant speed up because most of the real-life graphs have sparse neighborhood matrices; therefore, the graph edges number is of dimension O(|V|). In this way, the execution time is improved from square to linear in relation to the number of nodes in the graph. The main idea in GF is to obtain a matrix of vector representation of the graph Y, so that $Y^T Y$ is as close as possible to its adjacency matrix W [19].

4) High-Order Proximity preserved Embedding (HOPE)

HOPE [20] is a method for graph embedding in a vector space, which tries to preserve the proximity

between nodes of higher order. The weights $W_{i,j}$ of an edge of a graph are called first-order proximities between nodes v_i and v_j, since they are the most basic metric for similarity between two nodes. If the first-order proximities for node i are defined with $W_i = [W_{i,1}, ..., W_{i,n}]$, then the similarity of the vectors W_i and W_j is called the second-order proximity between the nodes v_i and v_j. The second-order proximity treats two nodes for similar if they have similar neighborhoods. HOPE tries to preserve the property of asymmetric transitivity in directed graphs.

5) Structural Deep Network Embedding (SDNE)

SDNE [21] is a graph embedding method that attempts to preserve the nonlinear network structure. Additionally, SDNE tries to preserve the local structure of the graph by preserving the first-order proximities, but also the global structure of the graph by preserving the second-order proximities. This solves the problem of sparse graphs where the existing edges do not carry sufficient information about the global structure. The SDNE model consists of a deep convolutional network and uses a semi-supervised approach. The system consists of two components, an unsupervised and supervised part. For the unsupervised part, a modified version of a deep autoencoder is used.

B. Evaluation metrics

Multiple metrics are used to evaluate the methods for graph mapping. In the tasks of graph reconstruction and edge prediction, the metrics Precision at k (Pr@k) and Mean Average Precision (MAP) are used. For nodes classification, micro-F1 and macro-F1 metrics are used.

C. Evaluation methods

1) Graph reconstruction

Since the basic task of graph embedding methods is to maintain the graph structure in vector space, the basic method for evaluating these methods is to assess their ability to reconstruct the existing edges in a particular graph. The true graph edges are previously known, so they can be easily compared with the reconstructed edges obtained by the vector representations. Each embeddings method uses a different way of obtaining vector representations, so the method of reconstructing the weights of the edges between two nodes will depend on the applied embedding method.

2) Edge prediction

Every network incorporates observed interactions between objects, which may be incomplete or inaccurate. One of the main challenges in graph analysis is the detection of inaccurate associations and the prediction of missing interactions. The problem of edge prediction deals with the prediction of missing edges, or edges that may occur in the future in dynamic networks. Edge prediction is used in many disciplines. For example, in the analysis of biological networks, determining the existence of edges requires expensive experimental procedures. By means of edge prediction, the edges can be ordered according to the probability of their existence and the experiments can be limited to a smaller set of edges. In social networks, edge prediction is used to predict likely friendships which can be used to provide user recommendations. Good network embedding methods should preserve the structure of the network well enough in order to predict the edges that have higher probability to occur. To test the performance of the various methods, a certain percentage of the network edges are randomly hidden. Using the rest of the edges, the embedding is learned. Then, the edges that do not exist, but have the highest reconstructed weight (obtained by the methods explained in the previous section), are inserted into the graph. The results are compared using the MAP metric.

3) Nodes classification

In a wide range of networks, some of the nodes are labeled. In social networks, labels may indicate interests, beliefs, or demographic characteristics; in language networks, documents can be labeled with topics or keywords, whereas, in biological networks, labels represent some functionalities. However, for most of the nodes in the network, these labels may unknown. For example, in social networks, many people do not give their demographic characteristics for security reasons. Missing labels can be found using labeled nodes and edges in the network. This task is called nodes classification. The vector representations of the nodes can be considered as node features based on the network structure. These features can be used as an input to many classifiers that use vectors as input. In this paper, the vectors are used to train one-versus-all classifier - logistic regression. The set of nodes is divided into training and testing set. The training set is used to train the model, while the testing set is used to compare the performances using the micro-F1 and the macro-F1 metrics.

III. SYSTEM SPECIFICATION

For the development of the web-based system, we have used the implementations of the graph embeddings transformation techniques from the GEM library [9]. Some of the techniques work well with large graphs, while others do not have the ability to finish in real-time with graphs larger than several hundred of nodes. Different implementations were adapted in order to work on graphs of the same size. For example, the SDNE architecture was reduced in order to have the ability to generalize smaller data sets. Using the data sets given in section V, experiments were made in order to determine the optimal values of some of the hyperparameters. These values proved to be the best compromise between execution time and system accuracy.

A. System functionalities

The system provides several basic user functionalities. First, the user can test the effect of the vector representation dimensionality on the performance of each of the algorithms. In addition, the user can test the influence of certain hyperparameters on the graph embeddings algorithms performance. Specifically, the system offers the ability to test a beta parameter [20] in the HOPE algorithm, a beta parameter [21] in the SDNE algorithm, and a lambda parameter [19] in GF algorithm. For each of these functionalities, the user should select one of the three evaluation methods: graph reconstruction, edge prediction or classification of nodes. Finally, the user can select a particular graph embeddings algorithm and

get a vector representation of the graph of interest. Each of these functionalities are described in more detail below.

1) Testing the effect of the vector representation dimensionality

The users have the option to attach a graph in an edgelist format where each line specifies one edge of the graph. To classify nodes, users should additionally attach a labels file for each node. Then, the user can choose a range of values for the dimensions of the vector representation. This is achieved by selecting the minimum and maximum size of the dimensionality, as well as the size of the step between the different number of dimensions. Additionally, users have the ability to choose specific values for the hyperparameters used at some embeddings methods. To reduce the effect of randomness in final results, users can choose the number of iterations each algorithm should perform for a given dimension, showing the average of all iterations. After performing all graph embeddings algorithms, a result is obtained for each combination of the algorithm and the vector representation dimension. The results consist of the MAP value in graph reconstruction and link prediction, or from the micro-F1 and macro-F1 values in the nodes classification. These results are displayed on interactive graphs shown in Figure 1. The graph allows an option of excluding some of the algorithms in order to obtain better visibility and to allow comparison of pairs or subsets of methods.

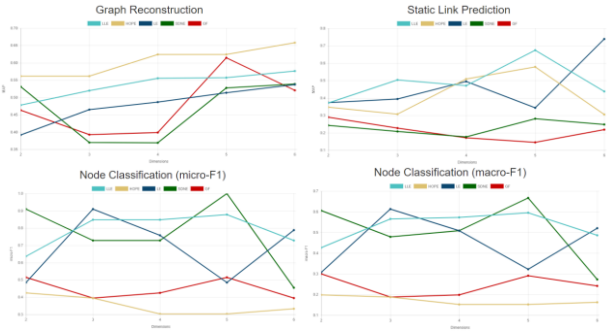

Figure 1. Testing the effect of the vector representation dimension

2) Testing the effect of the value of hyperparameters

The user can choose one of the algorithms that have setup hyperparameters - HOPE, SDNE or GF. Afterwards, the user can attach a graph file in edgelist format. Additionally, the user can specify the minimum and maximum values of a hyperparameter, as well as, the size of the step between the different parameter values. The form offers the option of selecting the vector representation dimension, as well as the number of iterations of execution for each value of a hyperparameter. The final result is consisted of the mean value obtained from all the iterations. After performing the algorithms, a result is obtained for each value of the hyperparameter. The results consist of the MAP value in graph reconstruction and link prediction, or from the micro-F1 and macro-F1 values in the classification of nodes. The results are shown in Figure 2.



Figure 2. Results of testing the effect of the parameter beta in HOPE

3) Downloading a vector representation

The user can select one of the methods for embedding into vector space and enter specific parameters for the method. After this, the user can download a file with the graph nodes vector representation. In this way, once the user has compared the performance of the various algorithms, one can decide on the most appropriate algorithm and parameters for its application and obtain a vector representation of the graph that can be used in their applications.

IV. EXPERIMENTS AND DISCUSSION

A. Datasets

Two datasets are used as example graphs for the system evaluation. The first dataset is the Zachary Carate Club Dataset (social network of a karate club that has been researched for a period of 3 years [22]) one of the most popular datasets used in graph analysis. The network consists of 34 nodes, where each node represents one member of the karate club, while the edges represent interactions of members outside the club. The second dataset is the David Copperfield dataset which consists of the most common nouns and adjectives in the book David Copperfield by Charles Dickens [22]. To construct this network, the most common 54 nouns and the most common 58 adjectives are taken. Each of the words represents a node in the network, while the edges are the appearances of both words in each sentence in the book.

B. Experiments

To illustrate the system functionalities, experiments were performed on the above datasets. First, the performance for different values of the vector representation dimension was tested. The experiments were performed on the two datasets with the same values of the other hyperparameters in order to obtain the most appropriate comparison. In these experiments, a dimensionality of the vector representation from 2 to 10 with step 1 is tested. The number of iterations is set to 5. The performance is evaluated using the three evaluation methods. Figure 3 shows the results obtained for the edge prediction task. Figure 4 shows the results obtained for the task of graph reconstruction. The results for the nodes classification are shown in Figure 5. It can be noted that for edge prediction tasks and graph reconstruction, the

SDNE algorithm yields the best results for all dimensionality values.

Additionally, the maximum accuracy is similar for both datasets. In other algorithms, one can notice the difference in performance between the two datasets, but the algorithm layout remains unchanged. For most of the algorithms, a slight increase in accuracy with an increase in the dimension is observed. This points to the fact that a larger vector representation dimension allows better preservation of the graph characteristics. On the other hand, in nodes classification, we note that for different values of the dimension, different algorithms yield best results. An increase in dimension does not greatly improve accuracy, and in some cases also causes a decrease in performance. Additionally, in this task we can notice the greatest difference in performance between the two datasets, which means that this task is most sensitive to the properties of the graph of interest.

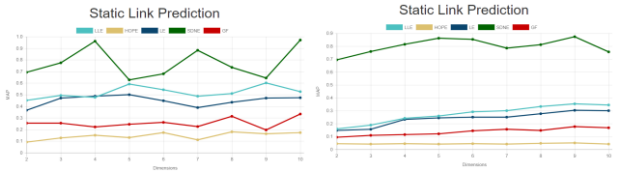

Figure 3. Evaluation of the effect of the dimension to the edges prediction task in Zachary Carate Club dataset (left) and David Copperfield dataset (right).

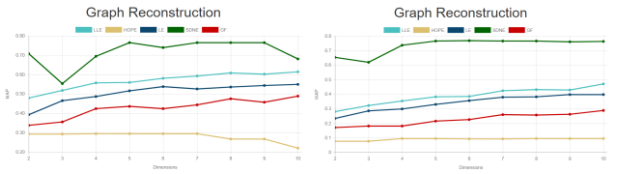

Figure 4. Evaluation of the effect of the dimension to the graph reconstruction task in Zachary Carate Club dataset (left) and David Copperfield dataset (right).

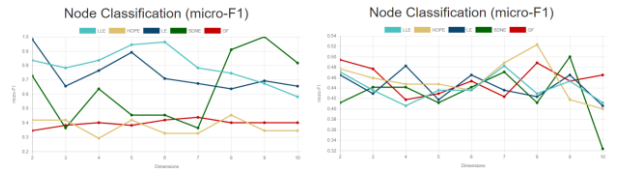

Figure 5. Evaluation of the effect of the dimension to the nodes classification task in Zachary Carate Club dataset (left) and David Copperfield dataset (right).

Next, we have evaluated the impact of some of the hyperparameters on the graph embeddings algorithms. As an example, we have illustrated the impact of a beta parameter [20] on the performance of the HOPE algorithm. The vector representation dimension was set to 10, and each experiment was performed 5 times. Beta values were tested in the range from 1 to 10 by step 1. The experiments were again performed on both datasets and on each of the three evaluation methods. The results are shown in Figures 6-8. For edge prediction tasks, we note that increasing a beta value increases the accuracy of testing in the first dataset, but reduces it in the second. In the task of node classification, the opposite effect is observed, where greater beta values increase the accuracy of the second dataset, but lower them to the first. We can conclude that for these tasks the effect is strongly dependent on the properties of the graph. When reconstructing the graphs, we note that in both datasets, the increase of beta decreases performance. Additionally, in the first two tasks, we notice that performance is much better on the first dataset, which leads to the conclusion that these beta values are not the most appropriate for the second dataset. For the task of classification of nodes, the performance of the two datasets is quite similar.

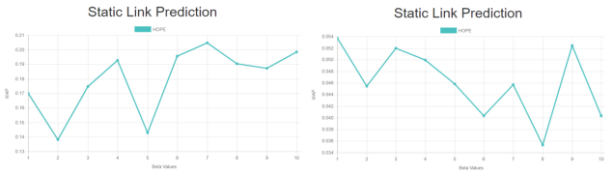

Figure 6. Evaluation of the testing of the parameter beta (HOPE) to the edges prediction task in Zachary Carate Club dataset (left) and David Copperfield dataset (right).

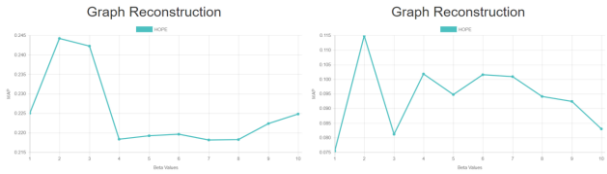

Figure 7. Evaluation of the testing of the parameter beta (HOPE) to the graph reconstruction task in Zachary Carate Club dataset (left) and David Copperfield dataset (right).

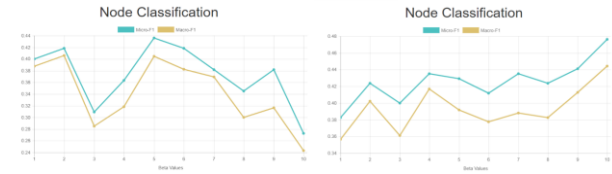

Figure 8. Evaluation of the testing of the parameter beta (HOPE) to the nodes classification task in Zachary Carate Club dataset (left) and David Copperfield dataset (right).

V. CONCLUSION

In this paper we have presented the development of the web system for evaluation of vector representation techniques on graphs. These techniques are one of the most powerful tools for graph analysis today. However, the choice of the most appropriate technique for a given problem is interfered by the non-unification of their implementations and the need for technical knowledge for their modification and testing. The web system presented in this paper enables users to evaluate different algorithms in an easy and intuitive manner. Currently, the system supports five techniques for vector representation of graphs: Locally Linear Embedding, Laplacian Eigenmaps, Graph Factorization, High-Order Proximity preserved Embedding and Structural Deep Network Embedding. In addition, the system enables evaluation of techniques using three different methods: graph reconstruction, edge prediction and classification of nodes. The current version of the system allows an evaluation of the effect of the

vector representation dimension on the performance of the algorithms, as well as the evaluation of the effect of some hyperparameters on the corresponding algorithms. Additionally, the system enables the download of a vector representation with the choice of algorithm and the value of its hyperparameters. In this way, it allows users to quickly and easily find the best technique for their problem and download the vector representation for further analysis.

In order to illustrate the functionalities of the system, we have conducted several experiments on two datasets. From obtained experimental results it can be concluded that the choice of the most appropriate technique for vector representation strongly depends on the graph properties as well as the planned application of the vector representation.

The current version of the system works with relatively small graphs with several hundred of nodes. This is due to the fact that the current implementations of algorithms from the GEM library are not scalable for large graphs in real time which is a problem that should be solved in future.

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Distillation of a CNN for a high accuracy mobile face recognition system

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***Abstract* - In face recognition systems, the use of convolutional neural networks (CNNs) permits to achieve good accuracy performances, which derive largely from a huge number of well-trained parameters. While using online services any mobile device can suffice for an accurate identification, in the offline scenario, implemented on a wearable mobile hardware, it is difficult to achieve both real-time responsiveness and high accuracy. In this paper we present a solution to replace a large open source face recognizer network (provided as part of the dlib libraries), distilling its learned knowledge into a less demanding CNN. The former is used as an expert oracle that provides the targets, while the latter is trained on the same input image, following a regression approach. In addition to lightness, our CNN is trained to use smaller input images, naturally allowing the recognition of identities in a wider distance range and with a reduced amount of computation. This eventually permits the porting of the network into a dedicated mobile accelerating hardware. The hypothesis we want to demonstrate is that since the feature space topology has been deeply explored during the training of the expert network, and due to the fact that no information is created during the up sampling of a tiny face to the input size of the expert oracle, the smaller network can provide the same accuracy at a reduced computational cost.**

Keywords* - *face recognition, convolutional neural networks, deep learning, mobile, assistive technologies, model compression, knowledge distillation

I. INTRODUCTION

Face recognition system have been made ubiquitous and really accurate by the use of Deep Convolutional Neural Networks (DCNN) that, used as features extractor and classifiers, surpassed the performances of previous hand-crafted algorithm. The feature extractor is the most critical component of the entire signal chain, because it is responsible of generating discriminative and robust descriptors for each identity. Unfortunately, reliable *DCNNs* require *complex* (deep) *structure* that use both an high amount of memory and lots of processing power, making the use of this accurate but cumbersome models practically impossible on mobile hardware. The solution that many big companies offer is to provide an online service, but the inner privacy problem is highly evident.

It has been said that there is the need of a complex structure in order to achieve the complex task of face recognition, but it has to be clarified that *what* really *requires complexity is* the *extraction of* general *characteristics* from the provided samples (during the supervised learning process), *not their* actual *representation*. This means that when this knowledge has been inferred, it can be represented by a simpler structure, that can be deployed to mobile hardware.

In a previous work [1], we identified a framework and a technique for a reliable portable face recognition application, evaluating the performances obtainable using different types of classifiers, trained on a limited number of images for any such identity. The problem can be considered as a *multiclass recognition* in an *open set* scenario. We highlighted the crucial need of a good features extractor which, when paired with a dedicated classifier, allows to get a high *True Positive Rate* (TPR) while maintaining the *False Positive Rate* (FPR) and the incorrect classification rate (*misclassification*) close to zero.

In order to achieve this result, we needed a pre-trained feature extractor whose training typically requires weeks on a high end GPU accelerated hardware and on a huge dataset. Fortunately, the open source project "Dlib" [2] provides many advanced image processing routines, and even a face recognition model (*dlib-resnet-v1*) pretrained on a dataset composed of roughly 3 M images. This Deep CNN is an *embedding network* because, for any given input image (of a face), the model provides a 128-dimensional features vector which virtually belongs to the embedding of that particular identity, meaning that all the possible images of that person would lie in a hyper-sphere of radius lower than 0.6. This value represents the threshold (imposed during the training) which defines a particular identity in a Euclidean space metric. In spite of the undiscussed high accuracy, *dlib-resnet-v1* cannot be deployed satisfactorily on an embedded device with a mid-end ARM CPU, because the time of inference becomes unaffordable without a CUDA compatible GPU.

In this paper we present the results obtained with some new CNNs, with a lower number of parameters with respect to the original Dlib model; these networks are obtained by *distilling* (in a regression approach) the ability of *dlib-resnet-v1* to extract the features descriptor, i.e. its *knowledge*. This in turn will allow the use of such network on a mobile hardware. In order to reduce even more the processing power needed, the image input size has been even reduced by half and despite this, the accuracy of the network is comparable.

II. COMPRESSION TECHNIQUES

Distillation and transfer learning are somehow related but are actually two completely different concepts. ML practitioners apply *transfer learning* in order to train a model in a short period of time on a specific task, using a small not-so-diversified dataset. In the Computer Vision community, we typically use models pre-trained on a huge dataset called *ImageNet;* this procedure has been proven to generate a good set of weights for the convolutional kernels and represents the best available starting point for the training of the same model for a different task. We want to stress that in order to take advance of this sweet spot in the Loss-Parameters space, we need to use the network in exactly the same configuration as the training; this means, for example, that we have to replicate the number of channels of a grayscale image, or scale our image in order to fit the input size.

Model Compression [7] is the first step for reducing model complexity: in a Deep CNN, the majority of the memory requirements is in the fully connected layers, while both the computation time (number of MAC operations) and the buffer memory size are highly related to the convolutional layers. A large speed-up can be obtained with an aggressive quantization [7, 13, 14] and pruning of the weights [7, 15, 16], as well as the decomposition of each fully connected layer weight matrix; in any case the structure of the net remains unchanged.

The form of compression we used [4, 5, 6] takes a completely different approach, that decorrelates the accuracy in a task from the learned weights: what is really important to transfer to a new model is the I/O relationship of the model itself, or the capacity to reveal the latent distribution $p(T|X)$ that relates the inputs X and the outputs T. This capacity is called "*dark knowledge*" [5] and the act of transferring it from a cumbersome but well trained and powerful model is called "*knowledge distillation*" [5]. The ground truth (for example the one-hot encoded target of a classification task) can be seen as a "fact" and no explanation or verification are provided. The well-trained network dark knowledge is its vision of the world, a sort of metric learned while solving the task; this is the precious component that the "*teacher network*" has to teach to a "*student network"* [5] speaking their own "language" (error minimization in the weight/loss space). Said in other words, up to a certain limit, it is possible to disentangle the structure needed for learning to the one used during the inference, transferring the soul (the knowledge) from the teacher network to the student one.

Initially, knowledge distillation was used to train multiclass classifiers, investigating the role of outputs and logits vector [4]; later, the concept of regression of some particular quality of the teacher network by the student network emerged [5]. A recent and exhaustive review of many compression techniques is provided in [7]. With this work we experimentally demonstrate distillation in a metric framework, contrasting its supposedly limited applicability to the classification task.

III. DISTILLATION FRAMEWORK

Distillation is the best way to gather the dark knowledge of a feature extractor network like *dlib-resnet-v1*. That's why we casted the problem as a regression of the features produced by the teacher network. A similar situation (even in the applicability to face recognition) has been described in a 2016 paper [6], where the research team used a regression approach to learn the features generated by a deep network (Deep ID2/3) to a shallow network. The novelty of our work is threefold: 1) we do not use a subset of the features, but the entire vector, permitting a blind swap of the feature extractor network; 2) the entire framework is minimal, since it only requires the regression of the output target; 3) we reduce by half the image size at the input network, permitting the recognition of smaller faces by design, and avoiding the use of expensive upscaling operations for far people recognition. From the best of our knowledge, this type of distillation has never been tried before. While facing a more difficult task, our framework is simpler than the one used in [6]. One possible explanation for this outcome can be imputable to the teacher embedding characteristic: *dlib-resnet-v1* is an embedding network trained using a contrastive/siamese loss, without constraints on the vector norm. A big part of the training time is devoted to centroid positioning of the many identities in the feature multidimensional space. Only when the centroids are stable and far apart, the network actually starts to reduce the intraclass variance of the feature distribution of each ID. When distilling the knowledge into a student network, the centroid positions have been already chosen and the only task for the lighter network is to approximate that distribution. This behaviour is somehow similar to the concept of model reuse in [9].

The train set for the distillation framework, carried out as a supervised learning, is composed of the tuple *(X, T), input* and *corresponding target.* It is important to have the highest possible number of centroids, that are the representation of different individuals. In order to obtain a good cluster, we experimentally saw that is not the number of samples for each identity that counts, but the number of distinct individuals. This would make the student model to infer the latent embedding between faces. In order to synthetically increase the number of these individuals, one idea could be to generate random images and the corresponding targets, but the problem is that those points cover mainly uninteresting parts of the multidimensional space [3].

Further investigation has to be carried out before using generative models for synthesizing new subjects, because the metric learning for those fictitious ids can be tricky without a study on the particular face quality represented by each element of the features vector. This last sentence has not to be viewed as a negligence: we wanted to generalize as much as possible our procedure, without applying custom solutions for the particular *dlib-resnet-v1* network. That's why for the moment we decided to exclude samples generation, and we experimentally verified that its use is not even mandatory for having good results.

The last component of the distillation process is the loss function. Forcing the student network to provide the same descriptor generated by the teacher can be directly described in a distance metric framework: a distance greater than the hypersphere radius of each cluster automatically means a bad learning. In a typical regression problem, the mean square error (MSE) between each target element t_i and the corresponding predicted descriptor y_i

$$L_{MSE} = \frac{1}{N_{dim}} \sum_{i \in N_{dim}} ||t_i - y_i||^2 \qquad (1)$$

is the first choice, but in our study, we have seen that the use of the Euclidean distance L_d

$$L_d = \sqrt{\sum_{i \in N_{dim}} ||t_i - y_i||^2} \qquad (2)$$

as a loss provides the best result, even if it is not critical to use it. Comparing the gradients of each loss (calculated with respect to each element of the generated features vector y_i of the aforementioned losses)

$$\frac{\partial L_{MSE}}{\partial y_i} = -\frac{2}{N_{dim}} ||t_i - y_i|| \qquad (3)$$

$$\frac{\partial L_d}{\partial y_i} = -\frac{2}{\sqrt{L_d}} ||t_i - y_i|| \qquad (4)$$

it can be shown that the coefficient that multiplies the common factor is higher in the case of the distance, thus resulting in a faster convergence (for distances less than ${N_{dim}}^2$). The gradient of the Maximum Absolute Error (MAE) is a sign function, and it is insensitive to different shades of error; we have experimentally verified that in our scenario this is the worst choice.

IV. DISTILLATION EXPERIMENTS

The Dlib network *dlib-resnet-v1* is based on a ResNet-34 structure [17] with few layers removed and the number of filters per layer reduced by half [2]: it has a 150x150 pixel input size, 29 convolutional layers and one fully-connected output layer for a total of 5.58 M parameters.

For the new CNN, we decided to use a more recent architecture such as DenseNet [8] which, for its structure, requires fewer parameters and FLOPs, compared with the ResNet structure, and is consequently less prone to overfitting. We propose different “cuts” of the DenseNet-121 structure, obtaining CNNs with different number of parameters. In analogy with *dlib-resnet-v1*, we set as the output a 128-dimensional fully-connected layer.

In our application, the faces identified at a certain distance in the video stream typically do not exceed 100x100 pixels: for this reason, we fixed the dimension of the input of the new network at 80x80 pixels. We implemented out models using Keras, in order to maximise the compatibility with future implementations on hardware accelerators, e.g. Intel Movidius.

At first we take a *DenseNet-121* model pre-trained on ImageNet, with an 80x80x3 input size: the first columns of Table 1 describe the structure of the reference model where the dense blocks consist of a sequence of bottlenecks and compression layers (DenseNet-BC) as proposed by G.Huang et al. [8]. In the following columns of Table 1 four possible cuts of the *DenseNet-121* are shown on which the proposed tests will follow: for simplicity we will denote the four variants as *‘Net2.5’*, *‘Net2.0’*, *‘Net1.0’* and *‘Net0.5’* with reference to the level of cut. At the selected output layer, we apply an average pooling layer followed by a fully connected one with 128-D output; only for *Net2.5* and *Net2.0* we applied a bottleneck layer in order to adjust the output dimension at 256 before the pooling layer. The described networks have a number of parameters equal to 3.94 M, 1.48 M, 381 k and 123 k respectively.

Layers	DenseNet121 [8]	Net 2.5	Net 2.0	Net 1.0	Net 0.5
Input	Shape (80x80x3)				
Convolution Output shape	Conv 7x7, stride 2, 64 kernels (40x40x64)				
Pooling Output shape	Max pool 3x3, stride 2 (20x20x64)				
Dense Block 1 Output shape	6x basic block (20x20x256)				**2x** basic block (20x20x128)
Transition Output shape	Conv 1x1, 128 kernel + Avg pool 2x2, stride 2 (10x10x128)				
Dense Block 2 Output shape	12x basic block (10x10x512)				
Transition Output shape	Conv 1x1, 256 kernels + Avg pool 2x2, stride 2 (5x5x256)		**Conv 1x1, 256 kernels** (10x10x256)		
Dense Block 3 Output shape	24x basic block (5x5x1024)	**20x** basic block (5x5x896)			
Transition Output shape	Conv 1x1, 512 kernels + Avg pool 2x2, stride 2 (2x2x512)	**Conv 1x1, 256 kernels** (5x5x256)			
Dense Block 4 Output shape	16x basic block (2x2x1024)				
Pooling Output shape	Avg pool 2x2 (1x1024)	Avg pool 5x5 (1x256)	Avg pool 10x10 (1x256)	Avg pool 20x20 (1x256)	Avg pool 20x20 (1x128)
Fully Connected	Output Shape (1x128)				
N° of Parameter	7,17 M	3,94 M	1,48 M	381 K	123 K

Layers	Basic Block
Input	Shape (NxNxK)
Bottleneck Output shape	Conv 1x1, 128 kernel (NxNx128)
Compression Output shape	Conv 3x3, 128 kernel (NxNx32)
Concatenate Output shape	ConCat(Input, Compression) (NxNxK+32)

Table 1. *Densenet121* [8] and our proposed variation. Each "conv" layer corresponds to the sequence BN-ReLU-Conv.

To train the new network we collected a training dataset of 250000 images coming from the Casia [10] and the Vgg [11] dataset. For the following tests we used the Facescub [12] dataset removing numerous disseminated errors in each identity. For each image, the face ROI were extracted using Dlib's HoG face detector, aligned and resizing the corresponding area to 80x80 pixel; at the same time the corresponding features extracted from *dlib-resnet-v1* were collected. Having built this set of (image, target) tuples, we then began to train the proposed network by regression at the features level.

We tried two different normalization schemes both for the images and the features: subtracting their average value, or using the standard scaling; experimentally we have noticed that the best choice is to subtract the respective average values, calculated on our training dataset.

While as said in section 3 we excluded exotic data synthesis procedures, we checked the effect of a simple

data augmentation scheme on the dataset: for a given target (features) of the original image, we tried to rotate (few degrees), to scale and shift (few pixels) the original image, following the concept that a slightly distorted image of the same subject should be mapped theoretically onto the "same" point. This idea, while obviously working during a normal inference, has not been confirmed during this type of training, as it yielded an evident clustering degradation during the tests: a possible explanation for this phenomenon could be related to the concept of "low temperature" target presented by Hinton [4]. Forcing the same label for many augmented images would represent a hard target for the network, that is not able to extract the subtle dark knowledge from the relationship between different features of slightly different images. Following the same idea we would have to find a different strategy for the target generation, but this would imply an *ad hoc* solution for *dlib-resnet-v1*, solution that we want to avoid.

In conclusion, we have trained the four network variants with the described input and output normalization, distance-based loss function, for 30 epochs with 250000 images with 128-size batches, using Adam optimization.

Finally, using the features of the distilled student model, shallow MLP classifiers were trained, for each network, on a variable number of classes to perform tests on the specific problem. The proposed MLP classifiers are composed of three fully connected layers: the first two layers have 100 nodes, while the last one obviously has a number of nodes equal to the number of classes.

V. Simulation Results

The main target of the tests is to verify if the performance obtainable using the features extracted from the proposed simplified networks are comparable to the ones given by *Dlib*, addressing a classification problem similar to the one proposed in [1]. In particular the target is to correctly identify known people, in an environment were also unknown people are present, avoiding as far as possible to exchange a stranger for a known person. An application example could be a blind person who uses the system to correctly recognize friends in a crowded location where several guests are present, avoiding in particular to exchange a stranger for a friend.

To solve this problem, we have developed some multiclass classifiers that after a training based on samples of the known friends would provide, during the inference phase, both the most probable class to which the input sample belongs and a "confidence index", i.e. an estimation of the confidence that the classifier has in identifying that particular class.

Adopting such an index it is possible to discriminate the people who have not been employed in the training set, since for them the confidence index is naturally low. In addition, it is also possible to refine the identification of known people, keeping as true only those values that have a relatively high index and rejecting all the others.

The classifiers adopted in our tests are the Multi-Layer Perceptron (MLP) described in Section IV, that proved to have excellent performances [1]. The output neuron which presents the maximum value identifies the class to which the incoming sample belongs. As a confidence measure, we suggest to use a normalized distance between the two most likely classes according to Eq. 5:

$$C = \frac{d_1 - d_2}{d_1 - d_n} \qquad (5)$$

where d_1, d_2 and d_n are all "logit", i.e. the output of the latest but one layer of the MLP (before the SoftMax operator) respectively of the largest, the second-largest and the smallest value. The proposed measure estimates the confidence through the idea that the smaller is this distance between d_1 and d_2, the less accurate would be the classification and vice-versa. The denominator of Eq. 5 serves to guarantee that the value of C is always between 0 and 1.

An appropriate threshold value for *C* makes it possible to introduce a discriminant between known and unknown identities. For each confidence threshold, all the results under the threshold will be classified as unknown persons while the results above the threshold will be classified as belonging to the class identified by the largest value in the last layer.

To set up a simulation as similar as possible to the actual application of the system, we prepared the following testbench: taking advantage from the well-known FaceScrub [12] image dataset, we initially proceeded to eliminate all the images which present more than one face depicted inside, since in such cases the belonging class suggested in the original database is obviously misleading. Subsequently, all the images have been processed by the four networks under test and by *dlib-resnet-v1*, generating five distinct databases, each one containing the features generated by the corresponding network. All the following operations have been carried out in the same way for all the five databases: the features of each database have been first split into two subsets: the first one, *'K_{dBi}',* would represent features of known people, while a second one, *'U_{dBi}',* would be related to completely unknown people. The former has been created selecting the 165 persons for which FaceSbrub provides at least 130 samples, while U_{dBi} contains all the remaining features. Then all the K_{dBi} databases have been split, as usual, into three different sets for the training, the validation and the testing of the classifier. The testing set is composed by 70 samples for each class (i.e. for each known person), the validation set has 20 samples per class while the training set uses no more than 40 samples per class.

The first test we addressed aims at comparing the performances of the four networks under test with those obtained through Dlib. Performances were analysed with reference to three specific problems, i.e. the identification of a certain number (10, 20 or 50) of known persons, respectively. Classifiers have been trained, separately for each network, using 40 samples for each person while performances have been estimated using a testing set consisting of 70 samples, taken from the testing set, for each known individual plus an equal number of samples taken from U_{dBi}.

The True Positive Rate and the False Positive Rate have been estimated adopting the following equations:

$$TPR = \frac{N_p}{N} \quad (6)$$

$$FPR = \frac{N_f}{N+F} \quad (7)$$

where N_p is the number of correctly classified samples and N is the number of positive samples provided during the test, i.e. the number of the known people samples. N_f is the number of misclassified samples. They are the sum of the number of samples extracted from U_{dBi}, which are classified with a confidence index above the threshold (thus they would be erroneously classified as a known person), plus the number of samples from K_{dBi} which have been misclassified. Finally, F is the number of negative samples, i.e. the number of samples taken from U_{dBi} used in the testing phase.

Please note that these ratios represent in both cases the proportion between a given number of selected samples and the entire number of the provided samples. In the evaluation of the TPR we must consider the proportion between the correctly classified samples and the entire number of positive samples. Thus, in the best case in which all positive samples are correctly classified, the TPR must be equal to one. By contrast, in the second case the total number of cases in which the system could fail is the entire number of proposed samples (rather than just F). In the worst case, indeed, if all the proposed samples belonging both to U_{dBi} and to K_{dBi} fail the classification the value of FPR must be equal to one.

Each test was repeated 10 times by randomly extracting both the identities to be identified from the K_{dBi} database and the unknown ones to U_{dBi}. In Figure 1, the shadowed regions, represents the areas where 99% of the results obtained during the 10 tests are located while the bold line represent the mean curve. The measure has been repeated using all the different features extractors in the 3 cases considered (i.e. 10, 20 and 50 known identities).

It is clear from these figures that the performances of the networks under test can be very close to the ones obtained through the Dlib network. The networks with more parameters perform better than the one with smaller size but obviously when the network size becomes too small, as for instance in the case of *Net0.5*, the performances degrade significantly. Furthermore, it can be seen that classifiers trained on a larger number of known individuals have generally slightly better performances, regardless of the network used to extract the features. Regarding the specific problem addressed in this paper, we want to avoid a stranger to be wrongly classified as a known person, even accepting the cost that some known people could be missed in the identification; it can be noted that, except for *Net0.5*, it is possible to achieve an almost negligible FPR with a TPR largely above 50%. Obviously, other applications could privilege a higher value of TPR but with a much lower FPR.

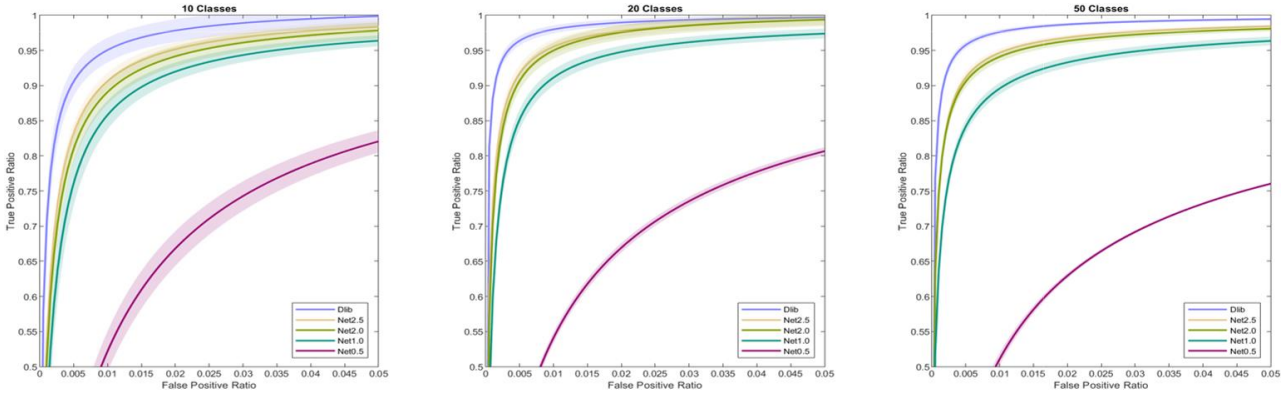

Figure 1. ROC curve: comparing distilled network with the teacher dlib network, in the case of 10, 20, 50 classes.

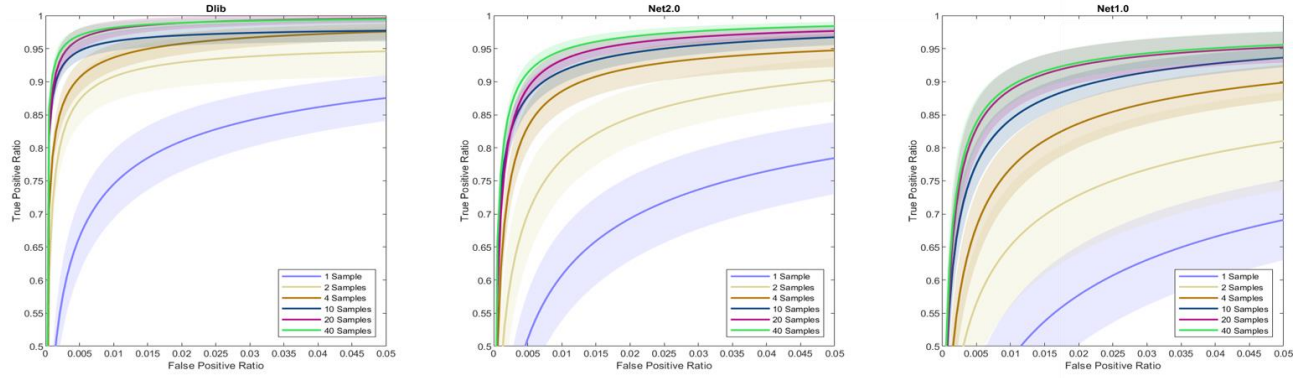

Figure 2. ROC curve: performance variation observed using different training set sizes for the two best distilled network and the teacher dlib.

In a second test, we wanted to determine the number of samples of each known individual that should be used to train the classifier to obtain an acceptable final result. This need arises from the practical constraint that, in real-world applications, the final user wanting to train his/her own classifier has typically very few sample images of each person he/she wants to recognize.

Therefore, in our tests, classifiers for 50 subjects were trained on the features extracted respectively from *Net2.0*, *Net1.0* and *Dlib* networks using respectively 1, 2, 4 10, 20 and 40 samples for each individual. As before, the tests were replicated 10 times by randomly selecting different identities from K_{dBi} and unknown subjects from U_{dBi}. Both the region containing 99% of the results and the average ROC, are depicted in Figure 2.

The results obtained are of high interest as it was observed that, although a training performed with tens of samples obviously leads to better results, the classifier could --when necessary-- be trained using only very few samples for each person without incurring a dramatic degradation of the results. At the lowest level, training the classifier using just one sample for each person provides acceptable results in all the examined cases.

VI. Conclusion

This paper presented a novel knowledge distillation experiment. It was carried out on a large a face recognizer CNN which is provided as part of Dlib. The final products are faster and lighter models built upon many "cuts" of a DensNet121 CNN. The obtained accuracy is on par with that of the original network. The distillation of the dark knowledge has been reached in a teacher-student framework, optimizing the final model as regression problem, in which the former network is used as an expert oracle that provides the targets, while the latter is trained on the same input image. In addition to be lighter, our model is trained to use smaller input images, naturally allowing the recognition of identities in a wider distance range, with lesser computational requirements. The latter outcome is critical to pave the use of the network on a dedicated mobile accelerating hardware. The described procedure can eventually be used for many feature-embedding CNNs.

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Deep Image Captioning: An Overview

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***Abstract* – Image captioning is a process of automatically describing an image with one or more natural language sentences. In recent years, image captioning has witnessed rapid progress, from initial template-based models to the current ones, based on deep neural networks. This paper gives an overview of issues and recent image captioning research, with a particular emphasis on models that use the deep encoder-decoder architecture. We discuss the advantages and disadvantages of different approaches, along with reviewing some of the most commonly used evaluation metrics and datasets.**

Keywords – image captioning, encoder-decoder, attention mechanism, deep neural networks

I. INTRODUCTION

Recent advances in deep learning methods on perceptual tasks, such as image classification and object detection [1, 2] have encouraged researchers to tackle even more difficult problems for which recognition is just a step towards to more complex reasoning about our visual world [3]. Image captioning is one of such tasks.

The aim of image captioning is to automatically describe an image with one or more natural language sentences. This is a problem that integrates computer vision and natural language processing, so its main challenges arise from the need of translating between two distinct, but usually paired, modalities [4]. First, it is necessary to detect objects on the scene and determine the relationships between them [5] and then, express the image content correctly with properly formed sentences. The generated description is still much different from the way people describe images because people rely on common sense and experience, point out important details and ignore objects and relationships that they imply [6]. Moreover, they often use imagination to make descriptions vivid and interesting.

Regardless of the existing limitations, image captioning has already been proven to have useful applications, such as helping visually impaired people in performing daily tasks. Automatically generated descriptions can also be used for content-based retrieval [7] or in social media communications.

Early image captioning approaches relied on the use of predefined templates, which were filled in based on the results of the detection of elements on the scene [8, 9]. However, the advantage of such bottom-up approaches in terms of the ability to capture details was not enough to keep them in the focus of research interest. Generated sentences were too simple, lacking the fluency of human writing. Moreover, such systems were heavily hand-designed, which constrained their flexibility. Some authors [10] have reformulated image captioning as a ranking task. Ranking-based approaches always return well-formed sentences, but they cannot generate new sentences or to describe compositionally new images [11], i.e., those containing objects that were observed during training but appear in different combinations on the test image. In contrast, today's state-of-the-art models are generative and neural networks based. They usually employ an encoder-decoder architecture by combining a Convolutional Neural Network (CNN) with a Recurrent Neural Network (RNN).

The rest of the paper is organized as follows: The next Section provides some background information on the typical architecture of image captioning systems. Section III. groups image captioning models according to the captioning task and describes relevant models for each type. Section IV. presents some of the most commonly used data sets, along with a description of how they were collected. Section V. lists the metrics and points to the problems that arise when evaluating generative approaches. The paper ends with a Conclusion.

II. ARCHITECTURE AND LEARNING APPROACHES

A. Encoder-Decoder Framework

Inspired by its success in Neural Machine Translation [12], many of the current state-of-the-art models for image captioning employ the encoder-decoder architecture (Fig. 1). In this architecture, the encoder is used to map the input into its real-valued fixed-dimensional vector representation. A decoder then generates output, conditioned on the representation produced by the encoder. The main advantage of such a system is that it can be trained end-to-end, meaning that the parameters of the whole network are learned together, thereby avoiding the problem of aligning several independent components.

Image captioning is often understood as a task of translating one modality, i.e. an image, into another modality, i.e. its description, so the encoder-decoder architecture has been successfully applied with a convolutional neural network (CNN) [13] on the encoder side, and a recurrent neural network (RNN) [14] on the decoder side.

A CNN acts as a feature extractor that is usually pretrained on a large dataset for a classification task [15]. A feature map from a convolutional layer or the vector representation from a fully-connected layer is then used as image representation. An RNN or one of its variants, such as the long short-term memory (LSTM) network [16], is employed for language modeling.

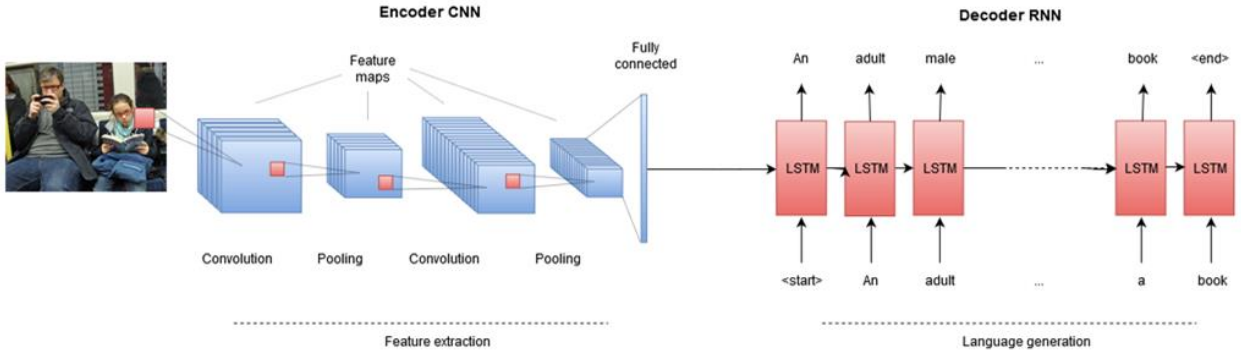

Figure 1. Encoder-decoder framework for image captioning: first a CNN encoder produces image representation (left), then an LSTM decoder generates caption conditioned on the representation produced by the encoder (right)

B. *Learning*

Majority of the encoder-decoder image captioning models use Maximum Likelihood Estimation (MLE) as their learning method. In the supervised learning setting, with training examples consisting of image-caption pairs, the model maximizes the probability of the correct caption given the image [17]:

$$\boldsymbol{\theta}^* = \arg\max_{\boldsymbol{\theta}} \sum_{\boldsymbol{I},\boldsymbol{y}} \log p(\boldsymbol{y}|\boldsymbol{I};\boldsymbol{\theta}) \tag{1}$$

where $\boldsymbol{I}$ is the image, $\boldsymbol{y} = \{y_1, \ldots, y_N\}$ is the corresponding caption of length *N*, $\boldsymbol{\theta}$ are the parameters of the model. The joint probability over words can be expressed as follows:

$$\log p(\boldsymbol{y}|\boldsymbol{I}) = \sum_{t=0}^{N} \log p(y_t|y_0, y_1, ..., y_{t-1}, \boldsymbol{I}) \tag{2}$$

where the dependency on $\boldsymbol{\theta}$is dropped for simplification.

To model $p(y_t|y_1, y_2, ..., y_{t-1}, \boldsymbol{I})$ usually an LSTM is employed, which is trained to predict the next word y_t conditioned on all the previously predicted words $(y_1, y_2, ..., y_{t-1})$ and the context vector $\boldsymbol{c}$ produced by the encoder [18, 32]:

$$p(y_t|y_1, y_2, ..., y_{t-1}, \boldsymbol{I}) = f(\boldsymbol{h}_t, \boldsymbol{c}) \tag{3}$$

where $f$is a nonlinear function that outputs the probability of y_t, $\boldsymbol{h}_t$is the hidden state of the LSTM at time step *t*.

Novel sentences can be generated by randomly sampling from the model's distribution or by using beam search [19, 17].

Although effective, some limitations of MLE learning have motivated the adoption of alternative learning methods. Reinforcement learning [20] can be used to address the exposure bias problem [21] and for the direct optimization of the standard evaluation metrics [22]. For increasing the diversity of generated captions, conditional GAN framework [23] or contrastive learning [24] were proposed.

C. *Attention Mechanism*

It was demonstrated in [18] that the fixed-length vector representation produced by the encoder is responsible for the degradation of the performance that occurs as the length of input increases. Regardless of the size of the input, in the basic encoder-decoder all the information is compressed into a context vector of a predefined size. Instead, the authors proposed to encode the input into a set of vectors.

The first work to employ an attention mechanism on the task of image captioning was [25]. In the proposed model, image features are extracted from a lower convolutional layer of a CNN as a set of L annotation vectors $a = \{\boldsymbol{a}_1, \ldots, \boldsymbol{a}_L\}$summarizing a pre-defined spatial location of the image. To each annotation vector, a positive weight α_{ti} is assigned, indicating the amount of attention each image feature receives. The attention weight α_{ti} is computed by an attention model f_{att}:

$$e_{ti} = f_{\text{att}}(\boldsymbol{a}_i, \boldsymbol{h}_{t-1}) \tag{4}$$

$$\alpha_{ti} = \frac{\exp(e_{ti})}{\sum_{k=1}^{L} \exp(e_{tk})}, \sum_{i=1}^{L} \alpha_{ti} = 1 \tag{5}$$

where $\boldsymbol{h}_{t-1}$ is the previous hidden state.

After obtaining the attention weights, the attention mechanism computes the context vector $\boldsymbol{z}$ as a dynamic representation of the relevant parts of the image at a given time step:

$$\boldsymbol{z}_t = \sum_{i=1}^{L} \alpha_{t,i} \boldsymbol{a}_i \tag{6}$$

The context vector is then used to update the hidden state of the decoder.

III. IMAGE CAPTIONING TYPES

We have grouped methods and models of image captioning given the task into three types: (1) standard image captioning, (2) image captioning with style and (3) cross-lingual and multilingual image captioning.

A. *Standard Image Captioning*

For the correct description of the image, it is necessary to:

(1) detect the content of the image in terms of objects, attributes, relationships, with the conclusion of what is new or interesting [26, 27],

(2) express the represented semantic content with properly formulated sentences [17] that are suitable for the image they describe [10].

The captions generated by most of the contemporary methods usually represent an objective and neutral description of the factual content of the scene.

An example of a model designed to generate new captions with previously unseen combinations of objects is reported in [11]. Authors proposed a multimodal Recurrent Neural Network (m-RNN) framework that is adapted to both the retrieval as well as to the sentence generation task. The model consists of a CNN and RNN, which interact with each other in a multimodal layer receiving three inputs: the word embedding layer, the recurrent layer, an image representation. A final soft-max layer generates the probability distribution of the next word.

In [17] authors introduce an end-to-end trainable Neural Image Caption (NIC) system, similar to [11] but with an LSTM variant of RNN as the decoder. The authors propose to use maximum likelihood estimation (MLE) principle for training the model. For its effectiveness, NIC became one of the most influential models, and other authors developed extensions on top of it [28, 29].

A similar end-to-end Long-Term Recurrent Convolutional Network (LRCN), combining a CNN encoder and an LSTM decoder, is introduced in [19]. Authors investigated the effects of different architectures and found that using LSTM instead of a simple RNN, combined with a more powerful CNN, contributed to better performance. Adding more LSTM layers did not bring expected improvements.

Different from the spatial attention model introduced in [25], the authors in [30] proposed a semantic attention model which combines different sources of visual information through a feedback process to attend to fine details in images while having an end-to-end trainable system. Top-down features, extracted from the last convolutional layer of a CNN, serve as a guide where to attend. A set of bottom-up attributes are detected as candidates for attention. Those with highest attention scores are then used by the attention mechanism which learns to attend to the semantically important concepts. Since irrelevant attributes may redirect attention to wrong concepts, attribute prediction plays a crucial role.

A similar approach is presented in [31] where authors combine top-down and bottom-up attention processing to calculate attention at the object-level. Instead of treating detected objects as bag-of-words that do not retain spatial information, they propose a different, feature-based approach. Bottom-up attention mechanism, based on Faster R-CNN [2], proposes a set of salient image regions. Combined with the more traditional top-down approach, this allows us to reveal the structure of the scene better and to interpret better the relationships between objects, which becomes important in dealing with compositionally new images.

Previously described attention models have a limitation in that they cannot selectively decide when to focus attention on the image. In [32] authors argue that directing attention to the image at every time step becomes unnecessary for words that do not have a corresponding visual signal such as "a ", "for" etc. They introduce an adaptive attention model that automatically decides whether to focus attention on the image or to use information stored in the decoder's memory. An LSTM extension, called sentinel gate, produces an additional visual sentinel vector, which is used when the model decides not to attend to the image. The new context vector is modeled as a combination of the context vector of the spatial attention model and the visual sentinel vector. It was shown that the ability to decide when to attend to the image was also useful for better directing attention to the appropriate image regions, which allowed the model to achieve state-of-the-art results.

B. Image Captioning with Style

There are two lines of work focused on enriching captions with more emotional content. The first group of authors includes viewer's attitude and emotions towards the image [29, 33, 34, 35], the second line of work includes emotional content from the image itself [36].

The authors in [29] were the first to incorporate positive and negative sentiments into captions. They proposed *SentiCap*, a switching RNN model with word-level regularization which emphasizes sentiments. Two networks, consisting of a CNN and an RNN, were used to generate stylized captions. One network was trained on a large image-caption dataset to generate standard factual descriptions, and the other was trained on a small dataset with sentiment polarity. Experiments showed that *SentiCap* was able to include the appropriate sentiment in 74% of the generated sentences.

The *SentiCap* model is limited in its ability to scale because it requires words labeled with sentiment strength. To address this issue, the authors in [33] propose StyleNet, an end-to-end trainable model which generates captions in a humorous or romantic style (Figure 2). A factored LSTM is used to factorize the weight matrices to account for factual and non-factual aspects of the sentences. Multi-task learning is used to optimize the generation of factual captions, and stylized language modeling. Almost 85% of the human evaluators found the stylized captions to be more attractive than the corresponding factual descriptions.

In [34] authors propose two mechanisms to inject sentiment into captions: (1) direct injection, in which sentiment is injected as an additional dimension at each time step, (2) injection by sentiment flow, in which sentiment is provided only at the first time step and then propagated over the whole sentence by a sentiment cell. Experiments showed that both methods were able to add sentiments, but direct injection generated more captions with sentiments.

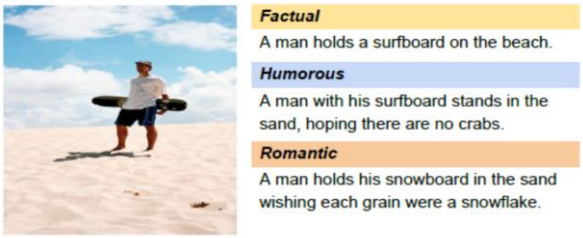

Figure 2. Comparison of factual and stylized captions [35]

FaceCap [36] model presents a different point of view and embraces the emotions detected in facial expressions of people depicted in the images. It relies on the use of a facial expression recognition model to extract facial features, which can be then used by an LSTM to generate captions. The authors observed that the model has improved in describing the actions on the scene.

C. Cross-Lingual and Multilingual Image Captioning

Cross-lingual and multilingual image captioning refers to the task of generating a caption in one language given a corpus of descriptions in one or more different languages [37].

Several approaches exist to tackle such tasks such as direct translation of generated captions, collecting a new dataset in a target language and its use for training, or learning a model from machine-translated texts. The first approach can give inferior results, among others because direct translations can worsen the errors in the generated descriptions [28]. Therefore, researchers are primarily focused on developing models that will be able to cope with different languages directly.

Authors in [38] treat the problem as a visually-grounded machine translation task in which the image is used to resolve ambiguity. In the proposed multilingual image description model, visual features are complemented with textual features of the source language (English) to generate captions in German.

The authors in [37] transfer the knowledge obtained from learning on English captions to generate captions in Japanese as the target language. The model was first pretrained on the large English dataset. Then, the trained LSTM was replaced with the new one, trained on the much smaller corpus of Japanese captions. The authors noticed that pretraining had the effect of learning on additional 10,000 images with Japanese captions. Moreover, the use of captions that are not direct translations made the model easier to scale.

Authors in [39] propose a single model capable of generating captions in multiple languages, but with a strong assumption that the images with captions in different languages are readily available. A token, provided as initial input, controls the choice of the target language.

Previous approaches rely on datasets with human-written captions in different languages. In [28] authors adopt a cheaper solution by using machine-translated text. To overcome the lack of fluency of such translations, they introduce a fluency estimation module to assign an importance score to the captions that are then chosen for training. Experiments were performed on English-Chinese datasets and showed that the model, trained on a smaller dataset from which less fluent sentence where excluded, achieved comparable results to the baseline, trained on all the machine-generated sentences (fluent or not).

IV. Datasets

The development of this research area greatly depends on the availability of large datasets that contain images with corresponding descriptions. In addition to the size of the dataset, an image captioning model benefits also significantly from the quality of captions in the spirit of natural language and their adaptation to a given task.

A. Collecting datasets

Images are collected primarily from photo-sharing services, mostly Flickr1 or by harvesting the web. Unlike the image gathering, obtaining appropriate descriptions turned out to be much more challenging.

As [10] pointed out, captions provided by users of photo-sharing websites are not suitable for the training of automatic image captioning systems. Such captions usually provide broader context, i.e., additional information that cannot be obtained by the image alone. Instead of using non-visual descriptions, [10] suggested focusing on general conceptual descriptions, i.e., those that refer to objects, attributes, events and other literal content of the image. Such descriptions are collected, on a large-scale, through crowdsourcing services, such as Amazon Mechanical Turk (AMT) [40, 10, 41], which involves defining a task that is performed by untrained workers [42]. Due to the low cost and high speed, crowdsourcing became the preferred way of collecting image descriptions for large-scale datasets.

B. Datasets

UIUC PASCAL Sentences [40] was one of the first image-caption datasets, consisting of 1,000 images and associated with five different descriptions collected via crowdsourcing. It was used by early image captioning systems [8], but due to its limited domain, small size, and relatively simple captions it is rarely used.

Flickr 30K [43] includes and extends previous Flickr 8K [10, 40] dataset. It consists of 31,783 images showing everyday activities, events, and scenes described by 158,915 captions obtained via crowdsourcing.

Microsoft COCO Captions [41] dataset contains more complex images of everyday objects and scenes. By adding human generated captions, two datasets were created: c5 with five captions for each of the more than 300K images and an additional, c40 dataset with 40 different captions for the randomly chosen 5K images. The c40 was created because it was observed [44] that some evaluation metrics benefit from more reference captions.

Flickr 30K and MS COCO Captions are widely accepted as benchmark datasets for image captioning by most models using deep neural networks.

V. Evaluation

Accessing the accuracy of automatically generated image captioning is a demanding task [44, 45]. The same image can be described in various ways, focusing on different parts of the image, using a different level of abstraction or different level of knowledge about objects on the scene. It is obvious that by emphasizing different aspects of the image, the resulting sentences can vary significantly while at the same time being entirely correct. In contrary, two captions can share most of the words and convey a different meaning.

Evaluation of automatically generated captions can be performed by human subjects, either by experts [10] or by untrained workers through crowdsourcing platforms [19, 22]. However, human-based evaluation creates additional costs; it is slow, subjective and difficult to reproduce [10, 46]. A better alternative is the use of automatic metrics, which, in turn, are fast, accurate and inexpensive [45]. To

[1] https://www.flickr.com

be useful, metrics should match the rating of human evaluators, but it turned out to be a goal that is difficult to achieve. Evaluation metrics should satisfy two criteria [22]: (1) captions that are considered good by humans should achieve high scores, (2) captions that achieve high scores should be considered good by humans.

Image captioning is sometimes compared [47] to language translation [8, 17] or with text summarization [48], which motivated the adaption of metrics developed initially for the evaluation of languages tasks [49, 50, 51]. All these metrics output a score indicating a similarity between the candidate sentence and the reference sentences.

BLEU [49] is a popular metric for machine translation evaluation and one of the first metrics used to evaluate image descriptions. It computes the geometric mean of n-gram precision scores multiplied by a brevity penalty in order to avoid overly short sentences.

METEOR [50] is another machine translation metric. It relies on the use of stemmers, WordNet [52] synonyms and paraphrases tables to identify matches between candidate sentence and reference sentences.

ROUGE [51] is a package of measures initially developed for the evaluation of text summaries. For image captioning, a variant ROUGEL is usually used, which computes F-measure based on the Longest Common Subsequence (LCS), i.e. a set of words shared by two sentences which occur in the same order, without requiring consecutive matches.

CIDEr [44] is a metric designed for the evaluation of automatically generated image captions. It measures the similarity between the candidate sentence and a set of human-written sentences by performing a Term Frequency Inverse Document Frequency (TF-IDF) weighting for each n-gram.

SPICE [45] is a metric designed for image caption evaluation. It measures the quality of generated captions by computing an F-measure based on the propositional semantic content of candidate and reference sentences represented as scene graphs [53].

The metrics above represent a standard set of metrics usually reported in papers. Their popularity can be attributed to their availability through the Microsoft COCO caption evaluation server [41], which enables a consistent comparison of different models.

However, it was shown [47, 10] that automatic metrics do not always correlate with human judgments. This was particularly evident during the Microsoft COCO 2015 Captioning Challenge in that some models outperformed human upper bound according to automatic metrics, but human judges demonstrated a preference for human-written captions [54]. It seems that "humans do not always like what is human-like" [44]. Since there is no best metric, some authors [45, 46] advise the use of an ensemble of metrics capturing various dimensions, such as grammaticality, saliency, correctness or truthfulness. In [22, 46] new evaluation metrics were proposed.

VI. CONCLUSION

This paper presents an overview of recent advances in image captioning research, with a particular focus on models employing deep encoder-decoder architectures. The main advantage of such architectures is in that they are trainable end-to-end, mapping directly from images to sentences.

An important extension of the basic encoder-decoder framework is the attention mechanism, which enables to focus on the most salient parts of the input image while generating the next word of the output. We group the related work into three types regarding the task: standard image captioning (with or without an attention mechanism), image captioning with style and cross-lingual or multilingual image captioning.

Large vision and language datasets have also contributed significantly to the development of the field. Additional features of the new datasets, such as emotions or descriptions in different languages, will certainly stimulate even faster advances in the periods to come.

However, there are some important tasks that are still unresolved, such as generating captions more in the spirit of the human descriptions, automatic adaptation of descriptions to the given task, and perhaps the most challenging among them, automatic assessment of the generated captions, since there are still no metrics to match human evaluation fully.

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Using High Performance Computing in Vehicles to Create Image Datasets for Deep Learning

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Abstract – Modern vehicles are equipped with multiple sensors that help engineers to automate driving functions as much as possible. Among other types of sensors, these vehicles are equipped with multiple cameras that enable capturing the video data of the surrounding vehicles. These video data can be later used in training deep neural networks that are typically used within the vehicles to detect objects of interest around them. However, before we can use the video data for training, we must annotate them. Nowadays, the annotation process is typically semi-automated, where the initial annotations are added in a datacenter and then fine-tuned by human annotators. In this paper, we investigate the possibility to utilize high performance computing inside the vehicles in order to add initial annotations at the edge, instead of using the datacenter. With this approach, we expect a more scalable overall solution for the annotation process, because we utilize the computing power that is already available in the vehicles. For this investigation, we focus on heterogeneous automotive platforms of Intel® and analyze their potential for the annotation tasks at the automotive edge.

I. INTRODUCTION

Today's modern vehicles are on the path towards full automation, as it is estimated that automated vehicles will bring many benefits to the human society [1]. These benefits include increasing traffic safety and passenger comfort and reducing the number of road accidents. Ultimately, with the full automation of driving function (i.e. Level 5 automation according to [2]), it is expected that the car ownership model will shift towards car-sharing services, thus reducing the number of vehicles on the roads, which brings many benefits including reducing air pollution and bringing traffic in the cities to the more manageable levels.

Automated driving ultimately relies on artificial intelligence in many of its functions, and image processing using deep learning is a great example of why automated vehicles ultimately require high performance computing at the edge. To train these deep learning models, we need lots of data with enough variety to cover all possible driving scenarios [3]. These data are typically captured by the vehicles that are equipped with different sensor types (cameras included) and the communication means to upload the sensor data to the cloud for further processing and annotation. The annotated data can then be used to train machine learning models used in the vehicles in the case of supervised learning.

The process of getting the data annotated and stored in the cloud in the optimal way requires careful development of the entire end-to-end pipeline. In this paper we introduce the idea that the vehicle, with its high performance computing capability, can be added to the pipeline, so that the initial processing and annotation of the sensor data (i.e. camera data) is already performed at the edge of what is really a big data Internet-of-Things system.

The work described in this paper was done as part of the Cloud-LSVA project, which was funded by the European Commission in the Horizon 2020 program.

II. CLOUD-LSVA PROJECT

The main goal of the Cloud Large Scale Video Analysis project (abbreviated Cloud-LSVA) is to develop a cloud platform for storing, processing and retrieving the automotive sensor data in the cloud, on a large scale [4]. The idea is to automate the entire end-to-end pipeline, which includes:

- sensor data capture in the vehicles,
- data upload, annotation and storage,
- deep learning model generation (for image processing), and
- download the new model to the vehicles.

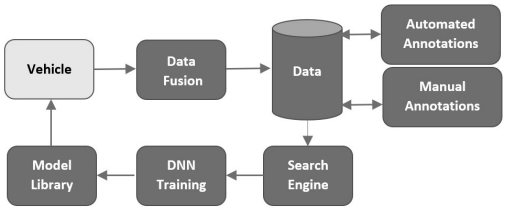

Figure 1. Diagram of the Cloud-LSVA architecture

The diagram depicting the idea of the pipeline is shown in Figure 1. The data is collected by the vehicle, and uploaded to the cloud. Typically, data fusion takes place next, as the data is collected by different sensors in the vehicle. Automated and manual annotations are done on the images, and they are stored together with the other data and meta-data. The search engine queries the data for training and after the training is done, the trained model can be downloaded back to the vehicle.

Historically, image annotations are inserted manually by human annotators, but such a manual process is both time consuming and error prone, and it does not really scale well for large datasets. Additionally, such annotations occasionally appear inconsistent, as different human annotators do not always interpret things the same way.

On the other hand, image processing using deep neural networks (DNN) has generated some groundbreaking results over the past several years [5]. It is still challenging to train DNNs for a wide variety of scenarios, weather conditions, situations and corner cases which together form everyday driving. Nevertheless, replacing (to a certain degree) the human annotators with algorithms that can perform most of the annotation task (possibly in real-time) with reliable and consistent accuracy is probably the only way to scale the annotation solution to ultimately meet the requirements of data volume for vehicles to be trained well enough and to be considered reliable. Therefore, the main idea of Cloud-LSVA is to combine the efficiency of the DNNs to process a large number of images, with the precision of the human annotators to fine-tune the annotations inserted by the DNNs..

For Advanced Drivers Assistance Systems (ADAS) and for automated driving, deep learning workloads for image processing typically perform object detection [6] and semantic scene segmentation [7], so the annotations that are needed to train these systems are bounding boxes for objects of interest (object detection) and pixel-wise class assignments (semantic segmentation). If pre-trained DNN models are already available to perform these tasks, we can deploy them in the cloud and process the uploaded images from vehicles in a way that these DNNs look for objects/classes of interest and insert annotations based on their inference results. In this way, we get initial annotations, which would not be perfectly accurate, but would serve human annotators as a good starting point for their manual work. As the next step, they would simply fine-tune the initial annotations manually , and finalize them to produce the accurate annotations that can later be used for training these DNNs. The advantage of this semi-automated process is increased productivity of the human annotators and probably even increased accuracy of the final annotations.

From the results that are published elsewhere (for example in [6] and [8]), we can see that the accuracy of the DNNs performing the tasks of object detection and semantic scene segmentation typically reach mIOU (mean Intersection-Over-Union) scores of up to 80%. With such high scores, we can expect the initial annotations inserted by DNNs to be a great basis for the entire annotation pipeline. One advantage of automatic annotations in the cloud is that they do not need to be performed in real time, but we can choose DNNs in the cloud that sacrifice speed of inference over accuracy, to get the best possible initial annotations.

A. Annotation

For machine learning algorithms, by inferring information based on what is contained in the dataset, the value can be defined as the extent to which the annotation goes. In other words, we imply that the same recording can contain various levels of details and various kinds of annotations and labels, ranging from bounding boxes, to pixel labeling, to situational (e.g. weather), actions (e.g. right turn) and events (e.g. pedestrian crossing the road). As stated later in the text (section II.C), the quality and nature of the labeling have direct relationship to the computational complexity, and therefore they need to be established.

Within the Cloud-LSVA project, a specific and exhaustive list meant to cover all aforementioned use-cases, as well as the description format, is named Video Content Description (VCD) [9]. VCD helps to automate the annotation process, but also simplifies the organization and management of the dataset, as well as the querying and retrieval of required segments of data, since they can be referred to by specific labels as well as time references and image sequences.

A well-defined mechanism for data retrieval is of utmost importance for the usability of the dataset. This is true not only in the creation and management of the dataset, but also in training and benchmarking machine learning algorithms, since the retrieving mechanism provides an easy way to establish use-cases and scenarios thanks to the in-depth visibility of the content of the entire dataset. Figure 3 illustrates the relationship of annotations and image sequences of a video-based dataset.

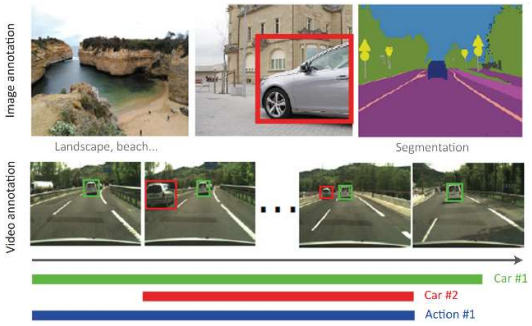

Figure 2. An example of annotation for individual images and image sequences, where cars and actions (e.g. lane change, not depicted) are annotated.

B. Using In-Vehicle Compute Power for Initial Annotations

Within the Cloud-LSVA project, we wanted to estimate the efficiency of inserting the initial annotations inside the vehicle, i.e. at the edge, rather than in the datacenter. The main advantage of this approach is that we utilize the compute power that is already available, and that the in-vehicle computers are performing the exact same tasks that we need to perform to insert the initial annotations. In other words, if the vehicle is already executing object detection as a part of an ADAS system, we can reuse the inferencing results as annotations and store them for each processed image. These annotations can then be uploaded together with the images to the cloud, and downloaded and fine-tuned by the human annotators.

The potential problem with this approach is that it requires the real-time capability of in-vehicle computers to insert the initial annotations. As stated before, in the cloud we do not expect the annotations to be inserted in real time, because the computers will be available at any time (for example, overnight) and we can also parallelize the annotation effort across several server nodes. In vehicles we do not have the luxury to insert annotations at some later point in time, because the vehicle will eventually be turned off and therefore unable to deal with the backlog of images that are still not annotated. Finally, the datacenter servers are not bound by the power, size and cooling limitations that are typically found in the automotive space.

The inference time of a DNN is typically inversely correlated with its accuracy. An overview of inference time vs. accuracy is shown in [8], for different scene segmentation DNNs published in the literature. It is apparent from this analysis that the accuracy of different DNNs for scene segmentation lies between 60% and 80% mIOU, but only the DNNs with lower accuracy are capable of real-time image processing, while the higher accuracy comes with about one second of inference time per image (i.e. one frame per second), which obviously cannot be considered real time [8]. Figures 3 and 4 show difference in segmentation quality for PSPNet [10] and Enet [11], respectively. Unlike Enet, PSPNet is not real-time capable, but achieves superior accuracy and therefore would probably be a better choice for inserting initial annotations, in terms of a better starting point for fine-tuning the initial annotations.

Therefore, for in-vehicle annotation insertion, it is important to pick the right DNN architecture for the purpose of 1) achieving the real-time capability, and 2) create annotations that serve as a good quality starting point for manual fine tuning of the annotations. These two requirements are somewhat conflicting, and require careful analysis of the DNN architectures and the in-vehicle hardware platforms.



Figure 4. PSPNet DNN *[10]*, mIOU 80%, 1 FPS

In this work, we concentrate on the hardware performance analysis, rather than designing new DNN architectures. Therefore we picked two well established DNNs for the analysis, and analyzed their inference time and quality on different processors. More details on these DNNs is given in the following section.

C. Target DNN Architectures

For ADAS and automated driving applications, the most interesting and relevant computer vision tasks are object detection and semantic scene segmentation. Object detection looks for objects of interest in the image, and if they are found, calculates the bounding boxes that enclose each of these objects separately. Semantic segmentation processes the image and assigns each pixel to a specific object class, essentially calculating contours around the objects of interest. If a pixel does not belong to any known object classes, it is assigned to the image background. In our work, we are looking at one example DNN architecture for each one of these two tasks.

For object detection, the target DNN architecture is MobileNet-SSD. It consists of a combination of a MobileNet-based feature extractor [12] together with the SSD meta-architecture [6]. It provides a strong accuracy-computational complexity balance.



Figure 5. Enet DNN *[11]*, mIOU 60%, real time capable

More details on MobileNe and SSD implementations can be found in [6] and [12].

On the other hand, for semantic segmentation, the target DNN architecture is ICNet [8]. Semantic segmentation is a significantly more complex task compared to object detection as the level of annotation is much more fine-grain and there are generally many more opportunities for mislabeling, as each individual pixel is annotated (as shown in Figure 5).

To understand the computing requirements for the two DNNs under investigation, it helps to calculate the number of floating point operations in each of them, so that we can estimate how much time a single forward pass requires for a given processing element. This estimation can simply be based on the FLOPS (Floating Point Operations per Second) requirement of the DNN and the peak performance capability in terms of FLOPS of the processing element. To calculate the number of operations in each DNN, we wrote a Python script to parse the DNN using pycaffe [13], and based on the type and size of the layers, to calculate the number of operations in each layer, as well as the total for the DNN. For MobileNet-SSD, we calculate the number of operations to be approximately 1.2 billion operations in a single forward pass, and for ICNet there are approximately 30.5 billion operations.

III. COMPUTE ARCHITECTURES

In this work, we investigate different Intel compute architectures that are nowadays used in different applications for DNN inference. Not all of them are used for inferencing in automotive applications, but we nevertheless studied them in this context to understand if they would be potentially suitable.

A. Xeon® CPU

The Intel Go™ automotive platform [14] comes in two distinct variations: one is based on Xeon processors, and one is based on Atom® processors. They both have optional FPGAs attached to the CPU for workload acceleration, but in this paragraph we concentrate only on the CPU capabilities and we analyze the FPGA separately in a later section.

One version of the Xeon-based Intel Go platform is Halo Creek, which is based on the Skylake Server CPU with 24 cores. Simple calculation of the peak performance capability for the floating point calculation shows 1.6 TFLOPs for the single CPU (24 cores x 32 operations per core per cycle x 2.1 GHz operating frequency). It should be emphasized, however, that the actual performance in practice may be significantly lower than the peak performance of the processor, if the software running on it is not optimized according to code modernization techniques that can be found in [15]. To ensure the highest performance, the Intel version of the Caffe framework [16] should be used for inference on Halo Creek, together with the underlying optimized performance libraries [17], such as Math Kernel Library (MKL) and Math Kernel Library for Deep Neural Networks (MKL-DNN).

B. Atom CPU

The Intel Go variant with the Atom processor is several orders of magnitude less powerful than the Xeon variant. What we investigated is the Car Branch version of the platform, with the Denverton CPU with 8 Atom cores. The simple calculation for peak performance yields around 54 GFLOPS (8 cores x 4 operations per core per cycle x 1.7 GHz operating frequency). Comparing Car Branch's peak performance with the requirements of the two DNNs under investigation, it is obvious that the Atom based Intel Go platform is not suitable for deep learning applications in automated driving. In fact, the market segment that this platform is targeting is in-vehicle infotainment , where DNNs are typically accelerated not by the Atom CPU, but a potential dedicated accelerator (which is outside of the scope of this paper).

C. Arria® 10 FPGA

The Arria 10 FPGA is the latest variant in the Arria family of Intel FPGAs (mid-range market segment). The Arria 10 can be used standalone as the Arria 10 Development Kit, but it is also available inside Car Branch and Halo Creek units, as a single FPGA attached to the CPU.

The peak performance of Arria 10 is 1.5 TFLOPS [18], but achieving that performance is a difficult task due to the way FPGAs are typically programmed. Historically, to program an FPGA, the designers had to use a Hardware Description Language (Verilog or VHDL), but for the modern type FPGA workloads such as DNNs, the High-Level Synthesis approach (HLS) is preferred due to much better turnaround times. One potential drawback of this approach is the inability to guarantee similar performance compared to the HDL approach, but that is negligible in comparison with the turnaround time benefits.

The recommended HLS approach with Intel FPGAs is to use OpenCL™, as described in [19], where close to peak performance was achieved for image processing using DNNs implemented using only OpenCL and Intel FPGA SDK for OpenCL [20]. This brings FPGAs performance to similar levels as the Xeon CPUs and some GPU offerings from Nvidia®.

However, it should be noted that OpenCL programming of FPGAs comes with significant effort, and requires expert knowledge of the FPGA design using OpenCL. To simplify the process of bringing DNNs to FPGAs for the customers, Intel offers the inference tool called OpenVINO™ [21], which hides complexities associated with the FPGA design and provides an easy to use platform. The drawback of OpenVINO for our investigation was a limited number of layers supported. In other words, OpenVINO did not support all of the layers used in the Caffe model of the two DNNs under

investigation, especially because ICNet uses a custom layer for bilinear interpolation that is not even available in the main Caffe master repository. This also meant that we could not run the two benchmark DNNs on FPGAs, but we nevertheless wanted to emphasize in the paper that for certain types of workloads (supported by OpenVINO) FPGAs present an attractive solution for efficient inferencing of DNNs.

D. Intel Integrated Graphics

Intel Integrated Graphics is the collective name for graphics processors produced by Intel in the same package with the main CPU [22]. The graphics processor communicates with the CPU over the ring interface, and the execution units within the graphics processor execute the given workloads in parallel and return the results to the main CPU. It should be noted that the integrated graphics are not typically used in the automotive space, but we still wanted to understand their capability in terms of DNN acceleration, for any future related work.

For Cloud-LSVA, we used the Intel Skull Canyon NUC computer with the integrated GPU being the Intel Iris™ Pro 580. This variant comes with 72 execution units, each capable of executing 16 floating point operations per cycle and running at 300 MHz, for the peak performance of over 345 GFLOPS. This is a formidable number for a part whose main application is not accelerating DNNs, and as such integrated graphics present a good choice for lower demand workloads.

For programming DNN workloads for Intel integrated graphics, the best approach is to use the clDNN library [23], which is based on OpenCL and contains primitives for DNN layers such as those found in Caffe. The users have the option not to use OpenCL directly, but to rather use OpenVINO, which is capable of translating the trained models (from Caffe, TensorFlow and other frameworks) directly to clDNN and execute the trained models on integrated graphics with minimum user effort.

Similar to the limitation of OpenVINO mentioned in the FPGA section, it is sometimes the case that the trained DNN model contains a layer which is not supported by OpenVINO. In this case, the user has the option to clone the clDNN library from Github, add support for the missing layer(s), and write their own host program in C++ based on templates provided in the clDNN documentation. Compared to adding a custom layer to the FPGA implementation, this is a much lower effort and easily doable for an experienced C++ programmer.

IV. IMPLEMENTATION

The implementation was done by following a standard process of defining the DNN architecture in Caffe and training the model using pycaffe. In our case, we used a pretrained model, which should not make any difference in terms of computational performance as we have not applied any compression and optimization to the network; the network is used as it was obtained in the training phase. The dataset used to train the network impacts directly the accuracy of that network, while the architecture of the network (in our case MobileNet-SSD and ICNet) impacts both the accuracy and the computational complexity, in other words the number of incoming frames that the DNN can process per second.

The Caffe version we used for testing was Intel's official branch of Caffe [16]. Intel's branch brings multiple performance improvements as it allows for better use of Intel's computational hardware using specific Intel libraries as listed above.

Once the network has been trained, we need two files to be able to run the inference step:

- the file that describes the architecture of the network (in the case of Caffe this is stored in the prototxt format), and
- the file that contains the values of the weights and biases obtained during the training phase (the so-called model file).

In our case, they were wrapped in a pycaffe file which also resizes the incoming RGB video data to fit the expected input of the network (300x300 pixels for MobileNet-SSD and 1024x2048 for ICNet).

The software component based on pycaffe was developed using the RT™ Maps SDK, by Intempora. An implementation of a software component allowing access to Intel's Realsense™ D435 camera was also developed in order to connect the camera to the network and feed it with real and live data. This pipeline displays one possible implementation using a combination of software tools and frameworks to setup a base annotation flow on any hardware system.

With this implementation on the Xeon-based Intel Go platform, we were able to exceed the requirements for real-time image annotation in the case of MobileNet-SSD. The camera is providing 30 frames per second and the neural network annotated all of them. In other words, Halo Creek and Intel Caffe were capable of handling the image annotation task out of the box, for the object detection based workload. For ICNet, which is a significantly larger DNN as described earlier in the test, we reached the performance of 11 frames per second annotated (pixel-wise), which is typically not considered real time performance. However, adding eleven images per second to the dataset, even from a moving vehicle, probably means that we would not be losing much of significant data, if any. Nevertheless, there is still room for improvement, because based on the peak performance capability of Halo Creek and the compute load of ICNet in terms of FLOPS, we should expect lower latency and a greater number of frames per second processed.

V. CONCLUSION AND FUTURE WORK

Bringing the vehicle into the pipeline for dataset annotation, as described in this paper, brings

multiple benefits. Reducing the workload in the cloud by utilizing the vehicles' processing power allows for a better scalability of a solution which handles the annotation task in a smarter fashion, given an increasing number of vehicles equipped with sensors and generating data that can ultimately be part of the dataset. Additionally, if the vehicles are used to create initial annotations, then these annotations can be created with a higher level of consistency compared to human annotations, but can also more efficiently extract value in the data and only send those interesting data points to the cloud rather than complete raw images for instance. This approach would significantly reduce the cost of uploading the vehicle data to the cloud.

There are several directions in which this work could be extended. One potential investigation would be to perform an extensive and comparative benchmarking exercise to understand how each neural network topology runs on each of the presented hardware architectures listed above. This could also lead the way to the use of compression and optimization methodologies to reduce the size of the networks, parameter types and connections to improve the computational loads at the expense of minor accuracy reductions. Some of these compression and optimization algorithms are already built into OpenVINO.

Additionally, if the initial annotations are inserted within the vehicle, we could investigate the possibility to cut out individually detected objects in a coarse fashion and assign them to generic classes. Later in the cloud, where we have more compute power and processing time, we could refine the boundaries to the detected objects (e.g. from bounding boxes to contour detections) and further assign the objects to the more specific classes (e.g. from vehicle class to sedan, compact, SUV or other).

Finally, based on the number of frames per second processed on Halo Creek for the two DNNs, work is underway to estimate the bottlenecks and any discrepancies between the expected and the obtained performance. This could lead to more optimizations of the Intel Caffe version that was used in this work.

ACKNOWLEDGMENT

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Emotion Classification Based on Convolutional Neural Network Using Speech Data

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***Abstract*—The human voice is the most frequently used mode of communication among people. It carries both linguistic and paralinguistic information. For an emotion classification task, it is important to process paralinguistic information because it describes the current affective state of a speaker. This affective information can be used for health care purposes, customer service enhancement and in the entertainment industry. Previous research in the field mostly relied on handcrafted features that are derived from speech signals and thus used for the construction of mainly statistical models. Today, by using new technologies, it is possible to design models that can both extract features and perform classification. This preliminary research explores the performance of a model that comprises a convolutional neural network for feature extraction and a deep neural network that performs emotion classification. The convolutional neural network consists of three convolutional layers that filter input spectrograms in time and frequency dimensions and two dense layers forming the deep part of the model. The unified neural network is trained and tested spectrograms of speech utterances from the Berlin database of emotional speech.**

***Keywords*—emotions, speech, emotion classification, convolutional neural network, deep learning**

I. Introduction

It is known that communication between people has two dimensions: verbal and non-verbal. Each dimension carries a portion of the information which can be examined both as a whole or independently. The verbal dimension will take into account only the lexical meaning of words that are produced while the non-verbal dimension comprises hand gestures, facial expressions, prosodic characteristics and emotion expressions [1]. In some situations verbal information by itself can be ambiguous and complete meaning of an utterance will be defined by a gesture, intonation, pitch fluctuations or any other component of non-verbal communication [1].

Emotions are an intriguing portion of non-verbal communication because they represent a biological response to an arbitrary event that is significant to a person involved in the event [2]. In other words, emotions unequivocally present a complex state of mind in a certain situation, where the state of mind is mainly defined by feelings, thoughts, and moods. On the other hand, emotions affect physiological state (e.g. heart rate, blood pressure, muscle movements, etc.) and thus provide a mechanism for direct mapping of an inner psychological state into a physiological state. Since physiological signals are measurable, by observing changes in such signals, it is possible to make conclusions about the presented emotions. The entire field of affective computing is based on that hypothesis and it tries to solve the problems of emotion recognition and prediction from different modalities such as facial expressions, electrodermal activity, heart rate variability, EEG and finally, speech, the modality which is focused on throughout this paper. Emotion recognition could be an useful enhancement in human-computer interaction (HCI) in a way that computers should modify their responses on user commands appropriately based on a estimated user's affective state. This improvement should take present HCI to the next level and make it more similar to the real-life interactions among people. Based on the survey in [3], affect-sensitive computer systems can find applications in the entertainment industry, intelligent vehicle systems, customer services such as call centres, health care, and research.

Speech production is a process in which a complex system of organs must perfectly collaborate to create series of sounds that are understandable and interpretable. The process results in a transformation of an abstract thought into a sequence of sounds that are spoken aloud and carry the meaning of the original thought. For this paper, the relevant subsection of the described complex chain of speech production is the mechanism of sound generation. Basically, Broca's area, the brain area responsible for speaking [4], uses the premotor cortex to send nerve impulses to all muscles involved in speech production, most prominent among them being the vocal chords that will either contract or relax. Simultaneously, the respiratory muscles will compress the lungs and a current of air will flow through the glottis. At that moment, if the vocal cords are tensioned, they will start to vibrate under the pressure of air (open and close very swiftly) and generate harmonical impulses of air which are manifested as voiced sounds. In contrast, if the cords are opened, the air flow will freely pass by and produce unvoiced sounds. Following the vocal cords, air flows through the rest of the vocal tract which ends with the lips and the nose. That part of the vocal tract can be represented by a system with a specific frequency response which defines the characteristics of the produced sound based on its shape, length, thermal capacity, the vocal tract wall elasticity and friction between the wall and the air. Specific

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sounds are result of different, small perturbations in the air flow and the air pressure which can be described with linear vocal tract model excited with vocal cords.

An emotional state in speech is observable thorough different physical characteristics of sounds which are induced by changes of the vocal tract and its excitation. Different emotional states will cause modulation of nerve impulses which will result in minor oscillations of pitch, air flow and the physical properties of the vocal tract. Previously stated changes will affect vocal tract frequency response especially in higher frequencies regions [5], which is observable when statistics of frequency response is computed through sufficient period of time.

Emotion classification and prediction tasks are usually performed by modelling patterns in arbitrary data. Most widely used models are statistical models (e.g. *Hidden Markov Model*, *Gaussian Mixture Model*), machine learning models (mainly *Support Vector Machine* - SVM) and deep learning models [6]. Statistical and machine learning models use handcrafted features as information describing specific physical properties of speech and they have advantage of low complexity and theoretical interpretability. On the other hand, deep learning models have the ability of automatically learning relevant features from raw data that best suit the given task and use them to perform classification. Popular deep learning models are inherited from the domain of computer vision and they usually consist of multiple consecutive subnetworks, in most cases some combination of convolutional neural networks and deep neural networks, and recently recurrent networks.

In this paper through Section II will introduce related work with similar architecture to the proposed model. Details about the explored model are given in the Section III. Final results and discussion are presented in IV and V.

II. Related work

Emotion recognition from speech data is to the present day still a challenging research problem. One of the reasons researchers like to experiment using the speech modality is because speech is a natural way of sharing information [6]. In recent years, the field of deep learning exploded and provided tools for designing complex models from raw data. These models have very high number of parameters and when trained on sufficient amount of data, they outperform conventional machine learning models.

Authors in [7] used convolutional neural network (CNN) that have been trained and evaluated on multiple emotional speech databases. The CNN model was inherited from AlexNet [8] and evaluated using the *Leave-One-Speaker-Out* (LOSO) cross validation method. Input features for the model were spectrograms computed on 1.5 s long speech fragments using 20 ms wide analysis window. To increase the amount of training data, authors computed spectrograms from speech signals with different sampling frequencies: 16, 15 and 14 kHz. The model was defined by five convolutional layers, with max pooling at the first and the last layer, followed by two dense layers with ReLU activation and 50% dropout and softmax layer at the output. Finally they reported unweighted recall averaged over each LOSO cross validation fold. For *Database of German Emotional Speech* (EmoDB) unweighted averaged recall (UAR) was 0.71 for the seven class classification problem, the eNTERFACE corpus produced an UAR of 0.66 for six classes and SUSAS 0.57 for five classes.

III. Motivation and methodology

In this preliminary research, the main goal is to design a stable and simple model by using deep learning methods and algorithms. The model should serve as a reference for future models that will emerge from upcoming research by authors in the domain of affective computing, mainly based on an exploration of the emotion recognition using the speech modality. In Section II a model has been introduced which is, by its architecture and parameters, the closest one to the model which is explored in this paper. In that manner, another important aim of this research will be a comparison between model used in [7] and model CNN model in this research. Additionally, a performace of the CNN model will be compared with the performance of an SVM model which is frequently used in affective computing [3], [6] and the AlexNet model [8] that is usually referenced in the computer vision tasks.

According to the survey in [6], every speech classification or prediction task consists of: defining the features that contain the highest amount of affective information from speech; subsequent design of the best possible model for a given task; and finally, careful preparation of the raw speech data for model training and evaluation. This section will describe these key points in detail.

A. Dataset

For the purpose of this paper, emotional speech data from the publicly available EmoDB corpus [9] was used. It comprises utterances from 10 speakers (5 female and 5 male). Each speaker had to pronounce predefined sentences while acting one emotion at a time from a set of seven basic emotions (fear, disgust, happiness, boredom, sadness, anger and neutral). The corpus includes 535 studio recorded utterances with a sampling rate 16 kHz.

B. Features

A widely accepted way of extracting features from utterances is by using some set of predefined features, e.g. *Computational Paralinguistics Challenge* (ComParE) [10] or *The Geneva Minimalistic Acoustic Parameter Set* (GeMAPS) [11]. In general, these features describe the statistical properties of specific physical occurrences present in a sample of speech. Each physical property should be calculated on short segment (frame of analysis) in which speech is considered to have

characteristics of stationary process. Finally, the statistics will be computed over a predefined number of frames, where results may vary depending on the number of frames.

Two types of features were computed for development of the baseline model and the CNN model. First type of features are functionals defined by the GeMAPS [11] feature set and they describe statistical properties of speech in terms of low level descriptors (LLDs) which are representing different physical characteristics of an utterance. Functionals were computed by using openSMILE feature extractor [12]. The other type of features are spectrograms which are carrying complete information about speech in frequency domain, in a given time segment.

It can be observed that selected features are, directly or indirectly, describing statistical properties of observed data and the statistics will depend on a span of a time window in which it is computed. To explore dependency of a model performance and width of the analysis window, previously stated features were calculated on speech fragments of length 720 ms and 1280 ms. Utterances were fragmented into fragments of aforementioned lengths and overlap between consecutive fragments in the case of length 720 ms was 480 ms (2/3 overlap), and for the length of 1280 ms, overlap was 560 ms (1/2 overlap). For the fragments that were 720 ms long, spectrograms were calculated by a using Hamming time window of 40 ms width FFT with frame advance of 10 ms, while for the fragments of length 1280 ms, spectrograms were calculated by using 36 ms Hamming window and 512-point FFT with the window advance of 5 ms. Resulting spectrograms had dimensions 256×72, and 256×256, respectively. In Fig. 1 is illustrated the process of spectrogram calculation for speech fragments lenght of 1280 ms.

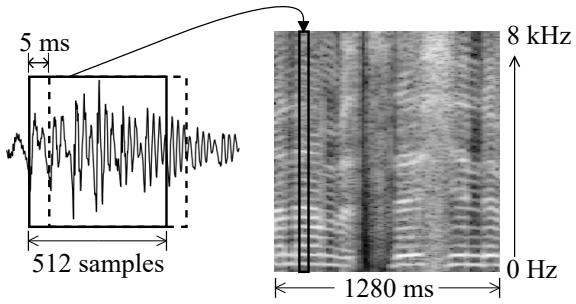

Fig. 1: Illustrated method of spectrogram calculation with parameters of analysis frame and resulting spectrograms dimensions

C. Data Augmentation

For the purpose of training a complex convolutional neural network, the data was expanded by using bootstraping techniques. More precisely, original utterances were downsampled to 14 kHz and 15 kHz (the method was adopted from [7]), a reverberation effect was applied, utterances were reversed in time and additive white and ambient noise was combined with everything previously stated. White and ambient noise were added with *signal-to-noise ratio* (SNR) of 20 dB. The white noise was derived from three different distributions: Gaussian, Laplace and uniform. The ambient noise was taken from the MUSAN dataset [13] and sounds of plane takeoff, keyboard typing and a motorcycle passing by were used. Alltogether, six noise types. The number of annotated speech fragments for each level of augmentation is displayed in Table I. The total number of original and downsampled fragments without noise is 46890 for the 720 ms fragment length and 14328 for the 1280 ms fragment length. When three types of white and ambient noise are added, the total number of fragments for clean and noisy utterances becomes 328230 and 100296 for the 720 ms and 1280 ms fragments, respectively. Finally, when the reverberation effect and the time reversed samples are added to the original and downsampled fragments and when the noise is applied, the database comprises the original clean fragments, the clean fragments with effects, the noisy fragments and the noisy fragments while the total number of fragments becomes 474110 and 144872 for the 720 ms and 1280 ms long fragments, respectively.

TABLE I: Amount of anotated speech fragments for different levels of augmentation

Augmentation type	**Fragment length** [ms]	**Utterances Number**
downsampled	720 (2/3 overlap)	46890
downsampled	1280 (1/2 overlap)	14328
noise	720 (2/3 overlap)	328230
noise	1280 (1/2 overlap)	100296
noise & effects	720 (2/3 overlap)	474110
noise & effects	1280 (1/2 overlap)	144872

downsampled - original and downsampled fragmets
noise - downsampled augmentation type extended with white and ambient noise
noise & effects - combination of downsampled augmentation type extended with reverberation and reverse effect with and without white and ambient noise

D. Baseline SVM Model

As stated above, a simple SVM model has been trained to serve as a reference for the more complex CNN models. Presuming nonlinear feature interactions, a radial basis function (RBF) kernel was used as an extension of the model, to ensure separability between data points in a high dimensional space. The model hyper parameters C and γ were tuned by using a grid search algorithm and by narrowing the range of values that C and γ should have. For the parameter C, the final range of values was $[3, 5]$ and for γ was $[0.005, 0.012]$.

The model was validated through 4-fold cross validation where each fold comprised train and test partition. Partitions in each fold were stratified by gender. The train partition was built from all utterances of a randomly selected four male and four female speakers. The remaining speakers (one male and one female) were included in the test partition. Such partition

organisation accomplishes a type of gender-stratified-speaker-independent cross validation evaluation.

E. CNN Model

The convolutional neural network comprises convolutional and dense layers. Three sequentially stacked convolutional layers define the first portion of the network. In the following description of model's architecture, strides were applied in both time and frequency dimensions of spectrograms. The first layer has 96 rectangular filters with size 7×7 and stride 3, then the second layer has 256 filters with size 5×5 and stride 1 and the third layer has 256 filters with size 3×3 and stride 1. After each convolutional layer max-pooling was applied with kernel 2×2 and stride 2. The aforementioned convolutional layers are used for custom feature extraction where the neural network aims to learn its own features throughout training. The second portion of the model consists of two dense layers with 1024 neurons which perform the classification. The final decision is made on a final dense layer with seven output neurons corresponding to seven emotion classes. The outline of the described architecture is presented in Fig. 2 with annotations of the data dimensions after each of the convolutional layers. ReLU activation has been used at three points in the model, after the third convolutional layer and after each of the dense layers. The high number of model parameters (7.626.848) along with the low number of speakers and spoken utterances in the dataset can result in poor generalisation of the model, with overfitting to specific speakers' utterances from the training partition. To accomplish better generalisation, several regularisation techniques were applied. Dropout regularisation [14] was used before and after the first dense layer and after the second dense layer. For convolutional layers, batch normalisation is used as a regularisation technique [15]. Finally, the RMSprop optimiser is used to optimize the softmax cross entropy loss function and update the model's parameters in the training phase. All the hyperparameters stated above were manually picked in the process of fine tuning of the model. Layers were jointly trained from a random state where weights were initialized by using Glorot random uniform initialization [16]. Additionally, step learning rate decay was applied which lowered learning rate by factor 0.9 every 10 epochs and an early stopping criterion was used to finish training at an optimal moment.

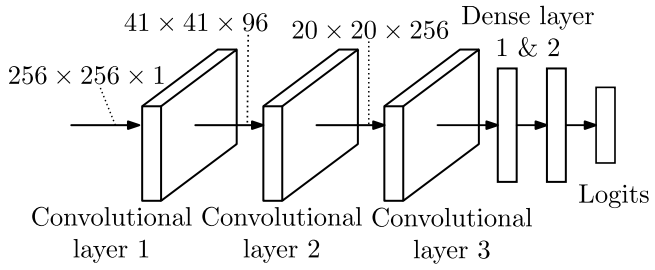

Fig. 2: Convolutional neural network architecture

For training and evaluation of the CNN model, the dataset was partitioned in a similar way as for the baseline SVM model, except for a validation partition created for the purposes of tracking the training performance of the model. In the end, training partitions were defined with three random male and female speakers, and remaining speakers were randomly organised in validation and test partition. Same as in the case of the baseline SVM model, the partitions were gender-stratified and evaluation was speaker-independent.

IV. Results

Table II summarises performances of all the trained models. As it was stated previously each model was trained with features that were calculated on speech fragments of different lengths. Additionally, it was explored how different degrees of data augmentation will affect the performance. The first type of augmentation included only ambient and additive white noise, while the second type was extended with reverberation and reverse effects. Finally, the performance of the proposed CNN model (denoted with *minimal* in the Table II) was compared with an AlexNet type model (the number of model filters and nodes in dense layers was reduced relative to the original architecture ([8]) in order to fit in the memory of used hardware). This smiplified AlexNet model is denoted *large* in the Table II. In comparison to the minimal CNN model, the AlexNet has two extra convolutional layers and its total number of trainable parameters without regularisation is 7.634.272. In average, the models reached 58% of accuracy in the training phase before their validation loss metrics started diverging (and training was stopped) . Depending on the model's architecture, the best test performance on the clean data set was achieved for the minimal model CNN-4 (32.28%) and the performance on the augmented data set was the best for large models CNN-11 (34.03%) and CNN-12 (33.17%) where original data set was augmented with additive noise and combination of additive noise and aforementioned effects, respectively. In general, the minimal model has better performance on the clean data set, in contrast to the large model which has higher accuracy in the test phase on augmented data set.

V. Discussion

Results show that a CNN model with higher complexity will have a greater ability to generalise when compared to minimal CNN models. On the other side, SVM models in this research outperform any of the given CNN models. This kind of behaviour is unclear since SVM models are trained on a small portion of handcrafted features in comparison to the CNN models which are able to extract a large number of custom features that are describing a pattern present in the data set. Depending on the length of the utterance fragments, features computed for an SVM model can contain slightly different information amounts and thus the separability of emotions in high dimensional space can increase for longer duration fragments which is observed in the test performance of an SVM model trained on features computed from fragments of

TABLE II: Comparison between the performance of the CNN model described in Section III (minimal) and customized AlexNet model (large). Models were trained with the datasets that have different augmentation levels (relative to the base dataset described in Section III)

Model	**Architecture**	**Fragment length** [ms]	**Data augmentation type**	**Train accuracy** [%]	**Test accuracy** [%]
SVM-1	—	720	—	—	52.01
SVM-2	—	1280	—	—	64.33
CNN-1	minimal	720	downsampled	50.18	30.64
CNN-2	minimal	720	noise	58.76	29.29
CNN-3	minimal	720	noise & effects	55.59	30.22
CNN-4	minimal	1280	downsampled	56.27	32.28
CNN-5	minimal	1280	noise	59.22	28.96
CNN-6	minimal	1280	noise & effects	75.35	28.81
CNN-7	large	720	downsampled	45.72	29.15
CNN-8	large	720	noise	59.05	31.32
CNN-9	large	720	noise & effects	58.87	30.64
CNN-10	large	1280	downsampled	57.51	29.55
CNN-11	large	1280	noise	62.71	34.03
CNN-12	large	1280	noise & effects	61.71	33.17

downsampled - original and downsampled fragmets
noise - downsampled augmentation type extended with white and ambient noise
noise & effects - combination of downsampled augmentation type extended with reverberation and reverse effect with and without white and ambient noise

720 ms and 1280 ms. The same behaviour is not observed in the case of the minimal CNN model where better evaluation results are achieved with shorter fragments. Regarding the augmentation level, it is observable that the test accuracy is higher for an augmented data sets in comparison to the clean sets which indicates that the EmoDB is still a small data set which does not contain a sufficient number of inter-speaker and intra-speaker variations of emotional speech and thus complex models do not have wide enough variety (and number) of examples of an emotional speech to generalise well between speakers and emotions. In between types of augmentation, better results were achieved for an augmentation with the additive noise only while the combination of an additive noise and effects is slightly inferior. It should be further explored why the effects degrade affective information since reverberation effects occur in real life situations while time reversing should not change the frequency content of an utterance or its statistics.

VI. Conclusion

The trained models are defined by the most widely used architecture in the domain of computer vision aided with deep learning. Results show that there is still room for significant improvement both with an architecture upgrade with recurrent layers and better understanding of the entanglement between data and the specific model architectures. Additionally, data sets with higher number of speakers and utterances per speaker should result in better generalisation of an CNN model, and would negate the need for data augmentation (which in the case of speech isn't as straightforward as in computer vision applications). Finally, further research should aim on devising specific model architecture used for the task of emotion classification in speech modality since models in this paper were constructed by using best practices from the domain of computer vision that might not be the optimal for the speech modality. Further work should continue to explore the model design to achieve similar or better performance than the SVM model which is relatively high when it is taken into account that the classification problem in this paper contained seven independent classes.

VII. Acknowledgements

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Feature Selection for Improved Classification of Protein Structures

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***Abstract* - Many research groups work on analyzing the structures of protein molecules since that may help to gain knowledge that can be used for designing drugs. To understand the protein structures, it is very important to categorize them in corresponding classes. Therefore, protein classification is one of the main topics in bioinformatics. In this paper, we propose an approach for classifying protein structures. First, the characteristics of the proteins are extracted in corresponding feature vectors. Then, feature selection is made in order to reduce the dimensionality of the dataset, as well as to keep only the most significant features. For feature selection, we use various feature selection techniques. Finally, we build models by using different classification methods. The proposed approach is evaluated in details and also the benefits of applying feature selection are analyzed.**

Keywords - protein structures; protein classification; feature selection

I. INTRODUCTION

One of the most important counterpart in our bodies are proteins, because they regulate the processes in the cells. Namely, proteins take part into various interactions, and by allowing the useful processes or disallowing the bad ones, we may regulate the processes in the humans' organisms. Because of the significance of this, and the impact it may have on humans' life, there is a huge number of research institutions that works on analyzing the protein molecules that may result in understanding the functions that they have. Due to the importance of understanding the proteins, different techniques are developed for determining their structures, which directly defines the functions that they may have. After determining some protein structure, the researchers deposit it in the Protein Data Bank (PDB) [1], [2]. However, the knowledge about the structure of proteins is not enough, because we may still not know what their functions are. In order to discover the functions of proteins, one approach is to make classification of these structures, so the structures that belong to a same class are expected to have the same functions. For that purpose, different types of methods for classification of proteins are introduced by various research groups. However, the main problem is the speed of these methods, because they are not able to make classification of proteins with a speed as it is desired, in order to be able to classify all structures that are determined and stored in PDB. This evidently displays the necessity for developing novel methods that would afford protein classification with suitable accuracy and in a fast way.

The state of the art literature offers variety of methods for protein classification. One of the most accurate method is SCOP (Structural Classification Of Proteins) [3]. This method is considered as very accurate because the classification of proteins is made manually by domain experts. Nevertheless, this manual classification is very slow. This could be escaped by using methods where the decisions are made in automatic or semiautomatic manner. Such method is CATH (Class, Architecture, Topology and Homologous superfamily) [4], which tries to make classification in automatic way, and if it is not possible to be done, then the classification is done manually.

Needleman–Wunch [5], BLAST [6] and PSI-BLAST [7], are among the methods where the protein classification is done by making sequence alignment. However, the sequence alignment methods are not able to recognize similar proteins that have similar tertiary structure, if their sequences are not that similar. Therefore, besides the methods that perform alignment of proteins' primary structures, also there are methods that make alignment of the proteins' tertiary structures. CE [8], MAMMOTH [9] and DALI [10] are among the most commonly recognized methods from this category. Of course, there are also methods that make alignment of proteins' primary and tertiary structures as well, like the SCOPmap [11] and FastSCOP [12] methods do.

The methods that make alignment of protein sequences or structures are time consuming. Therefore, also there are methods where the proteins' sequences and structures are not directly compared, instead of that their features are extracted, and then the comparison is done by making comparison of the feature vectors. For example, there are methods where the features of the proteins' sequences [13] and structures [14] are extracted. These methods extract the features of the protein sequences and/or structures, thus each protein is presented by its feature vector. Then, by using some classifier, the proteins are classified based on their feature vectors. By making feature extraction, a significant reduction of the information is made, thus the information that are processed during classification is significantly lower thus decreasing the classification time. Therefore, in our research we focus on the methods from this category. In [15], we introduced several approaches for extracting proteins' feature vectors. Based on the extracted features, the proteins could be classified by using some classifier.

Before building prediction model by using some classification method, selection of the most significant features could be done in order to rise the accuracy of the models, and also to shrink the training and testing times. In [16], we used different feature selection techniques in the process of protein binding sites prediction, with the aim to cut the number of features of the proteins' residues that would be used for predicting which residues could be involved in interactions. The feature selection techniques could be separated into wrapper and filter techniques. With the wrapper techniques, various subsets of features are observed and some classifier is applied to assess the generated models for the examined subsets of features. With the wrapper techniques, the final objective function (like classification accuracy, AUC-ROC, correlation coefficient) is enhanced. Contrary to that, by using filter techniques, we do not aim to improve the final objective function, but we are making selection of the features based on another criteria. In this research, the number of extracted features is considerably greater than in [16], therefore the number of subsets of features that should be examined drastically increases. For that purpose, in this study we focus only on the filter techniques. These techniques could be techniques that rank the features independently or techniques that examines subsets of features. The former try to select the features that are highly correlated with the class feature, but they do not analyze the dependency among the designated features. On the other side, the techniques that evaluates subsets of features are trying to find the best subset of features that holds features that are highly related with the class feature, but also has low dependency among the features in the particular subset. In this study we take into consideration techniques from both types (individual ranking of the features and evaluating subsets of features).

In this study we introduce an approach that could be used for classification of protein structures, where selection of the features is made in order to filter only the most important features. The classification of proteins is done in the following way. First, the features of the protein structures are extracted. For that purpose we use our protein voxel-based descriptor [15]. Next, selection of the features is made in order to filter the most significant features that would be used further in the classification stage. For that purpose we use several filter techniques for making feature selection. Finally, we generate classification model that would make forecasts in which class a given protein structure belongs to.

The rest of this research paper is structured in the following way. First, in Section 2 we present our approach for classification of protein structures. Detailed description of the extraction of the protein voxel-based descriptor [15] is presented. Also the feature selection techniques that are used are briefly described. In Section 3, we present the results of the evaluation of our approach, where different feature selection techniques and classification methods are used. In the same section, we also present the results that are obtained without making feature selection in order to show the benefits of applying the feature selection techniques. Section 4 summarizes the key conclusions and specifies several tips for additional advances.

II. OUR APPROACH

In this study we introduce a novel approach that could be used to classify unlabeled protein structures. It is done in three steps. First, the features of the proteins are extracted and incorporated in the corresponding feature vectors. In order to do that, in this research we extract the protein voxel-based descriptor [15] that holds features of the primary, secondary and tertiary structure of protein. In this way, for each protein a feature vector is generated, thus each protein is presented by a point in the feature vector space. Since the descriptor has larger number of features, thus, in the second step we perform reduction of the number of features by making selection of the most significant ones. For that aim, we use several filter techniques for feature selection. Finally, in the third step, by using only the designated features, classification model is produced that makes estimates in which class a given unlabeled protein fits in.

A. Extraction of the Features of the Protein Voxel-Based Descriptor

In this study we consider features about the primary, secondary and tertiary structure of the proteins. The primary structure, also known as sequence, is defined by the order in which the amino acid residues are connected in a corresponding protein chain. The secondary structure defines how these amino acid residues are positioned in the three-dimensional space, thus forming some particular local confirmations in the space. The amino acid residues have several atoms that are positioned in the 3D space in a particular way, so the tertiary structure shows how the atoms of the protein are distributed in the space. For the primary and secondary structure, we take into account the same features that are used in [17]. Concerning the features of the tertiary structure, we apply the voxel descriptor [18] that is originally proposed for 3D objects' retrieval. In this research, we apply that descriptor for presenting the distribution of the atoms of the protein which is very complex task.

As it was already described, the primary structure of the protein corresponds to its sequence and defines from which amino acids it is composed and in which particular order. We count how many residues the protein has from each amino acid and the ratio is calculated for each amino acid, so because there are 20 amino acids, we obtain 20 features from this. One very important property of the amino acids is their hydrophobicity, which shows the preferences the particular amino acid to be closer to the center of the protein or its surface. Therefore, we extract one feature that shows the ratio of the hydrophobic amino acid residues. Besides the order how the amino acid residues are connected, it is also important how the chain is placed in the space. Thus, the amino acid residues form particular local conformations, known as secondary structure elements, which could be helices, sheets and turns. We extract 3 additional features that indicate how many secondary structure elements the inspected protein has for the 3 types of secondary structure elements. Regarding helices, there are 10 types of helices, thus we extract 10 features that present the ratios of occurrences for each type. In this way, we obtain 34 features from the primary and secondary structure of the protein, as in [17].

For describing the tertiary structure, we use the voxel descriptor [18] that is introduced for the purpose of retrieving similar 3D objects. In this research, we have very difficult task because protein structures are very complex, and small changes in their structure make big differences regarding their functions and the belonging of the proteins in particular classes. The features of the protein tertiary structure are extracted as described below.

As it was mentioned before, proteins are composed of amino acid residues, which are further composed of several atoms. Because we treat the protein in the same way as the 3D objects are treated in 3D object retrieval, therefore, first we have to obtain a mesh model of the inspected object, the inspected protein in this case. In order to do that, the atoms of the protein, which could be viewed as spheres with a particular radius, are triangulated, thus each atom is presented by a set of connected triangles. In order to obtain descriptor that is invariant to translation and scaling, after obtaining the mesh model, it is translated and scaled thus the center of mass is placed in the center of the coordinate system and the mesh model is located in a sphere with radius equal to 1.

The next step is voxelization, from where the name of the descriptor comes from. Voxelization can be seen as a process of discretization of the 3D space into cubes called voxels. For each voxel, we calculate the fraction of the total area of the mesh model that is inside it. This is done in the following way. Each triangle of the mesh model is divided into smaller connected triangles with a same area equal to $\delta = S_j / p_j^2$, where S_j is the area of the triangle that is divided, while p_j^2 stands for the number of smaller triangles obtained after the division of the initial triangle. The parameter p_j is calculated as

$$p_j = \left\lceil \sqrt{p_{\min} \frac{S_j}{S}} \right\rceil, \qquad (1)$$

if the examined triangle has vertices in several voxels. Otherwise, if the examined triangle has vertices in a single voxel, then the triangle is not further divided, thus p_j=1. In (1), S is the area of all triangles, while p_{min} is a parameter that defines the level of approximation. As suggested in [18], in this study we set p_{min} to 32000. After making the division of the triangle, for each of the novel triangles that are obtained, we increment the total area by δ for the corresponding voxel in which the triangle belongs to.

The output of the voxelization step is a three-dimensional array, and it could be used directly as descriptor. Nevertheless, in this way the descriptor would have too many features. Another even bigger problem is that this descriptor would not provide invariance to rotation, meaning that if a given protein structure is rotated, we would obtain different descriptor from the case without making that rotation. In order to overcome that, over the array obtained as output from the voxelization, next we apply 3D Discrete Fourier Transformation. The output from this transformation is again a three-dimensional array, but with this array invariance to rotation is provided.

In the next step, first the indices of the voxels are shifted thus the central voxel has indices (0, 0, 0). Then, the non-symmetrical features that correspond to voxels whose indices (p, q, s) satisfy $1 \leq |p| + |q| + |s| \leq N/2$ are filtered, where N defines how many slices are made per coordinate during voxelization. The features are then normalized, so each of the features that are considered are divided by the value attained for the central voxel, which is the voxel with indices (0, 0, 0). For more detailed description of the extraction of the voxel descriptor, the interested reader is referred to [18]. In this way we get 416 features for the tertiary structure, thus resulting in a descriptor with 450 features at all. Finally, we perform normalization of the features, thus each feature attains values in the interval [0, 1].

B. Feature Selection

Before making the model for estimating in which class a given query protein fits in, we may apply selection of the features, especially because the number of features obtained in the feature vector is high (450 features as described before). In that way, not only reduction of the dimensionality of the dataset would be performed, but also it could help to improve the accuracy of the models, and also the time needed for generating model and making predictions could be reduced. In our previous work [16] we already made intensive analysis by applying different types of techniques for feature selection. However, in [16] the techniques were applied for selecting the most important features of the amino acid residues that could help to distinguish the residues that are counterpart in a binding region from the remaining residues. In this study we are not solving the same task as in [16], so here we apply these techniques over the proteins' feature vectors in order to make better predictions in solving the task of protein classification.

The literature provides various techniques that could be used for feature selection. In general, these techniques could be separated into wrapper and filter techniques. The wrapper technique consider some particular classification method, and by using this method different subsets of features are examined based on the accuracy that is attained by applying that particular classifier. In this way, the selection of the optimal subset of features is made by making optimization of the final objective function, which is the evaluation measure that would be later used for estimating the performances of the obtained models. On the other side, with filter techniques another objective function is optimized during feature selection. In [16], we used both filter and wrapper techniques. However, the number of features in that case was significantly lower than the number of features that we have in this study. So, in this research we focus on the filter techniques.

By using filter techniques, there are two options how the features would be examined. One possible way is to examine all the features and to estimate the dependency among the features and the class feature. In this way, the features are examined separately. However, it could result in selecting features that are highly related with the class feature, but also have high correlation between them, thus resulting in a set of features that is redundant. Therefore, the second option is not only to analyze the dependency

with the class feature but also to consider the dependency among the selected attributes thus reducing the redundancy. This could be done if the features are not studied individually, but subset of features are examined.

For estimating the significance of the features, we use two measures that are widely used in building decision trees, which are the information gain [19] and gain ratio [19], [20]. With the information gain we can estimate how much the entropy in the dataset reduces after selecting a given feature. This measure gives favor to features that have more different values, so therefore the gain ratio is calculated by dividing the information gain of the feature with the entropy, thus escaping this problem. We also use the Pearson's correlation coefficient (PCC) [21] to estimate the correlation of the individual features with the class feature.

In this research we also use an instance based learning technique named as Relief [22]. This techniques considers *k*-nearest neighbors from each class, and then the distances with the neighbors from other classes are taken as positive and the distances with the neighbors from the same class are considered as negative. In this study we take into account 10 nearest neighbors from each class.

From the techniques that examine subsets of features we use a greedy stepwise selection. This technique belongs to the group of sequential techniques because it makes sequential insertion or deletion of the features in the current optimal set. It can search the optimal subset of features in forward or backward direction. In this research we apply it in a forward direction, thus we start with an empty set of features and the features are iteratively inserted based on the increase in PCC in the newly obtained supersets that are obtained by inserting one of the remaining features in the subset that is currently the most optimal one. After finding the best superset, in the next iteration it is considered as the optimal one, and we try to expand it with some of the remaining features. In the last iteration, the set contains all the features, so finally we rank the features based on the iteration when they are included in the optimal set.

For all the techniques used for feature selection, in this study we make selection of the ten most significant features, thus the feature vectors are reduced from 450 to 10 features.

C. Generating Classification Models

After extracting the features and selecting the most relevant ones, the third step is to generate a model that would make predictions in which class the query protein belongs to. In this study we use several classification methods that are widely used: C4.5 [19], Naive Bayes [23], Bayesian Network [24] and *k*-nearest neighbors (knn) [25] classification method. For the knn method, we considered *k*=1 nearest neighbor.

III. EVALUATION

Next, we present the results obtained from the evaluation of the proposed approach. For that aim, we considered a dataset that holds knowledge about the classification of proteins deduced by the SCOP method [3]. The dataset is obtained in the following way. We randomly selected 6145 protein chains from 150 domains from the SCOP hierarchy. The distribution of these chains in the domains is almost uniform. The domains in this case correspond to the classes in which the proteins will be classified with our approach. Then, we separated the dataset into two parts: training set that contains 90% of the chains (5531 chains) and test set that contains 10% of the chains (614 chains). To estimate the prediction power of the attained models, we used the classification accuracy as evaluation measure.

We made experiments by applying the feature selection techniques and the classifiers mentioned above. The results are presented in Table 1. We also made experiments without making feature selection, thus keeping all 450 features in the protein voxel-based descriptor. The aim of these experiments it to show the benefits of making feature selection. The results show that in almost all cases, by making feature selection better results are achieved than from the case without applying feature selection. Exception from this are the models obtained with the C4.5 classifier. The results indicate that by using Gain Ratio for ranking the features or applying the Relief technique, significantly lower result are obtained in all cases (with all classifiers). On the other side, by using the Info Gain and Pearson's correlation coefficient for evaluating the features, or by using the greedy stepwise forward selection better results are obtained, and they are very near one to each other. Regarding classifiers, the maximal classification accuracy was achieved by using C4.5, Bayes Net and knn, while the best results with Naïve Bayes classifier was a little bit lower. Concerning feature selection techniques, by using Gain Ratio to rank the features or by using the Relief technique significantly worse results are obtained. The remaining techniques in general introduced improvements in the classification accuracy. For example, by using Naïve Bayes the highest classification accuracy is obtained by using the Pearson's correlation coefficient to evaluate the individual features, and by applying greedy stepwise forward selection. Regarding Bayes Net, the best result is achieved with greedy stepwise forward selection, while for the knn classifier best results are attained when Info Gain was used as a criteria to rank the features.

TABLE I. RESULTS FOR THE CLASSIFICATION ACCURACY BY USING DIFFERENT FEATURE SELECTION TECHNIQUES AND CLASSIFICATION METHODS

Feature selection technique	**Classification method**			
	C4.5	***Naïve Bayes***	***Bayes Net***	***knn***
Without feature selection	**97.39**	83.39	81.11	79.80
Info Gain	96.42	94.95	94.30	**97.39**
Gain Ratio	78.99	75.24	79.32	79.97
Pearson's correlation coefficient	95.44	**95.11**	96.58	97.07
Relief	78.50	75.41	79.48	79.80
Greedy Stepwise	96.25	**95.11**	**97.39**	97.07

On the following link, information about the protein chains that are used in the experiments can be found. On the same link, the interested reader may also find information about the features that have been selected by each feature selection technique.

In [15], we made comparison of the protein voxel-based descriptor with several approaches found in the literature. The evaluation was made on several datasets. The general conclusion from the analysis was that the protein voxel-based descriptor obtains better results from some of the approaches, but most of the approaches that were used in the comparison outperform the protein voxel-based descriptor. Therefore, in this research we wanted to improve this descriptor by making selection of the most relevant features.

IV. CONCLUSION

This research paper introduced an approach that provides classification of proteins with making selection of the most important features. First, the features of the primary, secondary and tertiary structures of proteins are extracted and thus the feature vectors are generated. For that purpose we used the protein voxel-based descriptor. In order to reduce the dimensionality of the dataset, various feature selection techniques were applied. We considered techniques that evaluate the features individually, as well as techniques that evaluates subsets of features. From the first category, we made ranking by using the Info Gain, Gain Ratio and Person's correlation coefficient to rank the features, and we also used the Relief technique. From the second category, we used a technique that makes greedy stepwise forward selection.

For evaluation purposes, we used a dataset that holds knowledge how the protein chains are distributed in different domains according to the SCOP method. In general, better results are obtained by applying selection of the features compared to the case when all the features are preserved. Exclusion from this was the case when C4.5 classification method was used for model induction. The results showed that by using Gain Ratio as a measure of the importance of the features, or by using the Relief technique, less accurate models are generated. The other feature selection techniques lead to improvements in the classification accuracy of the models.

This study could be continued with several variations in order to enhance the accuracy of the models. Regarding feature extraction, in addition to the protein voxel-based descriptor, we plan to make study by using other proteins' feature vectors. Regarding the second and third step, we plan to apply additional feature selection techniques and classification methods. For both feature selection and model induction, in addition to the feature selection techniques and classifiers based on classical sets, we think to consider such which are based on fuzzy sets in order to overcome the limitations of classical sets.

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Analysing the Influence of Two Similarity Metrics on the Ant Colony Optimisation Based Fuzzy-Rough Feature Selection Algorithm

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***Abstract* - As the amount of the data increases in volume, veracity, and value, and thus the number of the features rises, so the standard algorithms will find it difficult to process the data without help of huge computer power. However, the feature selection methodology offers help for this issue. In its core, the feature selection tries to find the most predictive input features for the output (target) feature. Feature selection combined with a hybrid variant of rough sets, fuzzy-rough sets provides fuzzy-rough feature selection that could offer better results in this task. To help fuzzy-rough methods to find optimal subsets, attempts have been made using feature selection mechanism based on Ant Colony Optimisation (ACO). This approach is applied to the problem of finding optimal subset of features in fuzzy-rough data reduction process by using different similarity metrics. In this paper, we investigate the influence of two fuzzy similarity metrics on the performance of the feature selection ACO strategy. The investigation is made by using several datasets. We experimentally compare several classical classification algorithms by using the AUC-ROC evaluation measure. Additionally, we show the benefits of making feature reduction.**

Keywords - feature selection; fuzzy-rough; Ant Colony Optimisation; similarity metrics

I. INTRODUCTION

The idea of applying feature selection for a given problem is to reduce the number of features, and in the same time retaining similar accuracy compared to the non-reduced dataset. Reduction of the features, improved accuracy, obtaining models that are compact and easy interpretable, and providing the learning algorithms to operate faster and more effectively are some of the advantages of applying feature selection. When we deal with real time problems, mostly the datasets contain noise and irrelevant features that contribute to further reduction of the model's accuracy. There are many algorithms that can be used for this task, but they can be quite unfeasible for many real datasets. For this purpose, many of the feature selection algorithms involve heuristic or randomized search strategies to reach optimal solution. The results of this is that in many cases the optimal number of features is hard to determine, therefore search strategies are implemented to fulfil this task.

One such search strategy is based on Swarm Intelligence, where the collective behaviours of simple agents interact locally causing patterns to emerge globally [1]. In this way, a collaborative way of solving the problem can arise, without setting any predefined model or centralized control. One such example is the ant colonies, which can find the shortest route between the nest and the food source by adapting to the environment and without using visual information or global model. The technique based on this analogy is widely known as Ant Colony Optimisation (ACO). So far, this technique has been successfully used to solve number of difficult problems like quadratic assignment [2], traveling salesman problem [3], job-shop scheduling etc. Since ACO technique has no heuristic towards searching the minimal subset, it is very attractive for the feature selection researchers. Many feature selection algorithms employ incremental hill-climbing algorithm to discover minimal subset of features, leading to subsets of non-minimal size. In order to overcome this, the paper investigates the implication of the ACO technique on fuzzy-rough set feature selection process.

Rough set theory (RST) [4] is one of the recent and most distinct approaches for modelling imperfect knowledge. RST can be used for feature selection, by reducing the number of features contained in the dataset using structural methods [5]. RST based algorithms process the given dataset with discretized values by finding a subset of the original attributes using rough sets that are most informative by removing the attributes with minimal information loss. But this doesn't mean that this class of algorithms is perfect, as any algorithm has flaws. One of the problems is that the algorithm knows about the investigated phenomena only from the information given in the dataset. Therefore, the algorithm assumes that dataset is true and accurate reflection of the measured phenomena, which of course in many cases is not true. Another important factor is reliance on discrete data for classification, according RST, implies objectivity in the data that is simply not present here [6]. Therefore, a subjective judgment is needed to set up boundaries by the objective measurements, so here, the fuzzy set theory can provide a help for this problem. This branch of RST is known as fuzzy-rough sets (FRS) [7]. The traditional fuzzy based algorithms can be used to handle the lack of sharp distinction of boundaries in the data, while FRS can model vagueness that is a result from a lack of information through set approximations. FRS uses two approximations called lower and upper approximations for

classification of the target feature into disjoint categories. The lower approximation describes the objects that we know with certainty that belong to the subset of interest, while the upper approximation describes objects that possibly belong to the subset. These concepts are combined by the FRS to extend the application of fuzzy set theory using fuzzy similarity metrics [8]. Because the RST uses set of pairs of precise concepts, FRS algorithms considers two fuzzy sets. In order the algorithm to use the advantages of both (fuzzy and rough set) theories, the lower and upper approximations are converted into fuzzy lower and upper approximations. The fuzzy lower approximation has membership degree of 1, belonging to the approximated set of absolute certainty, while the elements members of fuzzy upper approximation have membership values between 0 and 1. This allows the algorithm to handle uncertainty, but the subjective judgments are not entirely removed, since the fuzzy membership functions still need to be defined for application of fuzzy theory. Nonetheless it is still combination of methods that allow high degree of flexibility when working with real datasets, enabling the vagueness and imprecision present in the data to be modelled effectively [9].

This paper work focuses on investigating the influence of two fuzzy similarity metrics on fuzzy-rough feature selection (FRFS) algorithm based on ACO strategy for finding minimal subset of features [10, 11]. As authors stated in [11], to find fuzzy-rough set reducts, it is necessary to use the dependency measure in the stopping criteria. In [11], the authors have used non-rough set related entropy-based heuristics, but they have not investigated the influence of fuzzy-rough set related heuristic on the dependency measure itself and how this influences the whole feature selection process, as it is done in this paper. Furthermore, this also has impact on the size of the reduced set and on the performance of the classification algorithm. The features that hold little or no information related to the class attribute, can be removed [12], and the remaining features are used in the reduced dataset. We investigate how the similarity metrics influence on the ACO strategy to reduce the search space, to find optimal path, and to increase the accuracy of the algorithm. For this purpose, we compare the results obtained using twelve datasets [13] and four classification algorithms (Functional Trees (FT) [14], Self-Organizing Maps (SMO) [15], PART-Rule Induction Algorithm (PART) [16] and Multilayer Perceptron (MLP) [17]).

The rest of the paper is organized as follows. Section 2 provides description of FRFS and ACO techniques. In Section 3, the experimental results achieved by using the two similarity metrics are presented. Section 4 concludes the paper and gives directions for future research.

II. FUZZY-ROUGH FEATURE SELECTION WITH ANT COLLONY OPTIMISATION

A. Defintion of Fuzzy-Rough Feature Selection (FRFS)

RST is considered as an extension of conventional set theory that in the process of decision making includes approximations, i.e., lower and upper approximations. These two concepts are approximations of a vague set by pair of precise concepts. On the other hand, the rough set attribute reduction [18] is filter-based mechanism that helps to extract knowledge from the dataset by retaining the information content and reducing the number of features that are involved. This is done by exploiting the granularity structure of the data, and it doesn't require additional parameters to operate on the data at hand. The technique used to optimize the search for minimal subset, in our case Ant Colony Optimisation technique, provides comprehensible way to analyse the data.

To illustrate the inner working of FRFS algorithm, first we define the concepts of fuzzy-rough theory. For this purpose, let denote with U a nonempty set of finite objects, and A is a nonempty finite set of features such that: $U \rightarrow V_a$ for every $a \in A$. V_a is the set of values that the attribute a may take. A dataset contains descriptive and predictive (target) features, so we denote $A = \{C \cup D\}$, where C is the set of descriptive features and D represents the target feature(s). The class feature $d \in D$ is itself a variable d: $U \rightarrow \{0, 1\}$ such that for sample $x \in U$, $d(x) = 1$ if x has class d and $d(x) = 0$ otherwise. With any $P \subseteq A$ there is an associated equivalence relation $IND(P)$

$$IND(P) = \{(x, y) \in U^2 \mid \forall x \in P, a(x) = a(y)\}. \quad (1)$$

The partition of U generated by $IND(P)$ is denoted as U/P and can be determined as follows:

$$U / P = \otimes\{U / IND(\{a\}) \mid a \in P\}, \quad (2)$$

where $\otimes$ operator is defined as follows for both sets A and B:

$$A \otimes B = \{X \cap Y | X \subseteq A, Y \subseteq B, X \cap Y \neq \varnothing\}. \quad (3)$$

Now, using these concepts, we can define the lower and upper approximation for X, which can be approximated using only the information contained within P. The P-lower and P-upper approximations of the classical crisp set X are given as follows:

$$\underline{P}X = \{x \in U \mid [x]_P \subseteq X\}, \quad (4)$$

$$\overline{P}X = \{x \in U \mid [x]_P \cap X \neq \varnothing\}. \quad (5)$$

where $[x]_P$ denotes the values of the attributes in P for a given object x.

The tuple defined with (4) and (5) is rough set. The fuzzy lower and upper approximations are defined as

$$\mu_{\underline{P}X}(x) = \sup_{F \in U/P} min(\mu_F(x), \inf_{y \in U} max\{1 - \mu_F(y), \mu_X(y)\}), \quad (6)$$

$$\mu_{\overline{P}X}(x) = \sup_{F \in U/P} min(\mu_F(x), \sup_{y \in U} min\{\mu_F(y), \mu_X(y)\}). \quad (7)$$

The definitions of the supremum (sup) and infimum (inf) of the set of fuzzy numbers are given in [19]. For implementation purposes, we consider only $y \in U$ where $\mu_F(y)$ is non-zero and y is fuzzy member of class F. The tuple defined with (6) and (7) is called fuzzy rough set. One possible improvement of the reduction process is focused on fuzzy tolerance metrics [9], where alternative definitions of lower and upper approximations can improve the process of feature selection [20]. In this case,

T-transitive fuzzy similarity metric is used to approximate fuzzy concept *X*:

$$\mu_{\underline{R_P X}}(x) = \inf_{y \in U} I(\mu_{R_P X}(x,y), \mu_X(y)), \quad (8)$$

$$\mu_{\overline{R_P X}}(x) = \sup_{y \in U} T(\mu_{R_P X}(x,y), \mu_X(y)), \quad (9)$$

where *I* is a fuzzy implicator, *T* is a t-norm and R_P is fuzzy similarity metric induced by the subset of features *P*:

$$\mu_{R_P X}(x,y) = \bigcap_{a \in P} \{\mu_{Ra}(x,y)\}, \quad (10)$$

where $\mu_{Ra}(x, y)$ is the degree to which objects *x* and *y* are similar for feature *a*. In order to calculate $\mu_{Ra}(x, y)$ and preserve the *T*-transitivity, several fuzzy similarity metrics can be found in the literature [20]. Two of them defined below are considered in this research.

$$\mu_{Ra}(x,y) = e^{-\frac{(a(x)-a(y))^2}{2\sigma_a^2}}, \quad (11)$$

$$\mu_{Ra}(x,y) = \max(0, \min(\frac{\Delta_a + \sigma_a}{\sigma_a}, \frac{-\Delta_a + \sigma_a}{\sigma_a})) \quad (12)$$

where σ_a is the standard deviation of the attribute *a* and $\Delta_a = a(y) - a(x)$. Both similarity metrics will be evaluated for classification task over twelve benchmark datasets from [13] by using four classifiers. Next, we define the three regions important for each feature selection process. Let *P* and *Q* be equivalence relations over *U*, then we can define the positive, negative and boundary regions as follows:

$$POS_P(Q) = \bigcup_{x \in U/Q} \underline{P}X, \quad (13)$$

$$NEG_P(Q) = U - \bigcup_{x \in U/Q} \overline{P}X, \quad (14)$$

$$BND_P(Q) = \bigcup_{x \in U/Q} \overline{P}X - \bigcup_{x \in U/Q} \underline{P}X. \quad (15)$$

Now, we can use these three concepts to reduce the dataset and to provide efficient classification. The positive region contains all the objects *U* that can be classified to classes *U*/*Q*, with information in *P*, while the negative region compromises from objects that cannot be classified to classes of *U*/*Q*. And finally, the boundary region contains objects that can possible, but not certainly, be classified in this way. These three concepts also can be used for discovering dependencies between descriptive and predictive features.

For fuzzy rough set, the definition of these three concepts is as follows:

$$\mu_{POS_{R_P}(X)}(x) = \sup_{X \in U/Q} \mu_{\underline{R_P X}}(x), \quad (16)$$

$$\mu_{NEG_{R_P}(X)}(x) = \inf_{X \in U/Q} \mu_{\overline{R_P X}}(x), \quad (17)$$

$$\mu_{\mathrm{BND}_{R_P}(X)}(x) = \mu_{\overline{R_P X}}(x) - \mu_{\underline{R_P X}}(x). \quad (18)$$

From fuzzy perspective, object *x* belongs to the positive region only if the underlying corresponding class do so. So, object *x* will not belong to the positive region only if the corresponding class it belongs to is not a constituent of the positive region. Same applies for negative and boundary regions.

The dependency in rough theory is defined as: $Q \subset A$, it is said that *Q* depends on *P* in a degree *k* ($0 \le k \le 1$), denoted as $P \Rightarrow_k Q$, if:

$$k = \gamma_P(Q) = \frac{|POS_P(Q)|}{|U|}, \quad (19)$$

where $|U|$ indicates the cardinality of set *U*. Similarly, the fuzzy dependency function is given with (20).

$$\lambda_P(Q) = \frac{\sum_{X \in U/Q} U_P(X)}{|U/Q|} \quad (20)$$

Using (20), we can evaluate the overall uncertainty by averaging the uncertainty of all decision concepts. Based on the value of *k*, *Q* is related with *P* as follows: if k=1, then *Q* totally depends on *P*, if *k* is between 0 and 1, then *Q* partially depends on *P*, and if k=0, then *Q* does not depend on *P*. If the sum function is 1, this means that *x* belongs to the positive region, otherwise is 0. If $Q = \{a, b\}$ or contains two fuzzy features, objects could belong to many equivalent classes, the Cartesian product of *U*/*Q* must be considered in determining *U*/*Q*. Since there are multiple features in a given dataset, calculating the dependency when the features are removed from the set, the algorithm can estimate what features must be removed. If the change in dependency is high, the more significant the feature is, thus it is kept in the dataset, and otherwise the feature can be removed. Now we can define the concept of minimal subset or reduct.

The reduct is defined as minimal subset *R* of the initial feature set *C*, in a such way that for a given set of features *D*, satisfies the condition $\gamma_R(D) = \gamma_C(D)$. *R* is minimal if $\gamma_{R-|a|}(D) \neq \gamma_R(D)$ for all $a \in R$. Mathematically, the collection of all reducts is represented with:

$$R_{all} = \{X \mid X \subseteq C, \gamma_X(D) = \gamma_C(D); \gamma_{X-|a|}(D) \neq \gamma_X(D), \forall a \in X\}. \quad (21)$$

For the task of feature selection, a reduct minimal cardinality is ideal to search for, as stated in [9]. This means locating a minimal subset of elements $R_{\min} \subseteq R_{all}$:

$$R_{\min} = \{X \mid X \in R_{all}, \forall Y \in R_{all}, |X| \le |Y|\}. \quad (22)$$

Searching the optimal path usually is done by hill-climbing algorithm, which sometimes may lead to non-minimal size. Therefore, ACO technique can be implemented to improve reduct search.

B. Ant Colony Optimisation (ACO)

The search for the optimal feature subset using the ACO methodology, requires the given problem to be represented as graph, where the nodes of the graph are representing the features and the edges between them denoting the selection of the next feature. The ant

traverses through the graph in which minimum number of nodes are visited that satisfies the predefined criteria. Then, the ant terminates its travelling and outputs the subset of features (the nodes that she visited) as candidates for reduction. The criteria for stopping could be any heuristic, for example entropy-based measure [7] or fuzzy-rough set similarity metric [21]. Then, the heuristic attractiveness and edge pheromone level are combined in so called probabilistic transition rule [11], which represents the probability of an ant at feature i to choose to travel to feature j at time t:

$$p_{ij}^{s}(t) = \frac{[\alpha_{ij}(t)]^{\chi} \cdot [\beta_{ij}(t)]^{\delta}}{\sum_{l \in J^{s}_{i}} [\alpha_{il}(t)]^{\chi} \cdot [\beta_{il}(t)]^{\delta}}, \quad (23)$$

where s is number of ants, J^{s}_{i} is the number of unvisited features, β_{ij} is the heuristic attractiveness of choosing the next node j when at node i, and α_{ij} is the amount of virtual pheromone on edge (i, j) [11].

The process of FRFS with ACO can be described in several steps that starts with generating number of s ants, so that each ant starts with one random feature. It is also possible to set the number of ants to be equal to the number of features in the dataset, meaning that each ant starts different path construction. Considering the initial conditions, the ants travel over the nodes in the graph using (23), until the stopping criteria is satisfied. The optimal feature subset is searched using the ant traversal thought the graph where a minimum number of nodes are visited that satisfies the traversal stopping criterion [11]. The resulting subsets are gathered and then evaluated. If an optimal subset has been found or the algorithm has executed for a certain number of times, then the process stops and outputs the best subset of features. As we previously stated, to tailor this mechanism to find rough set reducts, it is necessary to use the fuzzy similarity metrics as stopping criteria, and therefore the investigation of the influence of these similarity metrics is very important. If no condition is met, then α_{ij} is updated, a new set of ants is created, and the process starts again. If we want to modify this mechanism, it is necessary to use the dependency measures given by (9) as stopping criteria. With this, the ant will stop building the set of features when dependency reaches 1. As it is stated in [11], it may be more useful to employ a non-rough set related heuristic for this purpose, in order to avoid the pitfalls of the QuickReduct style search [9].

III. Experimental Results

In this section, we present the results from the experimental evaluation of the two fuzzy similarity metrics denoted as Sim_1 (11) and Sim_2 (12) using ACO search algorithm in FRFS.

We use Łukasiewicz T-norm as recommended in [22] to produce fuzzy T-equivalence metric. The Łukasiewicz T-norm is defined as $\max(x + y - 1, 0)$, while the Łukasiewicz T-norm fuzzy implicator is defined with $\min(1 - x + y, 1)$.

The results from feature reduction with FRFS with ACO algorithm over the twelve datasets are given in Table 1. Table 1 holds the following information: number of objects, number of features in the original dataset, and number of features after making feature selection with Sim_1 and Sim_2 similarity metrics. The results from Table 1 depicts clear pattern regarding the comparison of Sim_1 and Sim_2 similarity metrics, namely Sim_2 reduces the number of features more significantly. However, this doesn't mean that this fuzzy similarity metric is more efficient than Sim_1.

Each dataset is reduced by making feature selection, and then the objects are classified by using a particular classifier. In Table 2 and Table 3 we present the experimental results by using four classification algorithms in combination with the two similarity metrics. In the first experiments (Table 2), the entire set was used for both training and testing, while in the second experiments (Table 3) 10-fold cross validation is made. Table 2 depicts improvement only for two datasets (Breast Cancer and Credit-g) by making feature selection. For the datasets Dermatology, Glass, Ionosphere, Mushroom and Waveform, although we reduce the number of features (in some cases up to 80%), the results for AUC-ROC remain the same for both similarity metrics. There are also datasets, like Water 1-4, where a reduction up to 90% was made, but these reductions lead to lower AUC-ROC. If we compare the classification algorithms, it is noticeable that FT and SMO classification algorithms are the most affected by the feature selection process.

More important is to see how the feature selection affects the predictive power of the classification algorithm on unseen data, which could be seen from Table 3. As expected, the results show that higher AUC-ROC is obtained when using the same data for both training and testing than by making predictions for unseen samples. Further analysis shows that for Breast Cancer (for which Sim_2 is much better than Sim_1), Credit-g (for both similarity metrics better results are obtained than for the unreduced dataset) and Mushroom dataset the AUC-ROC is improved by making feature selection.

TABLE I. Feature Selection over the Twelve Datasets by Using Similarity Metrics Sim_1 and Sim_2.

Dataset	#Objects	#Attributes in the original set	#Attributes in the reduced set	
			Sim_1	Sim_2
Breast Cancer	286	10	6	6
Credit-g	670	21	12	9
Dermatology	366	34	14	14
Glass	214	9	9	8
Heart-log	270	13	10	5
Ionosphere	365	34	8	4
Mushroom	8124	34	6	6
Water 1	218	116	16	6
Water 2	218	116	21	7
Water 3	201	116	25	8
Water 4	218	116	23	8
Waveform	5000	40	15	7

TABLE II. EXPERIMENTAL RESULTS FOR AUC-ROC ON THE ORIGINAL AND REDUCED DATASET BY USING THE ENTIRE SET FOR TRAINING AND TESTING. BOLDED RESULTS DENOTE AN INCREASE COMPARED TO THE RESULTS ON THE ORIGINAL DATASET. UNDERLIED RESULTS DENOTE A DECREASE COMPARED TO THE RESULTS ON THE ORIGINAL DATASET. ONLY DIFFERENCES GREATHER THAN 0.05 ARE TAKEN INTO ACCOUNT.

Dataset	Classification algorithm	Breast Cancer	Credit-g	Dermatology	Glass	Heart-log	Ionosphere	Mushroom	Water 1	Water 2	Water 3	Water 4	Waveform
Original set	FT	0.86	0.91	1.00	0.93	0.97	0.99	1.00	0.96	0.98	0.98	0.98	0.98
	SMO	0.73	0.89	1.00	0.81	0.86	0.92	1.00	0.80	0.77	0.75	0.87	0.94
	PART	0.83	0.97	0.99	0.99	0.99	0.96	1.00	0.93	0.94	0.91	0.97	0.99
	MP	0.97	0.95	1.00	0.97	1.00	0.98	1.00	0.93	0.97	0.98	0.98	0.99
Reduced set (Sim_1)	FT	**0.87**	**0.97**	1.00	0.94	0.86	0.78	1.00	0.91	0.93	0.99	0.92	0.91
	SMO	**0.79**	0.88	0.99	0.79	0.79	0.69	1.00	0.56	0.57	0.69	0.82	0.92
	PART	0.77	0.97	1.00	0.98	0.97	0.75	1.00	0.97	0.95	0.93	0.98	0.98
	MP	0.96	0.95	1.00	0.98	1.00	0.79	1.00	0.94	0.99	0.97	1.00	0.98
Reduced set (Sim_2)	FT	**0.87**	**0.97**	1.00	0.92	0.82	0.98	1.00	0.77	0.71	0.71	0.76	0.95
	SMO	**0.79**	0.88	1.00	0.77	0.82	0.50	1.00	0.50	0.54	0.50	0.62	0.90
	PART	0.77	0.97	0.99	0.98	0.92	0.95	1.00	0.74	0.88	0.66	0.95	0.96
	MP	0.96	0.95	1.00	0.98	0.91	0.96	1.00	0.93	0.72	0.94	0.92	0.95

For Heart-log and Water 1-4 datasets lower results are achieved after feature selection. Moreover, from the results in Table 2 we can note that for these datasets over-fitting of the models is made.

IV. CONCLUSION

In this paper, we investigated the influence of two similarity metrics that are used in the process of FRFS with ACO strategy. The evaluation is made over twelve datasets by using four classification algorithms. The models are evaluated using AUC-ROC evaluation measure, and the results show that both similarity metrics greatly effects the outcome of the classification process. As an overall conclusion, we can note that beside a reduction of the number of features, many of the datasets achieved better results for AUC-ROC. Of course, there are datasets for which the number of features was reduced significantly, but it also lead to reduction in classification performance. This is because important features are removed from the dataset, which are highly related to the class attribute.

A further investigating could be done in direction of testing other similarity metrics to improve the FRFS process. Other algorithms for effective backwards search elimination could be considered. Regarding ACO, further research could be make to improve the search process by investigating different heuristics. The investigation of more efficient search techniques may help in solving this problem and to further improve the efficiency of this approach.

TABLE III. EXPERIMENTAL RESULTS FOR AUC-ROC ON THE ORIGINAL AND REDUCED DATASET BY USING 10-FOLD CROSS VALIDATION. BOLDED RESULTS DENOTE AN INCREASE COMPARED TO THE RESULTS ON THE ORIGINAL DATASET. UNDERLIED RESULTS DENOTE A DECREASE COMPARED TO THE RESULTS ON THE ORIGINAL DATASET. ONLY DIFFERENCES GREATHER THAN 0.05 ARE TAKEN INTO ACCOUNT.

Dataset	Classification algorithm	Breast Cancer	Credit-g	Dermatology	Glass	Heart-log	Ionosphere	Mushroom	Water 1	Water 2	Water 3	Water 4	Waveform
Original set	FT	0.60	0.69	0.99	0.73	0.86	0.81	0.83	0.69	0.64	0.73	0.54	0.91
	SMO	0.70	0.50	0.99	0.74	0.79	0.77	0.81	0.59	0.54	0.58	0.57	0.93
	PART	0.72	0.71	0.94	0.81	0.69	0.76	0.83	0.56	0.50	0.71	0.52	0.88
	MP	0.65	0.60	1.00	0.78	0.87	0.82	0.93	0.64	0.60	0.72	0.58	0.96
Reduced set (Sim_1)	FT	0.63	**0.86**	0.99	0.77	0.77	0.78	**0.88**	0.64	0.59	0.59	0.54	0.87
	SMO	0.61	**0.84**	0.98	0.71	0.74	0.69	**0.87**	0.52	0.49	0.54	0.51	0.91
	PART	0.64	**0.89**	0.92	0.71	**0.76**	0.75	0.75	0.56	0.49	0.49	0.50	0.87
	MP	0.65	**0.86**	0.99	0.82	0.83	0.79	0.93	0.60	0.59	0.58	0.48	0.94
Reduced set (Sim_2)	FT	0.63	**0.88**	0.96	**0.80**	0.71	0.76	**0.88**	0.58	0.53	0.52	0.56	0.93
	SMO	**0.79**	**0.89**	0.96	0.71	0.71	0.59	**0.87**	0.50	0.53	0.50	0.53	0.89
	PART	**0.77**	**0.88**	0.85	0.73	**0.75**	0.72	0.75	0.53	0.50	0.55	0.57	0.87
	MP	**0.96**	**0.89**	0.96	0.81	0.72	0.79	0.93	0.58	0.52	0.55	0.54	0.93

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A Novel NLP-FUZZY System Prototype for Information Extraction from Medical Guidelines

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***Abstract*—Medical guidelines have a significant role in the field of evidence-based medical treatment. The content of a medical guideline is based on a systematic review of clinical evidence with instructions and recommendations that clinicians can refer to. Most of the guidelines are available in an unstructured text format. Hence, clinicians must take a considerable time to search and find relevant recommendations in their semantic context. Using Machine Learning algorithms, automatic information extraction from medical guidelines has recently become possible. We present a novel system for information extraction and a fuzzy rule database developed for clinical guidelines. The proposed system, dubbed NLP-FUZZY, combines capabilities of Natural Language Processing (NLP) and Fuzzy Logic approaches. First, the NLP-FUZZY performs a semantic extraction of medical guidelines using a bi-directional Long short-term memory (LSTM). Subsequently, using the extracted semantic, it creates fuzzy rules, which are able to recognize new cases in a learning domain while predicting and extract the grade of recommendation. In order to test the NLP-FUZZY system, we compared its performance with state-of-the-art NLP approaches for clinical information extraction.**

***Index Terms*—Digitalization; Medical guidelines; Machine learning; Natural Language Processing; Fuzzy Logic**

I. Introduction

A medical guideline systematically makes recommendations for doctors that provide the necessary tools to make decisions in clinical situations [1]. Clinical practice guidelines are defined as "systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances" [2]. Fuzzy logic can be used in different medical problems like image processing [3] and automated prediction of diseases [4]. It is also widely applicable in image processing and pattern recognition [5]. The main advantage of fuzzy rules is their representation similar to natural language. Authors in [6] modelled the uncertainty of clinical guidelines with a fuzzy logic. They developed a fuzzy model derived from a clinical guideline for the treatment of febrile seizures. In [7], researchers suggested a fuzzy classification procedure to model uncertainty in the context of a medical guideline for diagnosis and treatment of hypertension. In [8], researchers considered fuzzy logic and investigated multiple approaches for clinical guideline knowledge extraction. In addition, NLP techniques have been suggested to interpret and understand sentences [9], [10]. Many statistical methods were also introduced into this field such as hidden Markov models for speech recognition [11]–[13]. In [14], the authors present an information extraction methodology for legal text. They combined a syntactic-based rule extraction approach (Stanford Parser) with a logic-based approach. In [15], [16], a new method is recommended for text summaries, where a deep learning algorithms and fuzzy logic were used to improve the efficiency of the generated summary. The study [17], introduced a combination of Natural Language Processing (NLP) and a fuzzy representation of words, enabling an enhanced goal extraction in the context of geolocation. In [18], the authors described a fuzzy logic-based NLP method, which was applied to speech recognition. It was able to predict the words failed to be recognized by speech recognition. The researchers in a recent study integrated NLP and fuzzy graphs to address contract ambiguity in the context of the procurement process [19].

Clinical practice guidelines are available online, however this does not sufficiently addresses the problem of clinicial information management as most of the guidelines are only available in an unstructured text format. Therefore, in this work we present a novel NLP-FUZZY system prototype for the semantic extraction and a fuzzy rule database of clinical guidelines. Our NLP-FUZZY system prototype performs a semantic extraction of a medical guideline using Bi-directional Long short-term memory (bi-LSTM) in the first step. In the second step, using the extracted semantic classes, the NLP-FUZZY system creates fuzzy rules and a database that recognizes a new case while predicting a priority of a recommendation. Modeling and validation of the NLP-FUZZY system approach is performed in Python, MATLAB and PostgreSQL.

The paper is organized as follows: In Section I, we describe the medical guideline concept and the related problems for clinicians to find relevant recommendations in their semantic context. Furthermore, we review existing research studies on different approaches of combination of NLP with FUZZY logic. In Section II, we explain the methods used in our framework along with the description of the proposed bi-

LSTM model in the NLP part and the fuzzy rule data base used in this work. Section III proposes a novel NLP-FUZZY system prototype, where we describe the NLP-FUZZY system design architecture. We explain the design of the applied user interface, containing several sub-systems. Section IV illustrates the numerical results from training and testing error, compared to other known tools and algorithms. The conclusion is described in Section V.

Notation Bold capital letters correspond to matrices and bold non-capital letters correspond to vectors respectively.

II. Methodology

A. Data preparation

Since there is no training data available for clinical practice guidelines, manually tagged training sentences were used for the first phase of our NLP-FUZZY approach [20]. All training guidelines that we used in training data were found in the web application of Medical Guideline Central [21]. In total, 1020 recommendations out of 45 guidelines were used in the training process. As the task of the training is trying to estimate the key information and the type of information, labelling is a paramount step. We defined five different classes, as proposed in [20]: *actiontaker, symptom, action, purpose and circumstance*. In the second phase of our methodology, we used the information from new 15 different guidelines [22], [23]. Each guideline contained a set of recommendations (40 recommendations on average). For a neural network preparation, we use the pre-trained *Word2Vec* dictionary [24] that focuses on bio-medical semantic indexing. The *Word2Vec* tool processes large full texts and maps the words of the corpus to vectors of a continuous space. All data and code are available at https://gitlab.umwelt-campus.de/Lejla/nlp-fuzzy.

B. Neural Networks

Recurrent Neural Networks (RNNs) are popular models for many NLP tasks. The idea behind RNNs is to make use of sequential information. However, due to the vanishing gradient problem, regular RNN are not able to store knowledge over large time periods [25]. Long Short Term Memory (LSTM) blocks were introduced in [26] to overcome long-term problems of the RNN. The big advantage of an LSTM is the memory, to collect and store state information [26], [27]. A very good introduction to LSTMs is presented in [34]. The formulas are form the LSTM model [28].

Both LSTM and RNN can only get information from the previous context so that further improvements are necessary using a Bi-directional Recurrent Neural Network [29].

C. Mamdani Type Fuzzy Modeling

Fuzzy logic was first introduced by Zadeh in 1965 as an extension of the Boolean logic [30]. Unlike classical logic, which requires an exact modelling of a system, precise equations and numeric values, fuzzy logic uses a different type of knowledge representation. It allows the modeling of complex systems by a higher level of abstraction. This way of modelling is very close to the establishment of human knowledge and experience [31]. In the first step of a fuzzy system design, the input-output variables are specified and the fuzzy sets and the corresponding membership function are defined. Using fuzzy conditional statements like ”If A Then B”, where A and B are labels of fuzzy sets characterized by appropriate membership functions, a fuzzy rule base system (FRBS) is formed. FRBS are commonly used for identification, classification, and regression tasks. We developed a fuzzy inference system using the Mamdani type fuzzy inference technique. As explained in [32], with the aid of a ”fuzzification interface”, ”the input is mapped onto a set of fuzzy partitions”. These are mapped to a single fuzzy partition using a predefined set of rules. The rules originate from the rule basis. This fuzzy partition is then passed to the de-fuzzification system, which in turn generates the actual output. Figure 2 (Fig. 1) displays a block diagram

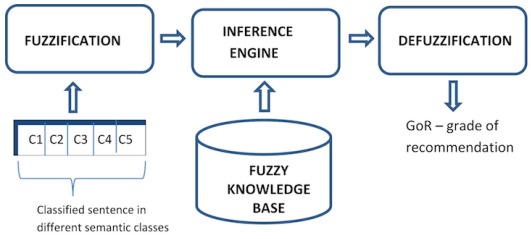

Fig. 1. Proposed Mamdani Fuzzy Inference System.

of our Mamdani Fuzzy Interface System.

III. NLP-FUZZY SYSTEM DESIGN

A. Step 1: Data Preparation

The first part of the NLP-FUZZY system (no.1 in Fig. 2) includes the preprocessing of the medical guidelines and a short introduction of the medical dictionary that will be used for training. Combining python tools such as PDFminer, our data preparation process was performed. As a result, extracted recommendations from the guideline were ,idp lyedsae.g.: *”We recommend that, in the resuscitation from sepsis-induced hypoperfusion, at least 30 ml/kg of IV crystalloid fluid be given within the first 3 hours”*.

B. Step 2: Model Building

The second step (Fig. 2) represents steps of the model building where we created a model and obtained initialization parameters for the neural network. In this step, we created a model in a sequential format and specified all other parameters for our network. First, an embedding layer was added. In the hidden layer, a Bi-directional LSTM was added with a specific number of hidden units. To avoid over-fitting, after some experiments, a dropout rate of 0.3 was used. In the next step, a dense layer with the tanh activation function was used. A model compiler was added with specifying the optimizer (Adaptive Moment Estimation) and the loss function (categorical crossentropy). After we created the model, the training process should be proceeded. As an output result, the semantic extraction in five classes was performed. For

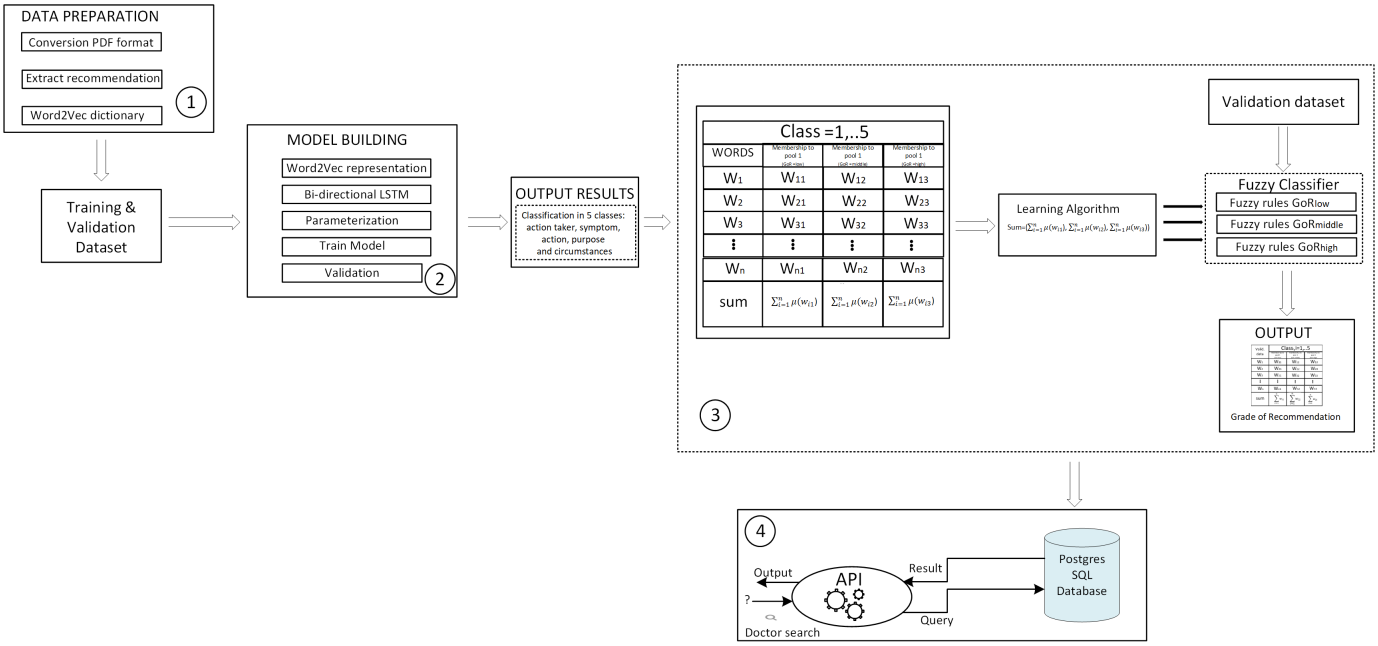

Fig. 2. NLP-FUZZY system design

example, for above mentioned recommendation, we will get as results:

"We (0) recommend (0) that (0), in (5) the (5) resuscitation (5) from (5) sepsis-induced (5) hypoperfusion (5), at (3) least (3) 30 (3) ml (3) / (3) kg (3) of (3) iv (3) crystalloid (3) fluid (3) be (3) given (3) within (3) the (3) first (3) 3 (3) hours (3)."

where numbers in parenthesis represents membership of the each word from recommendation to different class *(0- not defined, actiontaker (AC)= 1, symptom (S)= 2, action (A)= 3,purpose (P)= 4 and circumstances (C) =5)*. The same process was repeated for all other recommendations.

C. Step 3: FUZZY Classification

In the next step, using the extracted semantic classes, the NLP-FUZZY system created fuzzy rules and was consequently able to recognize recommendations and also predicts their respective grade of recommendation (strength of recommendations: *low, medium, high*) (no. 3 in Fig. 2). In a standard fuzzy approach, each fuzzy set corresponds to a linguistic value, as an example: *low, average, high, very high*, etc. In the reasoning process, the variables are related to the defined linguistic terms. Usually the numbers at the input of the fuzzy system are translated to linguistic variables. In our approach, the input consisted of parts of the sentence, extracted in 5 different classes in the first NLP model phase. To define the fuzzy sets and the corresponding membership functions, we developed an algorithm to create four different pools for each class, depending on the degree of membership of each input (*AC, S, A, P and C*) to output (GoR - grade of recommendation). In order to reduce the number of evaluated rules, GoR was classified into 3 categories (*low, middle, high*) and then for each one of the classes, an Mamdani inference model was implemented separately. The final output of the system is the accumulation of the maximum of such groups. For all classes from the training data set, 15 different pools of words are created (3 per class associated with GoR). For each word in a class, we calculated the membership to pools as a number of how many times that word exist in the corresponding pools. The same process was repeated for all other classes. In this step, the translation of words to numbers was performed. Finally, after the deletion of rule duplicates, there were a total of 125 successfully obtained fuzzy rules in the fuzzy rules database.

For the mentioned recommendation, one can see that part of *"at least 30 ml /kg of iv crystalloid fluid be given within the first 3 hours"* belongs to the class *Action*, so for each separated word from this class, the membership to *pool1 (low), pool2 (middle), pool3 (high)* is calculated. These pools are determined by the training data set. We used 1020 labeled recommendations to train these pools. The same process is done for class *Purpose (P)*. In this example, classes *AC*, *S* and *C* are empty. For the class *Action*, we got for *pool1* 4 and for *pool2* 5. For *pool3* we have 0 because no word exists in *pool3*. Similarly, the calculation was done for class *P*. At the end, as final result, the pool with the largest number was taken. It is also possible that we have an empty class (in our case only *AC* and *P* are recognized) and 0 are calculated for this class. Finally, the memberships of all words from class to one pool were collected together to get a final membership number to each pool by class. As the final result for each class, the maximum number that signifies affiliation was taken for the next phase of rule creation. In our example, for class *A* as result, the second pool was taken, so in the rule database it represents number 2. The affiliation of all elements - words

from all classes in relation to pools were summed together. As final result, we got for the example a form of rule $(0, 0, 2, 0, 2)$ that exist in our database and represent high GoR. We used triangular MFs and their ranges for the input and output variables.

$$\mu_{kj}(GoR) = \begin{cases} 0, & GoR \leq a_{kj}, \\ \frac{(GoR - a_{kj})}{(b - a_{kj})}, & a_{kj} \leq GoR \leq b_{kj}, \\ \frac{(c_{kj} - GoR)}{(c_{kj} - b_{kj})}, & b_{kj} \leq GoR \leq c_{kj}, \\ 0, & c_{kj} \leq GoR \end{cases} \quad (1)$$

where $k = 1, j = 1, 2, 3$, GoR represents grade of recommendation and $\mu_{k,j}$ represents j-th output MF. Parameters a_{kj}, b_{kj}, c_{kj} represent the shapes of the output MF. In the first step, the input values were converted to the membership values. After that, we applied the minimum operator to compute the weighting factor. The weighting factor for $n = (1, ..125)$ is represented by:

$$\omega_n = \min(\mu_{i,j}(AC), \mu_{i,j}(S), \mu_{i,j}(A), \mu_{i,j}(P), \mu_{i,j}(C)). \quad (2)$$

where $\mu_{i,j}$ stands for the j-th MF of i-th input. The implication was performed using minimum operator as follows:

$$\mu_{impl}, n = \min_{(n)}(\omega_n, R_n), n = 1, ..125. \quad (3)$$

where R_n represented the output of the n-th rule. Aggregation was performed using the union (maximum) operator represented by:

$$\mu_{out}(n) = \max_{(n)}(\mu_{impl}, n), n = 1, ..125. \quad (4)$$

In this model, as de-fuzzification technique, the COA method was used to convert the fuzzy output to a crisp number. We implemented the fuzzy rule database in MATLAB. The fuzzy rule viewer for validation data is shown in Fig. 3. The interaction effect for *Condition* and *Action* is shown in Fig. 4. For the validation process, we used 15 different guidelines for the validation data set [22], [23]. Each guideline contains a set of recommendations, 50 recommendations on average. A validation data set is used in the NLP-FUZZY model and each recommendation is classified by GoR.

D. Step 4: Graphical User Interface

A user-friendly graphical user interface was developed for doctors to facilitate easy search and extract relevant recommendations in their semantic context. The fourth part of the system (no. 4 in Fig. 2) represents concept how a doctor can access the data.

IV. TESTING AND RESULTS

F1 scores are calculated for testing the performance of the model (see Table I). Calculation of the F1-score of the classifier shows above average results considering a limited number of training data samples.

According to the classifier training, the F1-score is 0.88 in the first phase of the NLP-FUZZY approach. The validation

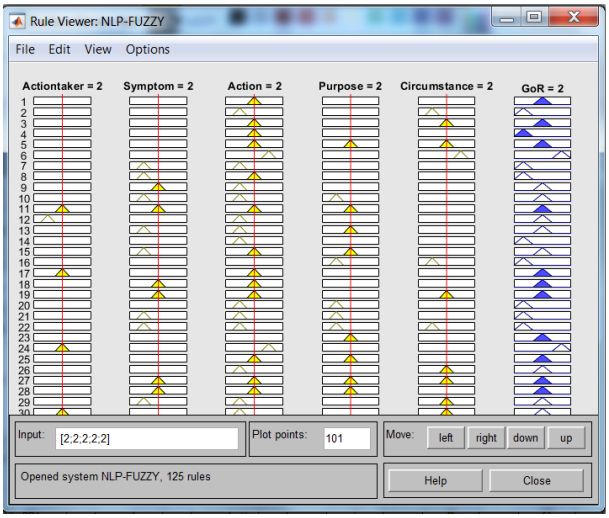

Fig. 3. Fuzzy rule viewer- NLP-FUZZY system

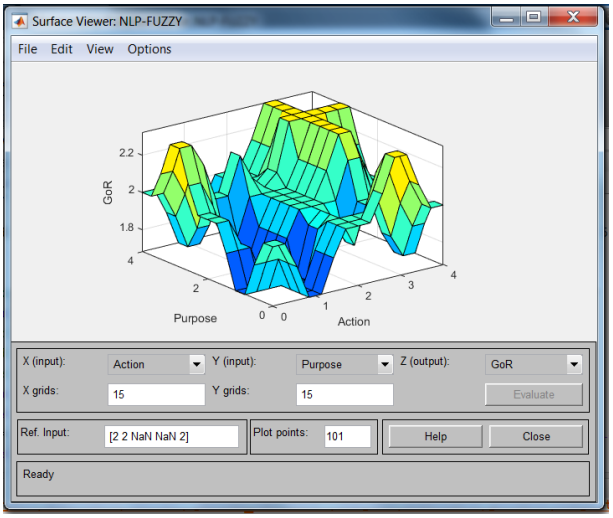

Fig. 4. Input-output surface NLP-FUZZY system

accuracy is shown in Fig. 5. After 3 epochs, the validation accuracy started to be lower than the training accuracy. The training accuracy increase. Validation accuracy decreases after 6 epochs. That means that the training started to overfit and needed to be stopped.

Table II represents our results compared to other research models. In the second phase, the F1- score is 0.97 for the prediction of the grade of recommendation. Only one recommendation from the validation data set was not properly predicted (Fig. 6).

V. DISCUSSION AND CONCLUSION

Our NLP-FUZZY system prototype allows the classification of recommendations by semantic meaning and prediction of the recommendation grade. One of the weaknesses is that the fuzzy rules in the NLP-FUZZY model are constructed based on training data, so the system is potentially biased to our selection of training data. The rules could also create

TABLE I
F1-SCORE NLP-FUZZY VS. LSTM

Class	NLP-FUZZY			LSTM
	Precision	*Recall*	*f1-score*	*LSTM f1-score*
AC	0.97	0.71	0.82	0.33
S	0.90	0.86	0.88	0.73
A	0.81	0.82	0.81	0.72
P	0.72	0.77	0.74	0.55
C	0.62	0.61	0.62	0.48
GoR	0.98	0.95	0.97	–

TABLE II
F1-SCORE NLP-FUZZY VS. LSTM

Approach	Precision %	Recall%	f1%
NLP-Fuzzy	83,5	78.6	80.6
Research [14]	78.5	62.5	68.76
Research [33]	-	-	66

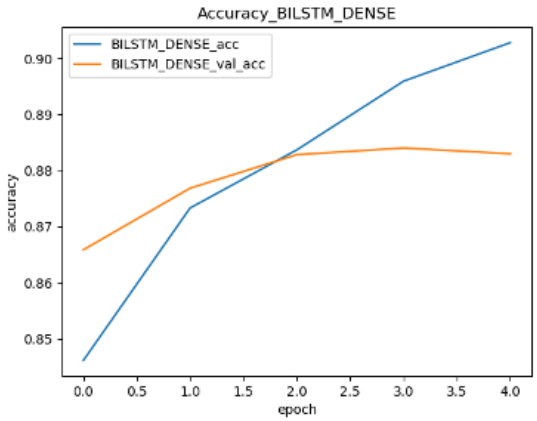

Fig. 5. Accuracy - NLP-FUZZY system prototype

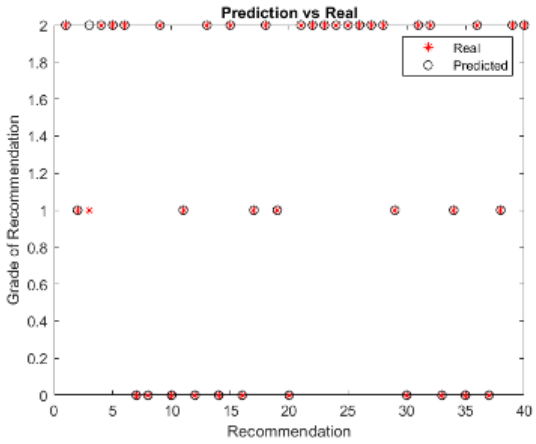

Fig. 6. Real vs. predicted GoR of recommendation

a false relation between irrelevant input variables and output variables. In order to overcome this problem, we developed a learning algorithm that is varied and accurate enough to represent all typical cases. Every new recommendation that comes in the NLP-FUZZY model is classified by the NLP in the first phase. In the second phase, new words from recommendations are always used to update the pool of words, which reduces the possibility of having some inputs that represents a situation which can not be detected by for our model. For increasing the model accuracy, some additional methods need to be considered, such as adding the parsing information that directly conveys the structure of the sentence into the neural network. The proposed NLP-FUZZY system prototype combines NLP, NN and FUZZY capabilities. Its aim is to build an inquiry system offering the clinicians the most relevant recommendations and instructions, e.g., for patients with specific diseases. The total classification accuracy of the NLP-FUZZY system prototype is better than in other suggested LSTM and CRF models. The proposed model has the potential to be used in the process of semantic information extraction and the prediction of the priority of the recommendation. Based on semantic search results, clinicians can then extract recommendations from different guidelines sorted by its grade.

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Improving case-based reasoning with the aid of multi-criteria and group decision-making methods

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Abstract - Solving semi-formalized and semi-structured tasks on the basis of a case-based reasoning (CBR) provides to use the accumulated knowledge and experience. Wherein, sometimes it is necessary to improve CBR results, for example, to reduce the set of possible solutions and to ground their correctness not only with the use of a similarity measure. One way to solve this problem is to use mathematical multi-criteria and group decision-making methods. This paper discusses the combined use of the ARAMIS (Aggregation and Ranking Alternatives nearby the Multi-Attribute Ideal Situation), AIR (Aggregation of Individual Ranking), MOPC (Method Of Pairwise Comparison processing), COIP (Complex processing Of Individual Preferences) and a case-based reasoning. The algorithm and case study for solving problem of selecting construction materials in petrochemistry are described. The application of the approach did not result to new decisions and/or the revision of decisions based on a case-based reasoning approach. But it provides their grounding from the point of view of mathematical methods and the growth of confidence from the point of view of the experts.

Keywords - decision-making, case-based reasoning, multi-criteria and group decision-making methods, industrial case studies.

I. INTRODUCTION

One of the ways to solve semi-formalized and semi-structured tasks is an approach based on a "by analogy" decision-making principle that allows one to reuse the accumulated knowledge and experience. In the field of artificial intelligence this approach is known as Case-Based Reasoning (CBR) [1].

Case-based reasoning as a separate scientific area in the field of knowledge-based systems is oriented primarily toward decision-making through the reuse of experience. This orientation requires investigation and development of effective methods for representation (modelling), evaluation, storage, indexing, retrieval and adaptation of knowledge. In accordance with this methodology, the standard decision-making process as a rule consists of four stages [1-3]: 1) retrieval of similar cases, including recognition of a new problem presented in the form of a pattern (a case); 2) reuse of information from retrieved cases, including its adaptation (if necessary); 3) revision of a new solution for correctness; and 4) retaining a new case in a case-base. The effectiveness of some these stages can be improved. In particular, detailed consideration of the retrieval stage showed that its results could be the following:

- An empty set of retrieved cases, because of there is no information in the case base about similar problems, i.e. this problem was not previously solved; in this case, the solution can be found by another way;
- The only one retrieved case with the highest similarity value;
- A set of retrieved cases with different similarity values.

The similarity measure that used in the retrieval stage is an objective expression of the intuitive principle of decision-making by analogy, but sometimes it is necessary to confirm the correctness of a decision based on other methods complementing or improving CBR. This improvement can be achieved through the use of neural networks [4], genetic algorithms [5], ontologies [6], mathematical methods of multi-criteria and group decision-making [7, 8] and others.

In turn, at the reuse stage the effectiveness of adaptation operators can also be improved including through the use of group decision-making methods [9].

Thus, the aim of the paper is to investigate the ability to improve the efficiency of CBR decision-making using mathematical methods of a decision theory, in particular: to reduce and ground CBR results at the retrieval stage, and to reduce a computational complexity of the adaptation process at the reuse stage. The proposed approach allows:

- to form a set of minimal cardinality for retrieved cases taking into account the problem features and accumulated experience;
- to generate a new solution via aggregation of a set of retrieved cases solutions.

The approach is tested on tasks, which are solved earlier without using mathematical methods of a decision theory: selection of constructional material for the design of constructions in petrochemistry and prediction of degradation processes and planning preventive measures in case of failures [10]. The main result of this testing is a qualitative assessment of the proposed approach.

II. PROPOSED APPROACH

A. Formalized problem statement

Most of decision-making tasks can be described by a set of characteristics, and can be formalized as follows:

$$M^{Task} = \{p_1, \ldots, p_M\},\ p_i \in Prop,\ Prop = \bigcup_i p_i,\ i=[1,N] \quad (1)$$

where M^{Task} is a task model; p_i are task properties (significant characteristics), *Prop* is a set of properties.

According to (1) the task model from a CBR point of view is defined as follows:

$$M^{Task_CBR} : Problem^{CBR} \rightarrow Decision^{CBR},$$

where M^{Task_CBR} is a task model in terms of CBR; $Problem^{CBR}$ is a task (problem) description, $Decision^{CBR}$ is a decision of a problem, while:

$$Problem^{CBR} = <c^*, C>,\ C = \{c_1 \ldots c_K\},\ c^* \notin C,$$

where c^* is a new case, *C* is a case base.

$$Decision^{CBR} = \{d_1, \ldots, d_R\},\ d_i = (c_i, s_i), c_i \in C,\ s \in [0;1] \quad (1)$$

where $Decision^{CBR}$ is a problem decision in the form of a set of retrieved cases with similarities s_i.

Let's formalize a case description:

$$c_i = \{Prop_i^{Problem}, Prop_i^{Decision}\},$$

where $Prop_i^{Problem}$ is a identifying (characterizing) part of a case, $Prop_i^{Decision}$ is a learning part of a case. In addition, each of these parts contains task properties and the composition of the parts has a problem-specific character:

$$Prop_i^{Problem} = \{p_1, \ldots, p_m\},\ Prop_i^{Decision} = \{p_{m+1}, \ldots, p_N\},$$
$$Prop_i^{Problem} \cup Prop_i^{Decision} = Prop,$$
$$Prop_i^{Problem} \cap Prop_i^{Decisio} = \varnothing.$$

The power of $Decision^{CBR}$ can be reduced with the aid of mathematical decision-making methods [11, 12] (multi-criteria and group), so, in accordance with (1) the task model is represented as follows:

$$M^{Task_MDM} :\ Problem^{MDM} \rightarrow Decision^{MDM},$$

where M^{Task_MDM} is a task model from the point of view of mathematical decision-making methods, $Problem^{MDM}$ is a description of the problem to be solved, $Decision^{MDM}$ is a decision of the task.

There are many statements of decision-making problems and they can be classified according to various criteria: the number of participants, the type of performance indicator, the degree of certainty of information, the problem structure, the degree of goals consistency, the structure of the alternatives set, the type of decision making model used, awareness of decision makers, the duration of the implementation period, the novelty of the problem, the type of final decision, time dependence, type of used information. In this paper it is proposed to use the methods of multi-criteria and group decision-making, in this regard, the following formalization for $Problem^{MDM}$ is proposed:

$$Problem^{MDM} = <Alt, Criteria, Experts, Ind_Preferences>,$$

where *Alt* is a set of alternatives (possible solutions to the problem). In this paper cases are alternatives, so $Alt = C$; *Criteria* is a set of features (characteristics) by which alternatives can be evaluated, $Criteria \subset Prop$,

$$Prop_i^{Problem} \cup Prop_i^{Decision} \cup Criteria = Prop,$$
$$Prop_i^{Problem} \cap Criteria = \varnothing,\ Prop_i^{Decision} \cap Criteria = \varnothing;$$

Experts is a group of experts involved in evaluating alternatives, *Ind_Preferences* is a set of individual preferences of experts expressing their opinion on each alternative for each criterion. Note that in the paper *Experts, Ind_Preferences* aren't be used because of automatic decision-making, for example, by generating the set of retrieved cases:

$$Decision^{MDM} = \{d_1^{MDM}, \ldots, d_R^{MDM}\},\ d_i = (c_i, f^{agg}{}_i),\ c_i \in C,$$

where $f^{agg}{}_i$ is a aggregated assessment of an alternative (a case) c_i obtained by one of the multi-criteria decision-making methods.

Thus, *it is required* to obtain a set $Decision^{MDM}$ satisfying the following conditions:

$$Decision^{MDM} \subset Decision^{CBR},$$
$$|\ Decision^{MDM}\ | < |\ Decision^{CBR}\ |.$$

In addition, mathematical decision-making methods can be applied at the reuse stage to adapt decisions. In this case there are following constraints for the task:

- mathematical methods are used for implementation of an adaptation operator of a structural (transformational) type,
- cases decisions ($Prop_i^{Decision}$) are presented in the form of plans, programs or scenarios consisting ordered alternatives (events, actions).

Group decision-making methods are most suitable [13] to solve the problem in these constraints. Then $Prop_i^{Decision}$ will be a non-strict ordered set with relationships of a strict preference ($\succ$) and equivalence ($\approx$).

Therefore, *it is required* to implement transformation $T: Decision^{CBR} \rightarrow Decision^{agg}$, where $Decision^{agg}$ is an aggregated solution that takes into account not only a decision of a retrieved case with the best similarity (*s*) or an aggregated assessment (f^{agg}), but taking into account decisions of a set of retrieved cases, which have similarity assessments in a certain interval.

To solve the stated problems, it is proposed to apply the mathematical methods of multi-criteria decision-making (individual and group). The verbal analysis methods, in particular, methods based on the apparatus of multisets [14] (ARAMIS - Aggregation and Ranking Alternatives nearby the Multi-Attribute Ideal Situation [15], AIR - Aggregation of Individual Ranking, MOPC - Method Of Pairwise Comparison processing, COIP - Complex processing Of Individual Preferences [16]) are used for processing properties values of a qualitative and quantitative type. These methods process qualitative and quantitative information, pairwise comparisons and ordering alternatives simultaneously.

B. The main stages of the approach

In general, the proposed approach coincides with the standard CBR and includes its main stages.

The proposed improvements relate to the stages of retrieval and reuse (Figure 1), so, let us consider these stages in detail.

Case retrieval. There are many methods that can be used for case retrieval [1-3]: nearest neighbour, decision trees, etc. The most popular method is the nearest neighbour, based on an assessment of similarity with the aid of different metrics, for example, Euclidean, City-Block-Metric, etc. The main result of this stage is a subset of cases with their simailarity assesmrnts ($Decision^{CBR}$). In order to reduce this subset it is proposed:

- To create a problem description for a multi-criteria decision making problem $Problem^{MDM}$. For this purpose the set of alternatives is defined in accordance with the set of retrieved cases: $Alt = Decision^{CBR}$; the set of criteria is formed on the basis of properties of the descriptive part of cases with adding one more criterion – a similarity measure.
- To solve the obtained multi-criteria decision-making problem using ARAMIS method [16].

Case reuse. This stage is the most difficult from the point of view of computer aided processing, since it requires the involvement of experts for a meaningful interpretation of the solutions obtained. In most cases, the result of a meaningful interpretation is the adaptation, i.e. some transformation with taking into account the current problem features.

Despite the existence of adaptation techniques [2, 17-21] it is very difficult to make the complete automation of this process, but it is possible to create more comfortable conditions for experts using a method that handles various forms of presenting individual preferences (COIP) when solving planning tasks. This method combines three ways of processing different forms of individual preferences: evaluations, rankings, pairwise comparisons. Accordingly it includes three methods – ARAMIS, AIR, MOPC.

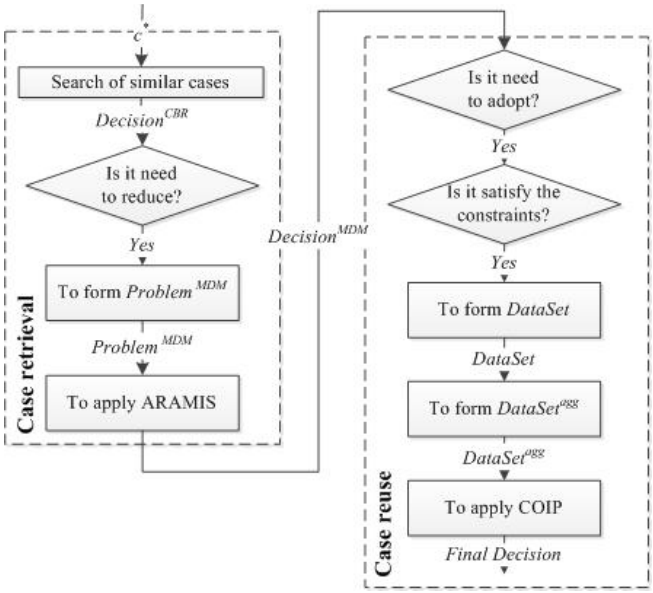

Figure 1. The scheme of the proposed approach

Note that for application of verbal analysis methods at the reuse stage it is necessary that learning part of a case c_i from $d_i \in Decision^{CBR}$ can be presented in the form of ranking $R=p_1Q^1...Q^{Z-1}p_Z$, $Q^j=\{\approx,\rightarrow\}$, p_i is an element of the solution. Representation of the decision in the form of ranking indicates that it contains some ordered sequence (actions, materials, etc.). Thus, for adaptation of retrieved cases at the reuse stage the following is proposed:

- To reduce the dimension of input data by transforming them to a single aggregated set $DataSet = \{ds_1,...,ds_W\}$; where $ds_i = <R, s^{av}, cnt>$, ds_i is a data set that includes unique (non-repeating) rankings, R – unique ranking, $s^{av} = \sum s_i/N$ is a average of similarity measures, cnt is a count of ranking equivalent R, W is a count of unique rankings.
- To solve the problem of multi-criteria decision-making using COIP method.

III. Illustrative Example

A. Brief domain problem description

Let's consider an example of the proposed approach application when selecting a construction material for the manufacturing heat exchange pipes in petrochemistry.

This is a multi-criteria problem because there are many materials that can be selected for component manufacturing and that satisfy the conditions of exploitation, manufacturing and repair (recovery). Exploitation conditions include losses in the case of failure, operating modes, manufacturing technologies, repair technologies, cost and availability, etc. Decision makers often ambiguously evaluate some of the selected conditions; moreover, there are approximately 80,000 different construction materials and at least 1,000 different ways to process them [22], and it is very difficult to select a material without special algorithms and software.

Methods for solving this problem can be divided into four main groups: specialized handbooks, mathematical methods of decision making [22, 23], methods of artificial intelligence (knowledge-based methods) [24, 25] and unformalized experience of specialists.

So, the joint application of some of these methods could to improve the decision-making in the selection of construction materials.

B. Application of case-based reasoning

Application of CBR required the development of a case model and forming a case base. The case model includes the identifying (characterizing) and learning parts. In turn the identifying part consists of the following main concepts: Structural component, High-temperature strength, Operation temperature, Service life, Corrosion resistance, Crack resistance, Manufacturability, Cost,

Pressure (expl.), Temperature (expl.), Agent (expl.), Heat resistance, High-temperature resistance. The learning part contains only one element: a material name. An example of a description of 20Cr3MoWV material in accordance with this model is given in the Table I.

The case base is formed on the basis of database of equipment failures [26]. This database stores information both on the material of the failed object and on materials recommended for repairs (recorded in recommended and accepted measures). So, this information has been migrated to the case base. Based on this knowledge, it is required to select suitable construction materials to solve the problem with due regard for its heat resistance, corrosion resistance, crack resistance, availability in the required quantity and at an acceptable price from the nearest manufacturer.

The Zhuravlev metric [10] with normalisation is used for case retrieval:

$$d_G(\bar{x},\bar{y}) = \sum_{i=1}^{N} w_i h_G(x_i, y_i) \Big/ N,$$

$$h_G(x_i, y_i) = \begin{cases} \text{for quantitative} \begin{cases} 1, if \left|x_i - y_i\right| < \xi \\ 0, else \end{cases} \\ \text{for qualitative} \begin{cases} 1, x_i = y_i \\ 0, x_i \neq y_i \end{cases} \end{cases},$$

where w_i is the information weight, and ξ is the constraint on the difference between the values of properties. At the same time, the normalisation (or standardisation) is follows:

$$x_{ik} \to \left(x_{ik} - \min_k x_{ik}\right) \Big/ \left(\max_k x_{ik} - \min_k x_{ik}\right).$$

The purpose of the illustrative example is to select the material that corresponds to the following operational conditions: a high internal pressure, a temperature of 300^0C, and a low aggressive agent affecting the outer surface of the pipes. The selected material must provide a long lifetime and crack resistance for the pipe in the reactor of the «pipe into pipe» type.

TABLE I. AN EXAMPLE OF A CASE DESCRIPTION

Property name	*Property value*
Structural component	PIPE_INTO_PIPE
High-temperature strength	YES
Operation temperature	-
Service life	-
Corrosion resistance	-
Crack resistance	YES
Manufacturability	LOW
Cost	HIGH
Pressure (expl.)	160_MPA
Temperature (expl.)	300_C
Agent (expl.)	LOW_AGGRESSIVE
Heat resistance	TO_500_C
High-temperature resistance	HIGH

The input data (new case $c^* = \{Prop_i^{Problem}, Prop_i^{Decision}\} \notin C$, where C is the case base that contains over 100 entries, so $Prop_i^{Problem} = \{$*Structural component = «pipe into pipe»; Pressure (expl.) = 160 MPa; Temperature (expl.) = 300^0C; Agent (expl.) = low aggressive; Heat resistance = yes; Crack resistance = yes; Manufacturability = high*$\}$.

The following materials with a similarity measure greater than or equal to 0.4 retrieved (Figure 2): *20Cr3MoWV - 0.86; 25Cr2Mo1V - 0.71; 30CrMoN - 0.71; 18Cr3MoV – 0.43; 12CrMo - 0.43.*

For other materials from the case base, the similarity measures were below 0.4. This value was defined on the basis of expert evaluation. According to this evaluation, only cases with more than 50% similar properties can be considered for decision-making. In particular, in the illustrative example, selected cases have similar values of at least 5 properties out of 13.

It is proposed to apply mathematical methods of decision-making to justify the decisions.

C. *Application of mathematical decision-making methods*

It is proposed to apply the ARAMIS method to justify results of the case retrieval procedure (in accordance of the scheme of the approach, see Figure 1).

In accordance with the definition of $Problem^{MDM}$ the following sets are defined:

Alt = {A_1 = "20Cr3MoWV"; A_2 = "25Cr2Mo1V"; A_3 = "30CrMoN"; A_4 = "18Cr3MoV"; A_5 ="12CrMo"};

Criteria = {Cr^1 = "Pressure"; Cr^2 = "Temperature"; Cr^3= "Agent"; Cr^4 = "High-temperature resistance"; Cr^5 = "Heat resistant"; Cr^6 = "High-temperature strength';
Cr^7 ="Crack resistant"; Cr^8 = "Manufacturability"; Cr^9 = "Cost"; Cr^{10} = "Similarity"};

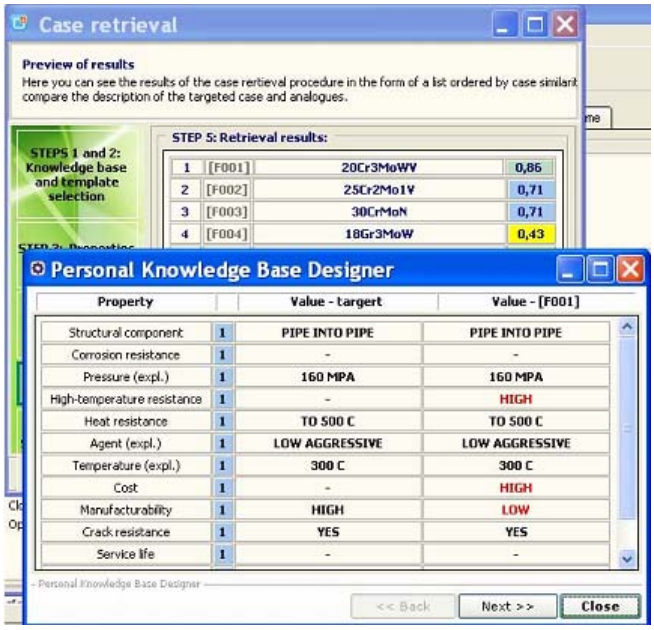

Figure 2. Results of a case retrieval procedure

TABLE II. ELEMENTS OF *IND_PREFERENCES*

	A_1	A_2	A_3	A_4	A_5
Cr^1	cm	cm	cm	cm	pm
Cr^2	cm	cm	cm	cm	cm
Cr^3	cm	cm	cm	cm	cm
Cr^4	cm	cm	pm	cm	pm
Cr^5	cm	cm	cm	cm	pm
Cr^6	cm	cm	pm	cm	pm
Cr^7	cm	cm	cm	cm	pm
Cr^8	l	l	h	l	h
Cr^9	h	h	a	a	l
Cr^{10}	0,86	0,71	0,71	0,43	0,43

Experts = $\{Ex_1\}$, the power of this set depends on the number of identical materials;

Elements of *Ind_Preferences* is presented in Table II, where each alternative is characterized by the following criteria evaluations: cm – complete match, pm – partially match, nm – does not match, l – low, a – average, h – high.

Then, multi-sets corresponding to each alternative are built. The multi-set for first alternative is presented below.

A_1 = {1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”l”, 0◦”a”, 0◦”h”; 0◦”l”, 0◦”a”, 1◦”h”; 1◦”0.86”, 0◦”0.71”, 0◦”0.43”}.

Multi-sets for better and worse alternatives are the followings:

A^+ = {1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”cm”, 0◦”pm”, 0◦”nm”; 1◦”l”, 0◦”a”, 0◦”h”; 1◦”l”, 0◦”a”, 0◦”h”; 1◦”0.86”, 0◦”0.71”, 0◦”0.43”}.

A^- = {0◦”cm”, 0◦”pm”, 1◦”nm”; 0◦”cm”, 0◦”pm”, 1◦”nm”; 0◦”cm”, 0◦”pm”, 1◦”nm”; 0◦”cm”, 0◦”pm”, 1◦”nm”; 0◦”cm”, 0◦”pm”, 1◦”nm”; 0◦”cm”, 0◦”pm”, 1◦”nm”; 0◦”l”, 0◦”a”, 1◦”h”; 0◦”l”, 0◦”a”, 1◦”h”; 0◦”0.86”, 0◦”0.71”, 1◦”0.43”}.

Next, in accordance with ARAMIS the distance from each alternative to A^+ and A^- are estimated with subsequent forming the final results (Table III). The final results can be represented in the form of ordered sequence of alternatives: $A_4 \rightarrow A_1 \rightarrow A_3 \rightarrow A_2 \rightarrow A_5$.

TABLE III. RESULTS OF ARAMIS

	A_1	A_2	A_3	A_4	A_5
$d(A_i, A^+)$	4	6	8	2	12
$d(A_i, A^-)$	16	13	20	18	18
Rez	0,20	0,32	0,29	0,10	0,40

D. Discussion

In addition to the illustrative example in the field of selecting construction materials in petrochemistry the proposed approach was tested on the basis of the Irkutsk National Research Technical University (IrNRTU). The case study involved 30 students, who graduated from the institute of high technologies, where they completed training in CASE-tools, Means of Information Technologies and Programming Technologies. As a result, the students know the basic concepts of decision making, knowledge management and expert systems.

The main objectives of the testing were: (1) to develop case bases for educational tasks of identification or selection of certain entities from some sets; (2) to solve the tasks with the aid of CBR; (3) to solve the tasks with the aid of ARAMIS; (4) to compare the solutions obtained.

The comparison of solutions showed that the application of the approach did not result to new decisions and/or the revision of decisions based on CBR. But it provides their grounding from the point of view of mathematical methods and the growth of confidence from the point of view of the experts (Figure 3).

IV. CONLUSION

The problem of improving the efficiency of decision making by cases is solved at different stages of the CBR cycle using various methods: neural networks [4], genetic algorithms [5], ontologies [6]. At the same time, the application of mathematical methods of decision-making theory [7, 8] is an interesting research and practical task, especially for case retrieval and adopting stages. This paper describes a hybrid approach for solving this task. The proposed approach is based on the joint application of

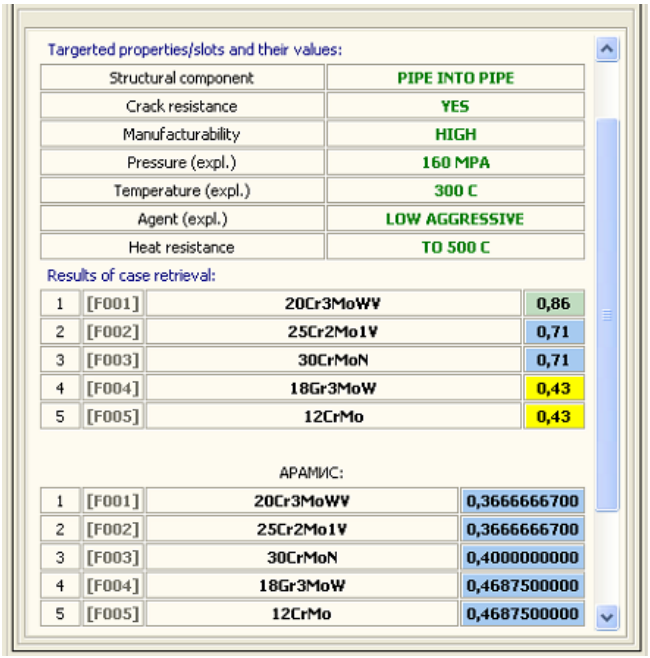

Figure 3. Comparision of CBR and ARAMIS results of the illustrative example

case-based reasoning and mathematical multi-criteria and group decision-making methods.

The application of the approach is demonstrated by the example of selection of a structural material in the design of tanks and apparatus in petrochemistry.

The approach was tested using the Personal Knowledge Base Designer software platform [27].

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Digital Archives Supporting Document Content Inference

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***Abstract*—Authoring documents is based on analysis of existing documents, collecting and processing their data, which is time consuming creative work. New documents may use parts of existing ones, *e.g.*, header data, names of persons and titles of organizations, tabular data and their description, footers, *etc*. Semantic description of frequently used classes of documents allows simplifying the authoring process. The paper presents an approach to creation of open document catalogs that involves technologies of Linked Open Data, document templates, and logical inference for deducing parts of documents from data of the catalogs. The approach is being realized as open software toolset and services on the base of other open source systems. The software under development is used to construct information system components in various application areas, *e.g.*, for synthesis educational processes regulations in departments of Irkutsk State University and organizations of joint accounting for source data collection.**

***Keywords*—Linked Open Data, component architecture, digital archive, document authoring, logical inference, Prolog, Semantic web**

I. Introduction

Technologies of Linked Open Data (LOD) [1] have been suggested by the W3C consortium to represent the semantic information in the published document in order to provide the possibility of its processing with software agents (Semantic Web, SW), as well as to link all available information into a single semantic graph, using relations and universal resource identifiers (URIs). The descriptive capabilities of the SW technologies, servers of HTML5 documents, and LOD technologies create infrastructural basis of document publishing, providing logical links between documents. The document content information is associated with the content information of another one by means of relations (links) to relevant resources. Resources represent both the static contents and the results of the procedure executions for publishing (converting) structural data, and generating marked up text content.

An important advantage of LOD using in organizations' information environments is weakening requirements for storage of the information being published: the document itself is a data warehouse in a formalized way. To some extent, this reallocates the time spent on designing the database structure for storage partially structured documents to the process of solving a substantive problems: developer markups the text data with semantic structures with an instrument.

The aim of this research is to develop technologies, software tools, and services allowing programmers constructing digital archives supporting document data inference from existing documents. The source data are to be stored in documents and databases; served from other services of data processing, recognition, and structuring. Document inference engines are to support both the test and essential data production, as well as ability to load source and derived data from external services. Thet's why SW and LOD technologies are of a great significance, as they provide methods of data integration on the basis of common standardized vocabularies.

A. Related works

Digital archive system development and domain adaptation is widespread topic of research in IT[1]. Research and development is being carried on in aspects of data storage, document representation, processing, retrieval, document flow modeling, security, *etc*. At present, digital archives are integrated with domain automation information systems, such as CRM, ERP, research and development support services.

One of the projects related to semantic markup control is Semantic MediaWiki; it extends a Wiki engine used for the site content representation. The text of the document is marked up with RDFa attributes with wiki tags. Semantic annotations allow development of search engines for Wiki pages that takes into account the semantics of the marked text [2].

Unlike Semantic MediaWiki, in OntoWiki project [3], similar results were obtained implementing different idea. OntoWiki is primarily based on the usage of the logical description of information in a semantic network. This logical structure is edited by means of the software generating user forms for known terms in a vocabulary. The user can change only one text property of LOD `lod:content`, which, in general, contains an HTML text. The HTML markup is not associated with the logical structure of the displayed object (the subject). The `lod:content` text is edited with OntoWiki built in WYSIWYG editor. The OntoWiki project is aimed at support of social network technologies based on Linked Data.

Project Dokieli [4] is aimed at constructing an environment for shared document authoring by integrating various algorithms, services, and vocabularies located on different servers and implemented as JavaScript modules. The project is, essentially, a WYSIWYG editor of LOD-marked HTML pages, display style sheet (CSS) and built-in subgraph (its content is not visible on

[1]See, e.g. `https://archiveshub.jisc.ac.uk/`

the page) presented in different formats (TTL, N3, JSON-LD, TriG). The user is able to add new RDFa markup with editor tools, in this case, the function of our interest is implemented in a general form. In addition, user authentication functions are implemented according to the WebID standard with client-side JavaScript. The system extensively supports commenting (text markup) with Open Annotation (**oa**). The annotation engine is integrated with `gitter.im` service, which shows readers' comments in the form of a dialogue. All the information is stored either on servers that support Solid protocol, or locally in the browser database.

There is also a huge class of browser document editors focused on the creation of scientific publications, see, *e.g.*, `http://substance.io/`. Our research is aimed at developing digital document archives enabling synthesis of new documents combining data stored in the archive and other services, as well as results of server-side logical inference over archive data.

In our invention, we are focusing on document parts inference during its authoring in a large, supposing that the user deals with repeating process or high document layout reusing in a data context. The declarative approaches allows us to express the document construction not bothering the devising algorithm.

B. Contribution

Our work presents a design of digital archives, which allows developers device information system and document processing services with the following features:

- load LOD marked up document, extract, store in a graph and index RDF data;
- retrieve RDF data as triples or as a result of full-text search query;
- combine existing LOD data and its content in new documents dynamically thanks to relatively simple browser based context inference machine;
- ability to use server site inference machine (Prolog) to process RDF data upon request from browser's part of the system;
- convert created RDFa marked up HTML5 documents into Excel and Word formats.

For the purpose of implementation of the features, we investigated existing vocabularies used to represent generic document data LOD markup. This was necessary to standardize relations classes used as document markup in a global scale. Then we developed a set of tools enabling one to construct documents as a result of various inference technologies.

Based on the produced tool set, a proof-of-concept digital archives of documents were developed, which intended for generation of the documentation on study courses. The use of LOD data formats, web browser HTML processing, and developed technologies allows us to solve a wide class of problems of synthesis of documents, starting from the generation of substantial parts of the texts ending the presentation of stylistic characteristics of texts and the integration of logical markup into a global data retrieval services.

This work continues the research outlined in [5] in the direction of the software tools development including services storage, processing and access to semantic information.

II. Approach

A. Technologies of LOD

The technologies of LOD are based on the representation of the published information in the form of semantically marked up document, usually web page, with content generated with database query result. The markup is realized with RDFa, the Resource Description Framework in Attributes. The markup defines a subgraph (of domain model) formed by the relations (triples) of the form `<subject, relation, object>`. The triples are integrated into HTML content with special attributes ignored by the web browser.

Separately from the visual content, standard SW formats RDF, OWL, TTL, N3 and 4, JSON-LD, RDF/JSON are used for presentation of additional LOD data, which either placed within `<script>` tag of the page or is referred as special `rdfs:seeAlso` resource. There are several binary formats that support compact storage of the graphs in the file system.

The representation of a SW graph in computer memory in most libraries and software frameworks is focused on fast search and filtering operations of triples according to their content, as well as the support of SPARQL standard. Some storages additionally support the interpretation of relations such as `rdf:subClassOf`, `rdf:subPropertyOf` and relations derived from the `rdfs:label`. This allows one to easily create visualization of the contents of the graph, for example, to build the administrator interfaces for the repositories.

LOD developers created a number of resources to discover domain vocabularies, including a set of base-level vocabularies for describing various aspects of the content (**scos**, **rdfs**, XMLSchema, **dc**, **prov**, **oa**, schema.org, *etc*.), graphs representing encyclopedic data, for example, DBpedia [6] and Wikidata [7], the Google Knowledge Graph, services of partial automation of semantic markup of text, such as DBpedia Spotlight [8], means of the distributed execution of SPARQL queries. The resources allow us to develop integration engines for data and graph distributed in Internet into a single information infrastructure.

B. Digital archive tools

Digital archive instrumental tools supporting LOD are being designed to provide development of publishing tools of data aggregated in an institution in a new form allowing its integration into the information infrastructure, *e.g.*, in form of web applications publishing data of processing result in a scientific research.

The digital archive tool architecture is based on components. Zope Component Architecture (ZCA) [9] used in the Python programming environment [10]. It has been chosen as a architecture basis for the implementation of the instrumental tools. Rdflib library is used for the internal representation of the LOD graphs. Graphs are serialized into appropriate text or binary formats when transferring data to an external process.

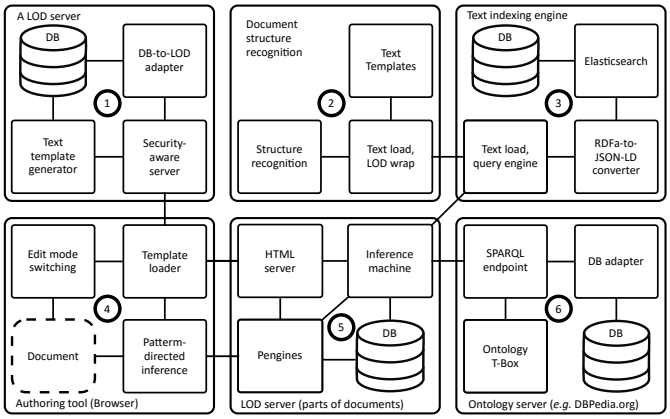

Figure 1. Architecture of digital archive tool set

The toolkit consists of the following main components (fig. 1):

- content and metadata repository with SPARQL (6) and full-text search (3); the engines for LOD processing (5) based on the logical inference;
- service for analysis of the stored content (2) enriching the archive with semantic information describing the content;
- tools for development of LOD applications and their user interfaces (1);
- browser based authoring tools (4).

All components interact by means of network protocols and use utf-8 encoded HTML, TXT, XML and JSON formats for data representation, which are expressive enough and easily debugged. Inference engines also support SPARQL protocol for issuing subqueries.

C. Storing LOD documents

The document content is stored either in the Kyotocabinet[2] key-value database, either as a file in a file system. Metainformation obtained by processing and analyzing a document is a content annotation and is described according to LOD standard vocabulary **oa** as a subgraph.

Each annotation (subject) is a tree with at least two nodes formed by the relations `oa:hasTarget` referring the original content and the `oa:hasBody` referring an annotation. The text content of the document, if it has been acquired, is the document annotation as well as a structure of type Dublin Core (**dc**) describing metainformation found. The contents (bytes, text) stored in Kyotocabinet is identified by its 128-bit Murmur3 hash function that allows us to create a reference key (hash) to the contents and in the backward direction. Using such hashing allows us to simply and effectively implement computational mapping at a sufficiently low probability of clash of hash values.

Let us list the basic properties of used vocabularies in description of the content.

Open Annotation (**oa**). The vocabulary standard is adopted in 2017 by OMG, it is used to represent the content annotation describing other content. A browser bookmark is an example of such content.

Friend-of-a-friend (**foaf**) allows one to describe information about agents: physical and legal entities, software agents.

Provenance (**prov**). The **prov** ontology is the base of a description of information flows in documents and their relationships. The **prov** vocabulary is used to associate the document and owner organization or physical entity.

Dublin Core (**dc**) represents metainformation about the creative work: authors, format, contents, description, *etc*.

DBpedia resource (**dbr**) is the namespace of the objects (resources) of Wikipedia. The **dbr** ontology is used to refer to a specific entity, geographical names, *etc*.

Schema.org (**schema**) represents the objects that are recognized by the crawlers of Google, Yandex, Yahoo, *etc*.

In addition to these ontologies, we use standard ontologies (RDF, RDFs, RDFa, XSD) and ontologies from the NEPOMUK project (`https://userbase.kde.org/Nepomuk`), describing objects stored in the full-text indexes of digital archives.

D. Component of content analysis

Metainformation about the content is enriched with results of the analysis by so-called extractors. The extractors analyze the content and try to acquire information about its text, author, time of creation, format, *etc*. Extractors are implemented with the Linux utilities such as `file`, `extract` (`libextract`), `tracker` and `recoll`. All these utilities are free software and integrated with the component as external processes.

The results of the extractor analysis are presented as a subgraph **oa**, associated with the source content and stored in a metadata repository of LOD.

E. The metadata storage

The implementation of metadata LOD graph storage is realized using ClioPatria [11] ontology server. The ClioPatria system is implemented in the SWI-Prolog programming environment. The project is under active development and aims to create a LOD graph storage service, implementing all the standards of storage and access, together with tight Prolog interpreter integration.

The system storage tier is implemented in C programming language. The store uses compact data structures to represent triples in RAM and on hard disk. A special feature of the storage is the fact that all triples are stored directly in RAM, as the service has no special assumptions about the structure of queries, which can be issued by client software. Thus, server memory space is a critical resource of the repository.

ClioPatria developers implemented repository accessing in several ways: the SPARQL queries according to a standard protocol, direct queries to the ClioPatria Prolog subsystem using Pengines protocol [12]. For the Pengines protocols a number of APIs has been created for object-oriented programming languages such as JavaScript, Java, Python. Using API classes, application developers and software agents are able to interact with the logic inference engine of the ClioPatria server. We used SWI-Prolog, ClioPatria and Pengines since such a combination

[2] `https://fallabs.com/kyotocabinet/`

provides services allowing us to develop the authoring tools around the Prolog language programming means as having a good scientific ground, and integrate these tools with other popular programming environments, making resulting product open.

F. The inference machine

Availability of ClioPatria's embedded programming system of SWI-Prolog [14] and the integration with RDFa allow one to process the marked up digital information stored in the archive on the base of logical inference. Prolog allows us to make queries in SPARQL and Datalog formats, as well as to build a knowledge system to process the received data.

As an experiment, in a very short time, we managed to integrate well known Turbo Prolog 2.0 example of a natural language interface to a database on the US geography with ClioPatria's built in SWI-Prolog RDF system. As a result, we developed a prototype with similar interface to a database of active faults of Siberia, aggregated at the Institute of the Earth crust SB RAS.

The server inference machine is used as regular engine of information processing at server side, resulting in set of variables of a query, which are filled in at the client side (browser) or templates at the server. The graph of document data at server forms fact set of the Pengine's Prolog interpreter. The set of rules are stored at server or sent with a query from browser. Pengines allows us to store Prolog rules and queries in `<stript>` tag text.

G. Full-text search

The ClioPatria system has instruments of searching the text information for keywords, however, we added a more powerful system of Elasticsearch full-text index engine [15]. Integration of this service is quite simple, since every RDF graph is representable as a JSON-LD object, while JSON is the primary format for storing indexed information in the ElasticSearch search engine; it is only necessary to separate a particular triples on the server responsible for the representation of the resource to the user in the search results. Elasticsearch has the means of fuzzy comparison of terms that allows developing search subsystems retrieving relevant information.

H. Tabular data interpretation

Stored documents may contain a lot of useful information in their tables. Extraction and understanding tabular data allows one to improve their semantic interpretation and get more qualitative metadata. To extract information from tables we should detect them, recognize their structure, implement a structural analysis, and provide logically related data for further processing [16].

Table structure recognition task consists in detection and extraction different structural elements such as cells, entries, labels, and categories. Detection of structural and semantic elements of a table is carried out with a set of rules in the CRL language. The rule engine is realized as a network service, it matches available facts of table elements against rules. As a result, we get new facts about matched structure elements. Recognition of semantic elements allows us to present table in a canonical form, with topmost row containing attribute names, and the remaining rows being data records. The attribute row refers cell columns and is associated with a categories, which are hierarchically organized, containing semantic labels. Thus, data records present recovered relationships between their attribute labels in categories. Usually each data record is unique within a canonical table [13], resulting in a possibility for restoring semantic relationships between elements of a table and their further mark up and interpretation. The corresponding conversion procedures are also implemented, producing various forms of rational tables.

III. Applications

The designed tools solving applied tasks built out of digital archive services, LOD and content processing components.

The Ministry of education and science of the Russian Federation incorporate the Bologna process in the educational environment of the Russian Federation. One of the tasks solved is the transition to competence-oriented representation of the requirements to the pedagogical process. The reform affects all aspects of the process, including the system of classification of specialties. Various new classifications are introduced in curriculum, including programs and directions of a course set, specialization according to skill levels (bachelor, master degrees, *etc*). Applied bachelor degree has been added, as well as list of courses, aims and objectives of the courses (negotiation with the competencies specified in the Federal standard), forms of conducting classes in universities (introduction of interactive forms of learning), the distribution of lectures and practical sessions. The existing documentation is supplemented by new forms of mandatory documents, *e.g.*, annotations of the courses. In addition, the university management with the aim of improving the quality of educational services introduced its own improvements to form, content and document design requirements, in particular, to the quality of the conversion to HTML for publication on the website of an university.

For the minimum requirements fulfillment of the university management for each course, the instructor is required to prepare at least two documents: working program of the course and summary annotation. This set is realized for each possible parameters combination of a course: the university, department, specialty, direction (profile), program, qualification (bachelor, specialist, undergraduate, graduate), academic or applied version of the qualification, form of study (full-time, part-time, evening, *etc*.). Each combination is reflected in the curriculum of the university, whose data is annually or twice a year being actualized in the work programs.

The last five years showed the level of maturity of decisions made by the managers of the Ministry in terms of requirements to the presentation of the course – four generations of the standards (1, 2, 3 and 3+) were developed. Each update required resubmission of the documents in the appropriate new form. The task of developing new handbook now seems more simple than before as compared to the fulfillment the course documentation requirements. Experience shows that most instructors are not able to cope with high-quality paperwork in the given time

constraints, thus requiring the departments to hire a secretary, whose function is to bring documentation to the required quality.

The solution to this problem consists in developing a software system that allows instructors to collect the texts of the work programs and annotations from separate parts: a list of competencies and curriculum, contents (subjects of taught module/course), which are shared between different versions of documents. The title pages are generated also from data of curriculum and templates set by the management. Microsoft Word and Excel tools, that are commonly used for this task including built in VBA, are clearly not enough to support problem solution.

Consider the scheme of construction of marked up work program as an HTML page with the proposed system. The presentation format is based on the results presented in [4].

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 ...>
<html lang="ru" xmlns=http://www.w3.org/1999/xhtml
xmlns:taa=http://irnok.net/engine/rdfa-manipulation
xml:lang="ru" metal:define-macro="page">
<head>
<!- Connecting stylesheets and modules ->
</head>
<body prefix="rdf: http://www.w3.org/1999/...-ns#
foaf: http://xmlns.com/foaf/0.1/ imei: imei.html#
course: https://irnok.net/college/plan/01..16-...\
%D0\%BA_PB-SM.plm.xml.xlsx-....2.3.1.html#"
resource="#post"
typeof="schema:CreativeWork sioc:Post prov:Entity">
<!- The application control panel ->
<main lang="ru" resource="#annotation"
typeof="oa:Annotation" id="main-doc-container">
<div property="oa:hasTarget" resource="#course-
work-prog"></div> <article property="oa:hasBody"
typeof="foaf:Document curr:WorkingProgram"
resource="#course-work-program" id="main-document">
<div taa:content="imei:title-page"></div>
<div taa:content="imei:neg-UMK"></div>
<section id="TOC" class="break-after">
<h2 class="nocount c">Table of Contents</h2>
<div id="tableOfContents"></div>
</section>
<section id="course-description"
  resource="#description"
  property="schema:hasPart"
  typeof="schema:CreativeWork">
<div property="schema:hasPart" resource="#purpose"
  typeof="dc:Text cnt:ContentAsText" >
<div property="cnt:chars"
  datatype="xsd:string">
<h2 property="dc:title"
  datatype="xsd:string">Aims and objectives of the
discipline (module)</h2>
<p>The aim of teaching the discipline ...</p>
</div> </div>
. . . . . .
```

In the example, the key structures are started from `taa:` prefix. Let us comment the structures.

The page displayed to the user is the abstract of the document "`#annotation`", and both the annotated content and the annotation text is the same at the stage of authoring the document – resource "`#course-work-program`". In LOD, all resources are global. This is achieved by substitution of the default namespace (the URI of the current page) at the left side of the name of the resource.

The title page and the approval sheet are inserted from the templates page "imei.html" (information about the Institute of mathematics, economics and informatics of Irkutsk state university[3]). The course data and the name of the specialty are filled in the templates from the context of the main document. All the key static templates of courses can be placed in one page of templates. The parts of the templates are arranged with a browser pattern-directed inference machine, implemented with JavaScript and special libraries, implementing HTML loading.

The text is divided into sections, surrounded by tags `<div>` and `<span>` with the relevant RDFa structures. Analysis of the experience of the developers LOD resources has shown that for the formation of the relationship is sufficient to use RDFa attributes `resource`, `property`, `typeof` and `datatype`. The use of `rel` and `about` attributes are recommended to be abandoned. This makes the structure of semantic markup more clean by reducing the number of used entities.

Attribute `taa:content` adds to the document a text from another HTML page, whose address is formed by the interpretation of the attribute, for example, `taa:content="course:time-distrib"` loads the text of a page generated by the table of distribution of time spent between the types of classes (lectures, practice, laboratory, independent work, *etc*.). To generate such tables, a web server has been realized for serving web pages of these courses. Each page represents a course/module, scheduled in the curriculum. The page content is encoded by the structure of its URL and rendered at the time of first request. Text templates are identified by the `id` attribute.

The presented approach supports various language processing for Russian, for example, declination of nouns, pronouns, participles and other words. For this purpose, a `data-<command>` attribute HTML extension, JavaScript browser support, and a language service are implemented, where the linguistic processing queries are sent from browser to service. The attribute combinations define structural language morphological relations, which are interpreted by JavaScript routines.

In the text content edit mode, the work program tags combination with attributes `property="cnt:chars"` and `datatype="xsd:string"` denote conversion of their texts to editable form. For clarity, the document without `taa:` inclusions is shown to the user, indicating these inclusions with the special tags and styles. At the end of editing, the text is stored in the server file system. The user can then commit the changes and sync the text of the saved document to the server control versions (git).

A. LOD markup output

Resulting HTML document is exported in Word and Excel formats. LOD markup is dome with comments of a special "__RDF__" user and contains list of `<RDFa attrinute>=<value>` pairs or Turtle sentences. Some RDFa key-value pairs refer the commented Word document text as a relation literal value. RDFa attribute name is written in form of RDFa of Turtle resource notation.

The comments are hierarchically interpreted, giving rise the relation structures of the markup. Printing documents is done

[3] `http://math.isu.ru`

with comments switched off, so a regular user is not disturbed with uncommon view full of comments.

Excel table exports can be marked up also with “Defined ranges” names. Names of the ranges and the ranges are obtained from original LOD markups. In this case the data exported can be directly used as input data for other table computations.

B. Accounting data collection

Another example of the technology application is a software for accounting data collection. In Russia there are a number of small-to-middle sized enterprises accounting software vendors, with market prevailing 1C. The 1C software automating wide aspects of enterprises activity including accounting, logistics, human resources departments, *etc*. However, the cost of the software even for schools is high, and Irkutsk city council decided to reduce expenses with removing 1C-Accounting software and organize five centralized accounting organizations.

In order to provide the service accountants must collect data from inferior organizations (schools, kindergartens). Data must be collected monthly, as well as upon a request from superior organizations (committees). By means of our LOD software we developed web-services, which automate this process.

At the first stage, accountant creates an Excel page, representing results of data collection in form of a report. The page can contain formulae for derivative values and aggregates, which must be expressed using “Defined ranges”. Each define located withing the special define, named `REPEAT` is the data value to be collected. The `REPEAT` defines parts of the Excel page, which is repeated for each organization’s collected data.

The second stage is data collection itself, where the page is converted into a HTML form, which is shown to inferiors to be filled in. At the last stage, the collected data is used to construct the Excel page repeating sections. The defines within `REPEAT` are corrected to contain all values for each organization, so aggregate formulae are not changed.

The data now can be imported to accounting software either from a rational table of collected values or from Excel report. In the last case a special dictionary is used to relate defines with LOD relations. The LOD published collected data is data sources for other documents.

IV. Conclusion and further development

The paper discussed the facilities of the use of Linked Open Data (LOD) technologies for the solution of tasks of organizing digital document archives with instrumental tools for creating new documents based on the stored data. Layout is carried out using algorithms that interpret the relationships between the elements of the HTML tree. The layout algorithms are triggered in the presence of corresponding conditions in the nodes of the document tree. Each algorithm makes changes in the tree, resulting the final content and styles of the document. Forming documents are stored on servers that support the HTTP protocol. Two applications are presented.

Further development of this project is carried in the following directions: a) improvement of the tools of typesetting documents, b) automation of the layout based on analysis of changes in the documents [5], c) collecting of additional information about user needs, d) develop a regulated access to information stored in digital archives. The created software tools and technologies aimed at the development of a software infrastructure of a global electronic document flow, allowing individuals and organizations to share documents, whose logical structure is partially formalizable within the framework of the traditional software of document automation.

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Multiagent Technology for Parallel Implementation of Boolean Constraint Method for Qualitative Analysis of Binary Dynamic Systems

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Abstract - The high computational complexity of qualitative analysis problems requires the development of software and tools for its solution using parallel computations and service-oriented access to the resources of high-performance computing environments. We offer a new implementation technology of Boolean constraints method for the qualitative research of binary dynamic system functioning on a finite time interval. According to this method, the satisfiability verification of dynamic system properties is reduced to solving the Boolean satisfiability problem or quantified Boolean formula problem. Offered technology is based on a decentralized multi-agent approach to managing the construction and study of Boolean models of dynamic properties in a distributed computational network. Microservices-based software for models constructing and studying are installed on dedicated computational nodes. The agents associated with installation nodes, run these microservices. Local agent's knowledge base stores information about their neighborhoods. The discrete event-driven agent's behavior model provides decentralized control based on direct peer-to-peer interactions of agents. Using this approach, we developed a multiagent system automating the constructing a dynamic property model and parallel solving the Boolean satisfiability problem and quantified Boolean formula problem. The results of computational experiments confirmed the effectiveness of the developed software based on the proposed technology.

Keywords - multiagent technology; qualitative analysis, Boolean model; quantified Boolean formula; satisfiability; parallel solver.

I. INTRODUCTION

Qualitative research helps to identify the significant, important from both a theoretical and practical point of view features of a dynamic system. The main objective of qualitative research is to analyze the behavior of the trajectories of a dynamic system to verify whether this behavior complies with the totality of constraints characterizing the property. For qualitative analysis of binary dynamic systems (BDS), we offer an approach based on the Boolean constraints method [1], in which the checking of the required dynamic property is reduced to the satisfiability verification of certain constraints on the trajectories behavior of the BDS. For BDS, whose functioning is considered on a finite time interval, such restrictions are written in the language of Boolean equations or Boolean formulas with quantifiers. The first type of constraints constitutes the Boolean satisfiability (SAT) problem [2]; the second type is associated with quantified Boolean formula (QBF) problem [3]. The following stages of the Boolean constraints method in the qualitative analysis of BDS could be singled out taking into consideration mentioned above:

- Formation of a dynamic property specification in the language of predicate logic using bounded universal and existential quantifiers.
- Conversion of a property formula with bounded quantifiers to one with universal quantifiers. Replacing the bounded quantifiers binding the variables with finite domains by equivalent without quantifiers.
- Construction of a property model as a Boolean constraint (a Boolean equation or a quantified Boolean formula), that satisfies the logical specification of the property and the equations of the system dynamics.
- Verification of satisfiability of the received Boolean constraint by the efficient SAT and QBF solvers.

In the first two stages, theoretical studies are carried out to develop specifications for the dynamic properties of BDS. The next two stages require software development. Applied software modules are implemented as independent microservices. The use of microservices allows operating the modularity properties in new conditions for the organization of distributed computing when inter-module communication is provided only through the message transfer mechanism. Multi-agent decentralized management and self-organization mechanism, namely direct interactions of agents [4], are used to organize the interconnection of microservices. The advantages of this approach are given in [4, 5]. The active group of agents of the multi-agent system (MAS), which are delegated the rights to manage the microservices, is formed for non-procedural problem

formulation using a logical inference on a distributed knowledge base (KB) of a subject area. As this base a computational model KB = (*M*, *P*, *N*, *In*, *Out*, *Com*) is used, where *M*, *P*, *N* are finite sets of, correspondently, modules, parameters and computational field (CF) nodes. Relations $In \subset P \times M$ and $Out \subset M \times P$ determine the relationship of the modules by the input and output parameters, respectively. The relation $Com \subset M \times N$ defines the topology of the CF [6]. A module $M_i \subset M$ calculates the values of the output parameters using the specified values of the input parameters. The KB is distributed the way that each agent has limited knowledge (only *In* and *Out* relations) of both the capabilities of other system agents and the topology of the CF as a whole. KB allow formulating a problem by specifying the given set $A^0 \subset P$ and the required set $B^0 \subset P$ parameters values. A couple of sets $T = (A^0; B^0)$ is called the non-procedural formulation of the problem on the KB model. Thus, the computational model determines the rules for the application and combination of modules in the process of automatic $T = (A^0; B^0)$ problem solving. The instrumental support of the offered technology is the HPCSOMAS (High Performance Computing Service-Oriented Multi-Agent System) framework 3.0 [7], which automates the creation and functioning of agents based on computational microservices. Based on HPCSOMAS agent implementation involves the stage of its local KB creation, which contains the information about the agent's predecessors and successors defined by *In* and *Out* relations. Thus, the distributed KB offers only direct pair interactions between agents to form an active agents group (Ag^*) required for solving the *T* problem. The agent behavior is based on a discrete event-driven model FSMwVW (Finite State Machine with Variables and Works) described in detail in [7]. This model supports agent coordination based on decentralized control "on the readiness of input data" (event-driven control). Offered approach without a central control node increases the fault tolerance and scalability of calculations. According to this approach, to implement the Boolean constraints method [1] we used HPCSOMAS for developing the MAS for the micro-services based qualitative analysis of binary dynamic system (MSQABDS).

II. Related Works

The existing software for qualitative analysis of BDS (in particular, Boolean networks [8-11]) have some systemic disadvantages, namely: these tools are limited by the complexity of the Boolean model and the format of its presentation; they require programming skills from subject specialists, since they are often used only as platform-specific command line tools. In [11], the drawbacks of the simulation, binary decision diagram (BDD)- and SAT-based algorithms are noted, associated respectively with the complexity of finding all attractors, limitation of the Boolean network dimension and the impossibility of parallelizing. The last disadvantage is explained by the fact that the SAT approach is used iteratively inside the attractor search algorithm to solve the auxiliary problem of finding a path of length *k* [8]. A parallel algorithm represented in [11] is based on the partitioning of the state transition graph. However, this algorithm does not exceed the algorithm [8] efficiency for searching attractors on classic examples of Boolean models of gene regulatory networks (GRN). In general, in existing publications, the focus of researchers is on finding attractors (equilibrium states and cycles of a given length) for autonomous BDS [8–11], while the important for dynamics analysis problem of checking the isolation property of an attractor is not considered. It should be noted that methods and means of qualitative analysis of reachability type properties are needed for a complete image of the dynamics of the functioning of autonomous nonlinear BDS. In [12], reachability property is defined as a classical one studied in a qualitative analysis of the behavior of BDS trajectories; however, verification of this property is performed only for linear systems, and the reachability property verification remains an open question for a nonlinear BDS.

The approach we propose, in contrast to the procedural one, used in [8-11], is declarative and oriented on the study of various dynamic properties. We developed not an algorithm for checking the satisfiability of a property, but a mathematical model in the form of Boolean constraints (SAT or QBF problem) that takes into account both the specification of the property and the equations of a specific object dynamics. The results obtained during the solving of this system using efficient SAT and QBF solvers determine the property satisfiability. This approach provides data parallelism by splitting the source property Boolean model. According to this approach, the aimed MSQABDS was created.

III. Architecture of MSQABDS

The architecture of the MSQABDS, reflecting the components composition and their interconnection by data, is shown in Fig. 1. The MSQABDS consists of two main subsystems: Boolean modeling and solving Boolean

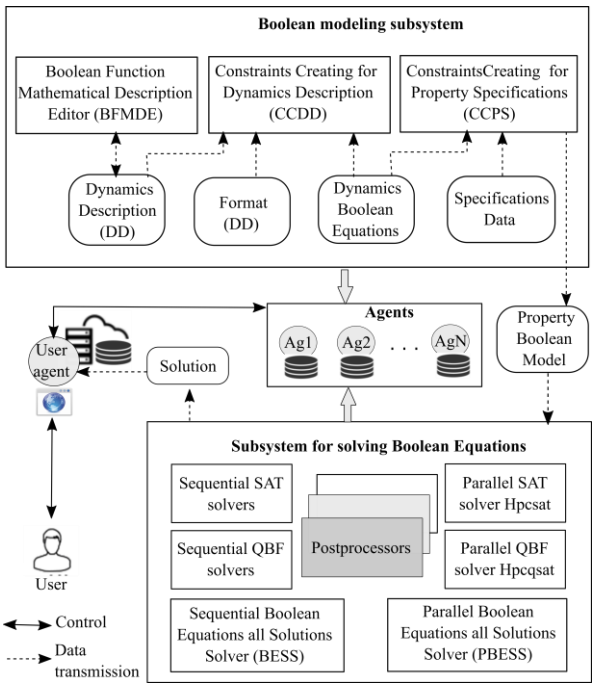

Figure 1. MSQABDS architecture

equations. The HPCSOMAS automatizes Tomcat based microservices creation for all subsystems modules, and agents, which are delegated the rights to manage the microservices. Analysis of the solving of some problems of studying the behavior of trajectories for autonomous BDS [6], non-autonomous significantly nonlinear BDS [7] and BDS with the additive perturbations [13] based on the Boolean constraints method allowed to distinguish the following stages of constructing a property model:

- Constraints creation using the dynamics description (CCDD module);
- Constraints creation using the logical property specification (CCPS module).

These modules are implemented using object-oriented technology in C++ language. Different CCPS modules correspond to different properties.

A. *Dynamics Description of BDS*

The dynamics description for autonomous synchronous BDS is represented by a vector-matrix equation

$$x^t = F(x^{t-1}), \quad (1)$$

where x – is a state vector, $x \in B^n$, $B = \{0,1\}$, n – is the dimension of the state vector; $t \in T = \{1,2,...,k\}$ – is discrete time (the time step number); $F(x)$ – is a vector function of Boolean algebra which is call transition function. For every state $x^0 \in B^n$ we determine the trajectory $x(t, x^0)$ of the system (1) as a finite-length state sequence of x^0, x^1, …, x^k from the B^n set. It is known, that (1) for $t = k$ is equal to the following Boolean equation

$$\Phi_k(x^0, x^1, ..., x^k) = \vee_{t=1}^{k} \vee_{i=1}^{n} (x_i^t \oplus F_i(x^{t-1})) = 0, \quad (2)$$

where x_i^t – i-th component of x^t vector; $\oplus$ – modulo-2 addition; F_i – i-th vector F component, function $\Phi_k(x^0, x^1, ..., x^k)$ denotes the k-step transition for t = 1, 2, …, k. For k = 1 the equation (2) acquire the form for one-step transition:

$$\Phi_1(x^0, x^1) = \vee_{i=1}^{n} (x_i^1 \oplus F_i(x^0)) = 0. \quad (3)$$

Obtained in correspondently with (3) the Boolean one-step transition formula is the basis for constructing a Boolean model of a dynamic property. This formula is used afterward to construct the k-transition (2).

B. *Specification of Dynamical Property*

At present, specifications and corresponding Boolean formulas are developed (the mathematical justification for the derivation of which is given in [1]) to identify branching of a state, equilibrium states, closed trajectories (cycles) and for the following dynamic properties of reachability type:

- the main reachability property, the security property, the simultaneous reachability property;
- the reachability property with phase constraints, the attraction property;
- the connectivity property of the goal set;
- the property of total reachability of the goal set from the set of initial states.

The specification of a dynamic property is written in the language of formal logic. The main syntactic elements of a logical formula are [1]: 1) subject variables (components of vectors x^0, x^1, …, x^k, time t); 2) bounded existential and universal quantifiers; 3) logical operators $\vee$, $\wedge$; 4) final formulas , which are the assertions about the belonging of specific states of the set of trajectories $x(t, x^0)$ ($x^0 \in X^0$) to the estimated sets X^* and X^1. The elements of these sets are determined by the roots of the Boolean equations $G^0(x) = 0$, $G^1(x) = 0$, $G^*(x) = 0$ or by the characteristic functions of these sets $\overline{G^o}(x)$, $\overline{G^1}(x)$, $\overline{G^*}(x)$.

C. *Boolean Modeling Implementation*

BDS dynamics description (1) can be formulated using the mathematical language in the Latex, MathML input formats, or represented in the "CNET" format [14] (for compatibility with other software systems). Output formats of the Boolean constraints for the property description are DIMACS [15] or QDIMACS [16]. The Boolean modeling subsystem includes BFMDE (Boolean Function Mathematical Description Editor) service (Fig. 2), which allows entering the system dynamics equations (1) in mathematical language. BFMDE is implemented in Java programming language and includes appropriate converters transfer these equations from the input format to the internal representation, based on which the algorithm for calculating the Boolean function is built (serial or parallel depending on the dimension of the state vector). This algorithm is used for dynamical construction a truth table according to which a Boolean function is generated in Conjunctive (or Disjunctive) Normal form (CNF or DNF). BFMDE uses the shareware FMath Javascript Equation Editor [17] for the formulas input.

D. *Example of Boolean Model Creation*

Let us consider an illustrative example from [18]. The BDS dynamics description is presented by the following system of equations (n=3):

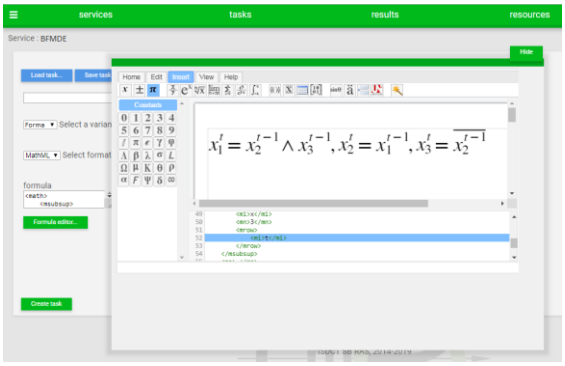

Figure 2. Web-interface of mathematical editor

$$x_1^t = x_2^{t-1} \wedge x_3^{t-1}, x_2^t = x_3^{t-1}, x_3^t = \overline{x_2^{t-1}}. \quad (4)$$

Correspondently with the above steps of creating a Boolean model, the CCDD module reads (4) from the input format and builds the equations for a one-step transition in the system (4) using (3).

$$\Phi_1(x^0, x^1) = \overline{x_1^1} \wedge x_2^0 \wedge x_3^0 \vee x_1^1 \wedge \overline{x_2^0} \wedge \overline{x_3^0} \vee \vee \overline{x_2^1} \wedge x_1^0 \vee x_2^1 \wedge \overline{x_1^0} \vee \overline{x_3^1} \wedge \overline{x_2^0} \vee x_3^1 \wedge x_2^0 = 0 \quad (5)$$

The CCPS module generates according to Φ_1 the Boolean equations for k-step transition (k=2):

$$\Phi_2(x^0, x^1, x^2) = \Phi_1(x^0, x^1) \vee \overline{x_1^2} \wedge x_2^1 \wedge x_3^1 \vee \vee x_1^2 \wedge \overline{x_2^1} \wedge \overline{x_3^1} \vee \overline{x_2^2} \wedge x_1^1 \vee x_2^2 \wedge \overline{x_1^1} \vee \vee \overline{x_3^2} \wedge \overline{x_2^1} \vee x_3^2 \wedge x_2^1 = 0 \quad (6)$$

Let us verify the main reachability property formulated as follows. Any trajectory starting from the set of initial states X^0 reaches the goal set X^* [1]. The specification of the reachability property in the language of predicate logic has the form [1]:

$$(\forall x^0 \in X^0)(\exists t \in T)(x(t, x^0) \in X^*).$$

The next logical equation correspond to this specification and the equations of dynamics (4)

$$(G^0(x^0) \vee \Phi_k(x^0, x^1, ..., x^k)) \vee (\vee_{i=1}^k \overline{G^*}(x^t)) = 0.$$

Let $X^0 = \{x \in X : x_1 = 0\}$, $X^* = \{x \in X : x_3 = 1\}$. Then $G^0(x^0) = x_1$, $\overline{G^*}(x^*) = x_3$. Φ_2 is given in (6). We get the Boolean model of the reachability property:

$$x_1^0 \vee \Phi_2(x^0, x^1, ..., x^2) \vee x_3^1 \vee x_3^2 = 0. \quad (7)$$

This Boolean model is converted to DIMACS format in which the variable is represented by its index. For x_i^t the index is calculated as $i + 3t$ when $i = 1,2,3$ and $t = 0,1,2$. The index is negative if the variable in (7) has the logical negation. The model (7) in DIMACS format for SAT solver takes the form (disjuncts are separated by «0»):

p cnf 9 15

-1 0 4 -2 -3 0 -4 2 3 0 5 -1 0 -5 1 0 6 2 0 -6 -2 0 7 -5 -6 0

-7 5 6 0 -8 4 0 8 -4 0 -9 -5 0 9 5 0 -6 0 -9 0

The SAT solver answers “UNSAT” therefore the reachability property is satisfiable [1], what can be seen from the transition diagram shown in Fig. 3.

The user needs to specify the input (A^0) and output (B^0) parameters for the non-procedural formulation of the T problem on the KB model in the web-interface of the user agent (Fig. 1): $T=(A^0=\{F, f, n, k, X^0, X^*\}; B^0=\{\text{BMR,Y_R}\})$ (Fig. 4). After launching the task, the problem solving process is performed automatically. As a result of logical inference, an active group of agents $Ag^* = \{Ag1, Ag2, Ag5, Ag6\}$ is formed (highlighted in Fig. 4). Decentralized control of the Ag^* active group and the problem solving based on direct agents interactions are supported by FSMwVW agents behavior model described in [7]. After the task is completed, the user receives the solving result – a Boolean model and a sign of the reachability property satisfiability (Y_R = TRUE).

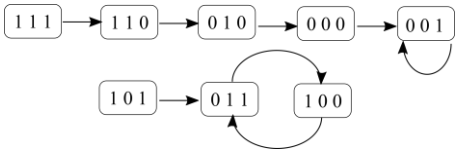

Figure 3. State transition diagram

IV. Subsystem for Solving Boolean Equations

The subsystem for solving Boolean equations includes the following components (software modules) developed by the authors: the complete search sequential solver BESS (Boolean Equations System Solver) intended to find all (or k) solutions, the parallel SAT solver Hpcsat and the QBF solver Hpcqsat. External shareware sequential SAT and QBF solvers can be connected to Hpcsat and Hpcqsat as base solvers. The description and evaluation of the effectiveness of Hpcsat are given in [19].

A. BESS Solver

The solver BESS (Boolean Equations System Solver) is implemented using the C programming language and based on the full search method, combines the constraint propagation technique with intelligent backtracking using a look ahead strategy. The basic idea of intelligent backtracking is to track the last change in the value of the variables and, in failure, return not to the nearest vertex of the search tree, but to the one to which the values leading to inconsistency of Boolean constraints were assigned. The BESS solver was used to compare the proposed declarative approach with the procedural one, based on

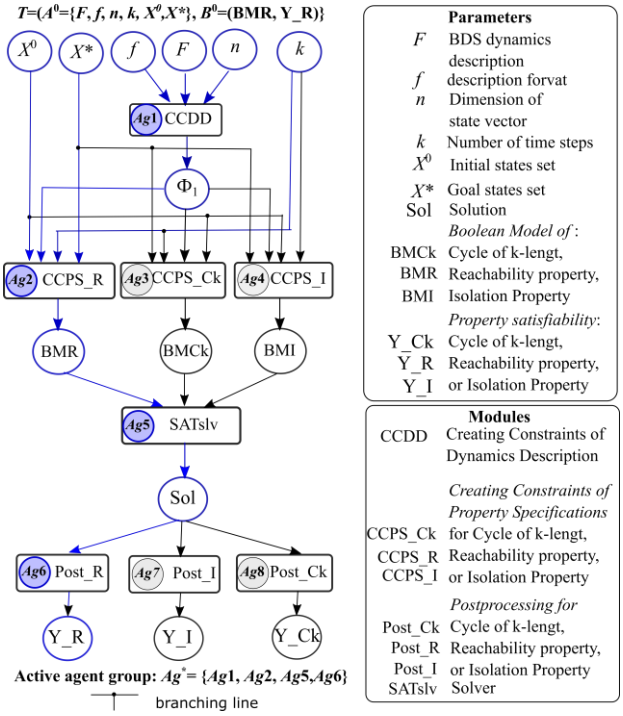

Figure 4. The fragment of computational model

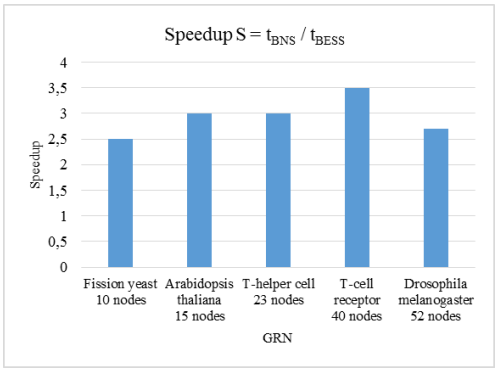

Figure 5. The comparison of BNS and BESS for problem of equivalent states search in Boolean models of GRN with different nodes number

which the solver BNS [8] was developed for attractors searching in the Boolean network. As an example, the Boolean models of gene regulatory networks (GRN) given in [20] were chosen. Based on the method of Boolean constraints Boolean models were constructed for checking the properties of the presence of equilibrium states in the GRN models. The results of BESS speedup compared to BNS are shown in Fig. 5. The declarative approach to solving these problems gives a speed advantage three times more than the procedural approach offered in [8]. The search for all solutions is required for solving some problems. In particular, the BESS solver has used for the finding a basin of an attractor and a domain of attraction. A parallel solution of large-scale problems is carried out using BESS as the base solver in Hpcsat. Here and below, the sequential solver, which is launched in the slave processes of the based on message passing interface (MPI) technology parallel solver is called the base solver.

B. A Parallel Solver Hpcqsat

The satisfiability verification of some dynamic properties of BDS (in particular, the properties of connectivity and total reachability) based on the method of Boolean constraints requires solving the QBF problem. The parallel solver Hpcqsat developed by the authors is focused on a 2QBF, in the form of which a Boolean model of the dynamic property is formed. Based on the master-slave architecture Hpcqsat solver uses data parallelism by splitting the original QBF. A sequential QBF solver solves the subproblems as independent subtasks in slave processes.

The parallel solver Hpcqsat is based on partitioning search space approach and implemented using MPI technology in C++ language. In the master process, the building of the splitting tree of search space and the control of the slave processes functioning is performed. The master process performs initial splitting the Boolean model and controls the queue of subtasks. The slave process performs the following functions: deeper splitting submodels, their simplification, and launch of base solver finding solution for this submodel. The simplification procedure is based on the constraint propagation method, as a result of which the values of other variables can be obtained, or the solution of this submodel can be found. The splitting procedure regulates (if possible, equalizes) the complexity of the subtasks, splitting first the submodels with the largest count of variables remaining

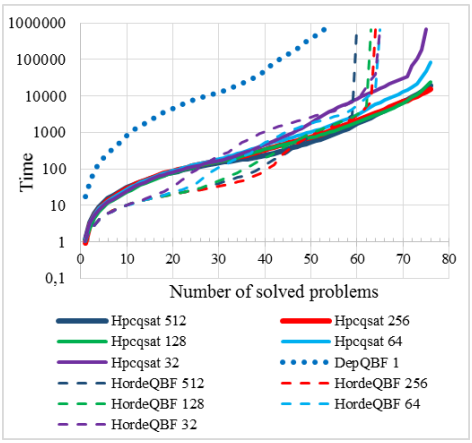

Figure 6. The comparison of DepQBF, Hpcsat and HordeQBF for 76 random 2QBF instances. The cores number is shown in the legend

after the simplification. In the first case, after completion of the simplification process, *k* variables remain unmarked in the submodel; this number *k* is taken as the subtask complexity. This approach balances slave processes by maintaining the tasks number in the queue according to the free resources number. The computational experiments are conducted using resources of Irkutsk Supercomputer Center of SB RAS [21] to compare Hpcqsat with a similar parallel solver HordeQBF [22]. As a base solver, DepQBF [23] is used in both Hpcsat and HordeQBF. The shareware versions of HordeQBF and DepQBF are installed on computational cluster "Akademik V.M. Matrosov" for experiments. Fig. 6 shows the results of the first experiment – the number of instances solved for a given time limit (168 hours). These 76 instances are selected from the test of 2QBF problems [24]. As a selection criterion, the solution time (no less than 17 seconds and no more than a given time limit) of these instances solved by the sequential solver DepQBF was used. According to these results, only the Hpcqsat solved all these 76 instances. Table 1 shows the statistical results data of a second computational experiment on a set of another test of 2QBF problems [25] selected with the analogical criterion. The average solution time is the quotient of dividing the total time of solving selected instances to their number. The limitation on the solution time for one instance in the second experiment is 4800 seconds. The results of these two experiments show a significant

TABLE I. COMPARISON OF HPCQSAT AND HORDEQBF

Processor cores	Characteristics	Hpcqsat	HordeQBF
64	Total runtime	2487,37	27798,72
	Average runtime	138,19	1544,37
	Number of unsolved problems	0	2
256	Total runtime	1049,75	26657,28
	Average runtime	58,32	1480,96
	Number of unsolved problems	0	4
512	Total runtime	855,86	29615,28
	Average runtime	47,55	1645,29
	Number of unsolved problems	0	6

advantage of the developed Hpcqsat solver. The differences between Hpcqsat and HordeQBF are as follows: 1) HordeQBF solver is based on the “portfolio” approach, and Hpcqsat uses the search space partitioning; 2) Hpcqsat does not use learning, and HordeQBF uses the exchange of conflicting disjuncts; 3) Hpcqsat manages the queue of subtasks for the slave processes.

Computational experiments were carried out, confirming the substantial advantage of the developed parallel solver Hpcqsat based on partitioning search space approach in comparison with the analogous solver HordeQBF based on a "portfolio" approach. A parallel software implementation of the logical method for solving problems of the qualitative analysis of BDS was performed. The developed software can be used during conducting computational experiments in various subject areas, wherein the process of research discrete Boolean models arise. It should be noted that the method of Boolean constraints [1] is a quite general method of qualitative analysis of BDS on a finite time interval. This method was also applicable to autonomous BDS; systems with control inputs; systems with a memory depth of more than one; systems of a general form, for which the transition function is implicitly specified.

V. Conclusion

Based on the multi-agent technology for implementing the Boolean constraint method, the microservice-oriented MSQABDS system is developed. MSQABDS automates the distributed solution of qualitative analysis problems for the BDS. The integration in one model of both the description of the property and the equations of the dynamics of a specific object is the unique feature of the models created on the Boolean constraints method basement. Reduction of the problem of the qualitative analysis to the solving of SAT and TQBF problems allows the data parallelism and high scalability with an increasing dimension of the problem. The developed technology is of great practical significance due to the extensive use of BDS as models in both theoretical and applied research.

Acknowledgment

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Exploring Keystroke Dynamics and Stylometry Features for Gender Prediction on Chat Data

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***Abstract*—Online anonymity is considered as one of the great gifts of the Internet, but it also brings dangers to society, such as cybercrime, online sexual abuse and bullying, and love scams. Many people are fond of chatting online to make new friends, but how can they be sure that the person sitting behind the other computer is really the person they claim to be? By studying stylometry and keystroke dynamics features from chat data, it is feasible to reveal the actual gender of an online user. In this paper, we examined stylometry and keystroke dynamics features from chat data, and proposed a Random Forest based gender prediction approach by analyzing these features. In order to evaluate the effectiveness of the proposed approach, a data acquisition was conducted to capture the keystroke dynamics and text information when participants were chatting remotely via Skype. All participants were invited to chat freely on any topic they prefered in order to get to know each other. Based on our experimental result, the proposed approach achieved 72% prediction accuracy by analyzing on this free-text data captured only in 15 minutes.**

Keywords*—gender prediction, keystroke dynamics, stylometry, free-text.

I. Introduction

Nowadays, people are absolutely dependent on the Internet for their daily life to do business, to entertain, to communicate, etc. One of the great gifts of the Internet is the online anonymity, which protects the user's identity from being stolen or misused by other parties [1]. However, online anonymity is a double-edged sword, which also favors the bad guys to commit cyber-crime, cyber-bullying, online sexual abuse, love scams, etc. Especially, online sexual abuse has made children extremely vulnerable to child predators, as children are more exposed on the Internet than ever before. Several tragedies have happened where young children were contacted and threatened by a sexual predator who normally associated with a fake profile. A recent example of the use of a fake profile was between a young Norwegian boy and a predator on a social media application. In this particular case the boy was extorted and this led to him taking his own life [2]. If an ongoing chat conversation would be analyzed and reveal the true identity details (such as gender or age) of the chat-partner to young Internet user, such tragedies might be prevented in the future. Therefore, in this paper, we focus on predicting the chatter's gender by analyzing the online chat data.

While discussing online chat data, there are two types of information that can be captured and analyzed: textual information typed by the user and keystroke dynamics (KD) information which represents the user's typing rhythm. Analyzing the textual information to recognize authorship is often referred to as stylometry analysis. This has been primarily studied for the purpose of forensic authorship analysis. According to the classification in [3], stylometry features can be categorized as: character-based (e.g. percentage of upper case symbols), word-based, syntactic (usage of punctuation), structure-based (e.g. average number of messages per paragraph), function words (to express mood or attitude), n-grams, etc. According to [4] can these stylometry features can be used for gender classification. Conventional stylometry analysis depends on a relatively long text, such as, a full paragraph or chapter from a book, or even the whole book and are difficult to apply to short texts like a text message sent via a social media application, or the 140 characters posted on Twitter [5] [6].

KD is a behavioral biometric which identifies or recognizes users based on the way they type on their keyboards. It can be collected unobtrusively without disturbing the user [7]. In KD we measure when a key is pressed and when it is released and from that we can determine various features, in particular the duration of a key (how long it is held down) or the latency between two keys (time between releasing one key and pressing the next one). Besides identification and authentication has KD been widely used for soft biometric goals such as emotional state detection [8], age detection [9] and gender detection [10].

In this paper, we focus on developing and analyzing the stylometry and KD features which can be extracted from single message sent out from an online chat conversation. The remaining of this paper is organized as follows: Section II overviews related work on the various methods of gender detection, and section III will describe the details of feature extraction method and the proposed gender prediction approach based on KD features; Section IV reports the data acquisition and parameter setting; Section V gives the experimental results and discussion; finally, conclusion and future work are discussed in Section VI.

II. Related Work

Applying KD to predict the gender has gained attention from various researchers. Giot and Rosenberger [11] presented

a method for gender recognition using KD with more than 91% of accuracy. They used the GREYC keystroke benchmark database and extracted different features from each sample. These features were related to the press and release of two consecutive keys, in particular press-press time, press-release time, release-release time, and release-press time. They also investigated the combination of all 4 features. Support Vector Machine (SVM) was used as the learning method to classify the gender, and the best result was achieved by using the combination of the 4 timing features. Fairhurst and Da Costa-Abreu [10] tried to classify the gender of users in a social network environment using the same GREY keystroke benchmark dataset, and they used K-Nearest Neighbour (KNN), Decision Tree (DT), and Naive Bayes (NB) as classifiers. Furthermore they also explored combining these three classifiers using three fusion techniques: (1) Dynamic Classifier Selection based on Local Accuracy class (DCS-LA); (2) Majority Voting; and (3) Sum. It was shown that the DCS-LA method performed best for gender classification.

Pentel [12] tried to predict the gender and the age of the user from KD data features. He did not only use latency and duration information, but for example also information about making corrections. In addition to keystroke dynamics data did he also include mouse dynamics features. He applied Logistic Regression, SVM, KNN, and Random Forest (RF) for binary classification, and finally, he showed that RF performed best for age and gender prediction. For gender prediction he obtained an f-score of 0.73.

Recently, Tsimperidis et al. [13] achieved a good accuracy (95%) for gender classification by KD. They calculated the average values of keystroke durations and press-press (PP) latencies. Several classifiers such as RF, SVM, NB, Multi-layer perceptron, and Radial Basis Function Network (RBFN) were tested. It was illustrated that RBFN had the best accuracy and had a good time complexity, while SVM showed the second best accuracy but it was the second slowest method for gender detection.

Tsimperidis et al. [9] created a database with 'IRecU', which is a free text keylogger, to predict the age of the users. He used Artificial Neural Network (ANN) to predict the age of a user, and it was shown that as he decreased the number of age classes to the three the performance became better than when useing four age classes. Pentel [12] tried to classify the 10-15 years old users against all others by using Keystroke Dynamics and mouse patterns; he used f-score as a performance metric, and among the different types of classification methods, RF achieved the best result for age detection with f-score 0.73, same as for gender recognition.

III. Proposed Approach and Its Features Investigation

In this section, we first describe the stylometry and KD features that could be used for predicting the user's gender. Secondly, a RF based classification gender prediction will be proposed by analyzing the KD features extracted from 20 letter bigrams.

A. Stylometry Feature Extraction

Online chatting is different from writing an essay or composing an email. Such tasks are normally carried out individually and provide relatively long time for thinking and preparation. Online chatting is an interaction between two (or more) users, each sitting behind their own computer and expecting to receive a response from the chat partner shortly after sending their own message. By considering natural characteristics of male and female, we think the response time from male users may be different (in particular shorter) than that of female users. Such shorter response time may also lead to more typing errors in terms of key deletions. Due to the limited amount of text involved in a short online conversation, conventional stylometry features (such as the frequency of preferred words by male or female) would not be effective in our analysis. Therefore, the following four stylometry features will be extracted from a short online conversation:

- **Average thinking time:** this is the time between two messages, in particular we measure the time duration between releasing the last key for one message and the time when the user presses the first key for the next message. Then we calculate the average value for all time durations generated from that user in an online conversation.
- **Ratio value of key deletion:** ratio value is calculated by the number of all deleted keys divided by the total number of keys typed by that user in an online conversation. This ration can be calculated based on the knowledge of all keys typed by a user, including the number of times the backspace key and the delete key are used to remove keys from the final output.
- **Average number of letters in a word:** we count the number of letters in all words typed by the user in an online conversation, then calculate the average value to represent this feature. Note that the words with less than 4 letters are excluded.
- **Average number of words in a message:** the total number of words divided by the number of messages is the feature value.

B. Keystroke Dynamics Feature Extraction

KD features are extracted from the 20 most common letter bigrams in a English corpus [14]. These bigrams and their frequencies are listed in Table I. From each bigram, we extract 6 KD features which have been proofed for their discriminability on user authentication by other researchers [15], [16], [17]:

- f_1 : the duration of first letter, which is the time elapse between pressing the first key and releasing that key.
- f_2 : the duration of second letter, which is the time elapse between pressing the second key and releasing that key.
- f_3 : the latency between first key released and the second key pressed, which is the time difference between releasing the first key and pressing the second key.
- f_4 : the latency between first key pressed and the second key pressed.

- f_5 : the latency between first key released and the second key released.
- f_6 : the duration of the first key pressed and the second key released.

According to these definition, features f_1, f_2, f_4 and f_6 are always positive, yet features f_3 and f_5 could be negative.

Table I. SELECTED BIGRAMS FOR KEYSTROKE DYNAMICS FEATURE EXTRACTION AND THEIR FREQUENCY ACCORDING TO [14]

Bigram	Freq.	Bigram	Freq.	Bigram	Freq.	Bigram	Freq.
th	1.52	he	1.28	in	0.94	er	0.94
an	0.82	re	0.68	nd	0.63	at	0.59
on	0.57	nt	0.56	ha	0.56	es	0.56
st	0.55	en	0.55	ed	0.53	to	0.52
it	0.50	ou	0.50	ea	0.47	hi	0.46

C. Keystroke Dynamics based Gender Prediction

The proposed KD based gender prediction approach consists of two stages: first stage is to predict the gender for each message; second stage is to merge the prediction results from all messages to produce a final prediction. Note that when we classify a whole conversation, we mean in this paper the classification of each of the chatters, based on only the messages of that chatter in that conversation. So the actual conversation between two chatters is processed twice, once to determine the gender of one chatter, and next to determine the gender of the other chatter. For simplicity's sake we will just refer to classification of a conversation while we actual mean the classification of one of the chatters in that conversation

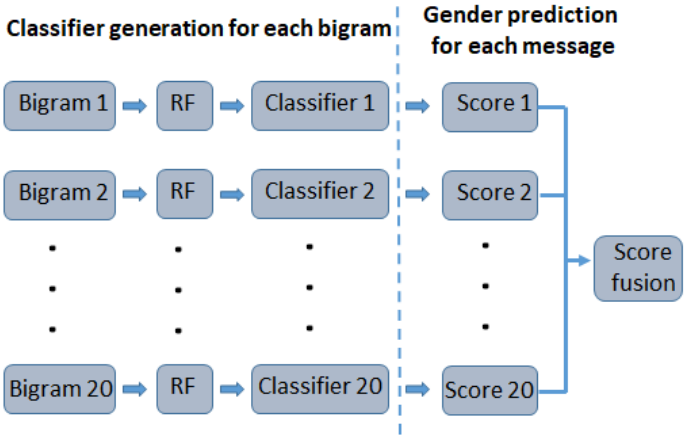

Figure 1. The diagram of a Random Forest (RF) based gender prediction approach by analyzing the keystroke dynamics features.

Figure 1 illustrates the core procedures of first stage prediction, which adopts RF as the classification technique to generate a classifier for each bigram. Each of the RF classifiers is trained to recognize 2 classes, 0 for female and 1 for male. The resulting classification score is value in the range $[0, 1]$, where a score less than 0.5 indicates female and a score over 0.5 indicates male. Each message contains a subset of the 20 bigrams that we consider in our analysis and each such bigram will result in a score for the classification into male or female. To classify that message, score fusion is used. In particular is the median value of the bigram scores calculated. Here again, the message is classified as female if the resulting fusion score is below 0.5 and as male if the resulting fusion score is above 0.5. We did also test with using the mean of the bigram scores for the score fusion, but we found that using median gave a better performance.

After obtaining the fusion scores of each of the messages in a conversation, in the second stage the fusions scores and classification of each of the messages in that conversation are considered. Each of these messages has a fusion score as well as a classification as male or female. In order to classify the whole conversation, we perform simple majority voting (MV) on the classifications. For example if out of 16 messages 12 are classified as male and 4 as female, then the whole conversation is classified as male.

However, it is possible that, with an even number of messages in a conversation, half of the messages is classified as male and the other half as female. This tie can not be solved using simple MV. In this case we use the fusion scores of each of the messages. Assume that in a conversation n messages are classified as male, with fusion scores $(M_1, M_2, ..., M_n)$, where each M_i value is between 0.5 and 1. There are also n messages in that conversations classified as female and the fusion scores of these messages are denoted by $(F_1, F_2, ..., F_n)$, and now each F_i is between 0 and 1. We now calculate 2 values as follows:

$$Average_M = \frac{1}{n}\sum_{i=1}^{n}(M_i - 0.5) \quad (1)$$

$$Average_F = \frac{1}{n}\sum_{i=1}^{n}(0.5 - F_i) \quad (2)$$

Each of these averages will be an indication of how certain the first stage classifier was in determining that the message classified as male/female are indeed from a male/female chatter. A lower value indicates less confidence and a higher value more confidence. Keeping that in mind, we will (in case of a tie for MV) classify the full conversation as female if $Average_F > Average_M$ and as male otherwise.

IV. DATA ACQUISITION AND PARAMETER SETTING

A. Data Acquisition

In order to be as realistic as possible, we set up two identical computers at different locations and connected via Internet and we invited the participants who did not know each other from before. Each participant was asked to chat with other participant and get to know him or her. Each chat lasted about 15 minutes and Skype was used as it is a commonly used social media application. A logging tool called BeLT [18], developed in our laboratory, was used to capture all KD information during the chat. There was no topic specified for the conversation. Participants were asked to chat as normal as possible and try to get to know each other a bit.

B. Parameter Setting

There were 45 participants joining the data acquisition of which there are 10 female participants and 35 male participants. Even though this is an unbalanced dataset, we made sure that the amount of data for training the classifier was evenly balanced, such that there is no gender bias in the classifier output. This however means that the testset is highly unbalanced. In addition, the thresholds used in the evaluation will be cautiously selected in order to be neutral during prediction. For instance, the predicted gender will be male if the generated score S from the classifier is $0.5 < S \leq 1$, and the predicted gender will be female if such score satisfies $0 \leq S < 0.5$.

The proposed approach was implemented and evaluated in Python. We call the RF function from *sklearn* with 3-fold cross validation. During cross validation, 2/3rd of the data is used for training and the rest of the data is used for testing. In order to find the optimal values for the number of trees in the forest and the depth of tree, we developed a random search function with two parameters: the number of trees ranges from 200 to 2000, and the depth of three ranges from 100 to 500.

V. Performance Analysis and Discussion

A. Performance Analysis on Keystroke Dynamics Features

In order to confirm the discriminability of the selected 6 KD features, we list the average values for two bigrams (from Table I) from 10 randomly selected male subjects and 10 female subjects. In Table II, we can see the difference between male and female subjects.

Table II. Selected bigrams for keystroke dynamics feature extraction and their frequency according to [14]

Bigram	f_1	f_2	f_3	f_4	f_5	f_6
th of male	79	70	38	117	108	187
th of female	70	75	67	138	143	213
ha of male	72	83	46	118	130	202
ha of female	78	95	60	139	156	234

Table III. Gender prediction accuracy based on keystroke dynamics features with different amount of training data.

Num. of training subjects	Num. of testing subjects	Prediction accuracy
5 female and 5 male subjects	35	53.33%
10 female and 10 male subjects	25	72%

Because of the uneven number of male and female participants, we were very cautious about the parameter selection to avoid biased training. During the classifier creation phase, the amount of KD features selected from the male subjects and female subjects are absolutely equal. Testing is done only with the data of participants that is not used during the training of the classifiers, i.e. the training and test dataset are disjunct. Table III gives the gender prediction accuracy by using different amounts of features during the training phase. As we can observe, the prediction accuracy can be significantly improved with a small increase of the training data. As this study was conducted on free-text KD analysis based on only 15 minutes conversation, we think that 72% accuracy is an encouraging result. We believe the accuracy could be boosted when we gain more data to build the classifier.

B. Data Analysis on Stylometry Features

The chat data was separated into message based data for generating the statistics of four stylometry features: average thinking time, ratio value of key deletion, average number of letters in a word and average number of words in a message. Note that these four features were extracted from message based data, which indicates that the time for awaiting the response from other user is excluded for the statistics.

Tables IV – VII give the statistics in terms of median value, mean value and standard deviation regarding these four features. Figures 2 – 5 plot all feature values, where each mark represents a value calculated from one subject.

As we can see in Table IV, the median value for male's average thinking time is 393.7 ms while it is 506.5 ms for female subject. With respect to the ratio value of key deletion, the mean and median values for male subject are 0.0406 and 0.0382 respectively while they are 0.027 and 0.0268 for female subject. These considerable differences confirm our early assumption that these two features have the capability to distinguish the male from the female subjects in an online chat. This discriminability can also be observed from Figure 2 and Figure 3. However, we could not find the discriminability for the average number of letters in a word and the average number of words in a message as seen in Tables VI – VII and Figures 3 – 5.

Table IV. Median, mean and standard deviation of average thinking time (ms).

Gender	Median	Mean	StDev
Male	393.7	565.9	421.7
Female	506.5	591.1	615.3

Table V. Median, mean and standard deviation of ratio value of key deletion.

Gender	Median	Median	StDev
Male	0.0382	0.0406	0.0189
Female	0.0268	0.027	0.0158

Table VI. Median, mean and standard deviation of average number of letters in a word.

Gender	Median	Mean	StDev
Male	4.0034	4.0079	0.22
Female	3.9898	3.9547	0.1579

Table VII. Median, mean and standard deviation of average number of words in a message.

Gender	Median	Mean	StDev
Male	9.6667	10.0761	2.6963
Female	8.3523	8.9136	1.6134

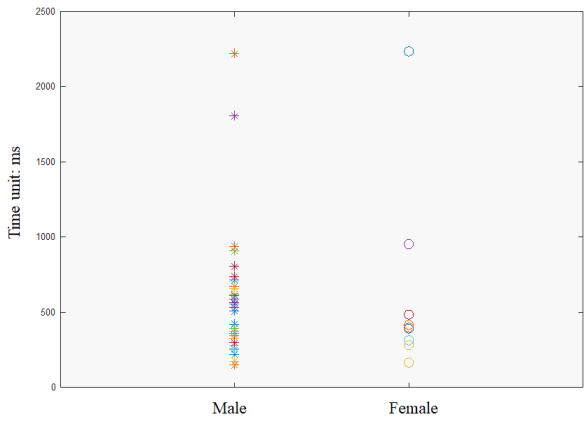

Figure 2. Average thinking time between two messages: each remark represents such average thinking time for one subject.

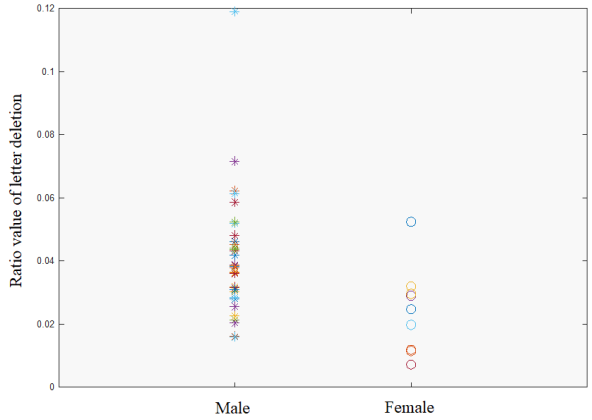

Figure 3. Ratio value of key deletion: each remark represents the ratio value of letter deletion for one subject.

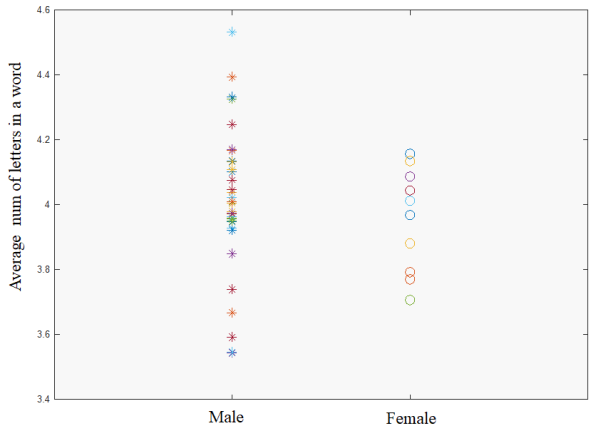

Figure 4. Average number of letters in a word: each remark represents such value for one subject, and this statistics excludes the words which has less than 4 letters.

Besides the above statistics, these stylometry features were also used to form a feature vector for training the RF classifier. As the KD feature based classification achieved the best prediction accuracy by using 10 male/female training subjects, we followed the same strategy and the prediction accuracy for stylometry features is 64% when the same amount of stylometry features extracted from 10 male/female training subjects were used to build the classifier.

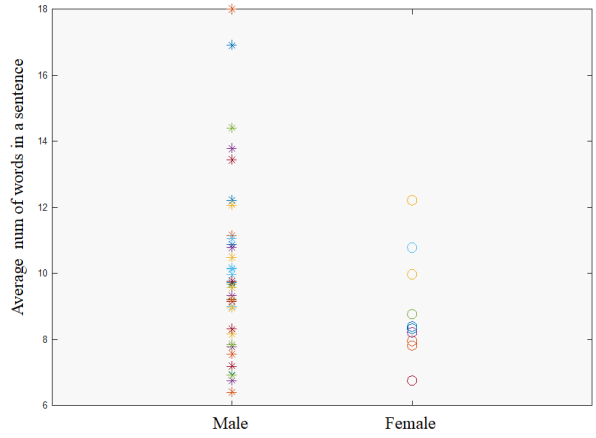

Figure 5. Average words of words in a message: each remark represents such value for one subject.

C. Score-level Fusion and Impact of Messages' Length

After separately analyzing the KD features and stylometry features, it is interesting to consider the combination from these features. As the KD based classification is built on individual bigram features and not all bigrams can present in a short message, we analyzed a score-level fusion approach instead of feature-level fusion. The prediction accuracy from the score-level fusion approach remains at 64% with equal weights assigned to scores generated from the KD based classifier and the stylometry based classifier.

As the length of message always varies and shorter message normally leads to less bigrams, it is also interesting to investigate the impact of messages' length from the performance perspective. Thus, we group the messages into three classes according to the number of typed keys in the message: (!) short messages (less than 20); (2) intermediate messages (between 20 keys and 40 keys); and (3) long messages (more than 40 keys). Tables VIII and IX give the prediction accuracy for KD features and for stylometry features respectively, when we consider the messages consisting of a certain number of keys. As we can observe, longer messages lead to better performance for the KD based approach, while the predication accuracy can be significantly improved when we only consider the message with more than 40 keys.

VI. Conclusions and Future Work

In this paper we investigated the Keystroke Dynamics and stylometry features for predicting the gender by analyzing the chat data. A Random Forest based classification approach

Table VIII. GENDER PREDICTION ACCURACY BASED ON KEYSTROKE DYNAMICS FEATURES WITH DIFFERENT LENGTH OF MESSAGES. THESE RESULTS ARE BASED ON THE TRAINING SET CONSISTING OF 10 FEMALE AND 10 MALE SUBJECTS

Length of message	Prediction accuracy
short message with less than 20 keys	52%
intermediate message with 20-40 keys	68%
long message with more than 40 keys	76%

Table IX. GENDER PREDICTION ACCURACY BASED ON STYLOMETRY FEATURES WITH DIFFERENT LENGTH OF MESSAGES. THESE RESULTS ARE BASED ON THE TRAINING SET CONSISTING OF 10 FEMALE AND 10 MALE SUBJECTS

Length of message	Prediction accuracy
short message with less than 20 keys	48%
intermediate message with 20-40 keys	44%
long message with more than 40 keys	84%

is also proposed to predict the gender by studying the KD features generated from 20 bigrams. In addition, we invited 45 participants to chat online with someone they never met before, for approximately 15 minutes, in order to evaluate the performance. The proposed RF classification was combined with a score-level fusion and a majority voting mechanism to predict the user's gender, and achieved 72% prediction accuracy. By analyzing the stylometry features on the collected data, we conclude that the pausing time between two messages and the letter deletion (or typo correction) have the capability to distinguish between a male and a female subject.

We think the presented work in this paper is a preliminary result, but revealed the feasibility of predicting the user's gender in a short online chat conversation. Regarding future work, there are many possibilities to explore and further improve the performance. Foremost we intend to extend the dataset with more participants, more data per participant (i.e. longer chats), while ensuring a more balanced gender distribution. Besides that we can also:

- consider the features from trigrams (instead of using only bigrams);
- consider more conventional stylometry features, such as the frequency of selected words, or words preferred by male or female, the number of punctuation, etc.;
- design different fusion mechanism when fusing the scores at message-level, as length of message affects the performance.

Predicting gender can be used to warn a chatter that the gender in the profile of the chat partner is not correct, for example a male subject trying to impersonate a female. In such a case, the chat partner of this impersonator would like to be warned as soon as possible about the incorrectness of the gender and not only find this out when a chat conversation has ended. For this we would like to extend this work such that a system continuously predicts the gender, based on the current and all previous messages received. Clearly, such a continuous gender prediction system needs to reach a certain level of assurance before a potential deviation between the claimed and determined gender is reported.

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People Counting in a Public Event—Use Case: Free-to-Ride Bus

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***Abstract* – In the case of traditional bus travel, there are many ways to gather statistics on bus passengers. Paid tickets can directly contain information about the stop at which the passengers came aboard and where they got off. Alternatively, stamping or reading travel cards can be used to obtain similar statistics. In the case of a free-to-ride bus service, these simple methods are generally not available. Yet, for further route and capacity planning, producing exact – or at least informative – statistics is crucial.**

This paper presents a real-life use case of collecting statistics about bus passengers on a free-to-ride bus route at a large public event in the summer of 2018 in Pori, Finland. The use case utilized cost-effective and off-the-shelf components such as the Raspberry Pi 3 computer, position sensors, cameras, and the Open Source Computer Vision Library version 3. The hardware and software components of the system, which was based on image analysis and shape detection, as well the results of the study, are explained in this paper. Furthermore, this paper presents a discussion on the challenges faced while developing and implementing the system.

***Keywords* – Raspberry Pi; image analysis; sensors; People count; Free-to-ride; public transport**

I. INTRODUCTION

In the case of traditional bus travel, there are many ways to gather statistics on passengers. Paid tickets can directly contain information about the stop where the passenger came aboard and where he/she got off. Furthermore, monthly tickets are a convenient means of payment, but they do not give enough information about the actual traveling. For example, cities wish to determine the number of bus passengers per stop, incoming and outgoing. This information can be used to design bus schedules and routes. This study focuses on a free-to-ride bus service, and therefore people counting methods using ticket information are not available.

In this study we present a prototype system for collecting statistics about bus passengers on a free-to-ride bus route. In this prototype we use cost-effective and off-the-shelf components such as a Raspberry Pi 3 computer, position sensors, and cameras. These devices are commonly used in different kinds of prototypes [1-3]. The prototype system software is based on the Open Source Computer Vision Library (OpenCV) [4]. People counting has been handled in several studies [5-7]. In addition, a wireless sensor network for people counting was introduced by [5]. They used images taken by vision sensors and processed them in a heterogenous network. In this study the references about people counting are extensively discussed. Furthermore, one research study [6] counted people in a queue using low-cost, off-the-shelf devices. In their study the devices used were the Raspberry Pi and a web camera. The proposed queue monitoring algorithm was implemented with Python and the OpenCV library. The accuracy of the proposed system was 95% for people counting and 86% for queue notification.

One research study [7] counted people in a bus using the IR sensors on both the front and rear doors. The sensors were equipped with Arduino. A GPS sensor was also used to obtain the location. The communication between Arduino and an Android phone uses Bluetooth and the phone sends the data to the cloud server.

The construction of this paper is as follows. In section II, we review the use case of this prototype system. The construction of our system and the proof-of-concept implementation is explained in section III. In section IV we describe the testing process of the prototype. The results of the use case are presented in section V. The discussion of challenges are in section VI, and finally section VII summarizes the paper.

II. USE CASE: FREE-TO-RIDE BUS

In this study, the use case was "Statistics on incoming and outgoing users by bus stop on a free-to-ride bus route." In addition, the aim was to find a cost-effective way to count bus passengers. The bus route in question was established to serve visitors at a Housing Fair. The fair was held in Pori from July 6 to August 5, 2018. The Housing Fair is an annual event in Finland where the current and future trends in the housing industry are introduced – architecture, building, materials, interior design, furnishing, and landscaping. There were about 120,000 visitors [8].

The motivations for this research were:

- To find out whether cost-effective devices could be used to implement the system (component reliability, performance requirements for image analysis).
- Optimization of routes requires details of ridership for future Housing Fair events.
- The City of Pori wished to know how many of the people visiting the event also visited the city.

- To find out from where to where people traveled.

The last two were addressed because this information was needed by the City of Pori. The results did not have to be perfect, only to give a general idea of which bus stops were more popular than others. In fact, the primary reasoning was that people who also visit downtown Pori bring money to the stores located downtown or otherwise use the city's services.

This prototype people counting system was tested during the Housing Fair and lasted one month. The camera system was installed in one bus on this free-to-ride route. The route had nine bus stops and, depending on the direction of travel, the Fair bus stop was the starting or ending point of the route. The buses stopped at pre-designated stops (i.e., traveled on a fixed route) and the buses, in general, let people off only at bus stops. The other cases were negligible in number and have been ignored.

III. IMPLEMENTATION

The purpose of this study was to implement a system of low-cost components and to explore new technologies. The choice of system components was influenced by their availability in the IT field, their affordability, low power consumption, physical size, and customizability. The primary reasons for choosing Raspberry Pi 3 was cost-effectiveness and its in-built features such as GPIO (general-purpose input/output) pins and WLAN.

Computer vision based visual inspection for image analysis and shape detection technologies were chosen because they are non-destructive methods and no counterpart is needed in the measuring target. The OpenCV library has various algorithms that can track objects such as people. Especially, Haar Cascade and HOG (Histogram of Oriented Gradients) are the most commonly used methods for image recognition and object detection.

A. Hardware

The prototype people counting system consists of a Raspberry Pi 3 computer, a Pi Camera v2, and an Adafruit Ultimate GPS Breakout module. The camera was connected to the Raspberry Pi´s CSI camera port and the GPS module to the GPIO pins. The external GPS antenna was installed in the ceiling of the bus to obtain a stronger signal.

The electrical system of the bus was 24 volts so a voltage converter was needed to power up the prototype system. Raspberry Pi 3 requires a 5 volt and 2 ampere power source. If the bus had had built-in USB charger sockets (which are becoming increasingly more common in newer charter and long-distance buses), the electrical connections could have been slightly simpler to implement. In this case, a commercial DC/DC converter from Traco Power Industrial was chosen for the task. It is able to output 5 amperes at 5 volts, which should be enough for all the components in the prototype system. The complete people counting system consists of two Raspberry Pi 3 prototypes and a 3G/4G wireless modem.

In this study a Huawei E5787 wireless modem was used to handle the remote connection to the prototype service. The modem provides a port forwarding feature, which enabled remote connection via a prepaid data subscription.

B. Software

The Raspberry Pi 3 is equipped with a Stretch Lite version of the Raspbian operating system. Stretch is a fork version of the Debian Linux distro. The Lite version means that there is no graphical user interface and minimal software installed. After installation, it is recommended to upgrade the Raspbian operating system and package repositories instance to the OpenCV library, which allows image recognition and object detection. However, for performance and feature reasons, we wished to use the most recent version of OpenCV (version 3.4 at that time), which was not available on the Raspbian package manager. Therefore we had to compile it ourselves.

In this study, we used Python programming language to create a program to recognize and detect people. All the source codes can be found from the GitHub [9] page created for the project. The code utilizes many features provided by OpenCV, such as routines to capture video frames, the MOG2[10] algorithm to detect the foreground of an image frame, and data types (arrays, matrices and such).

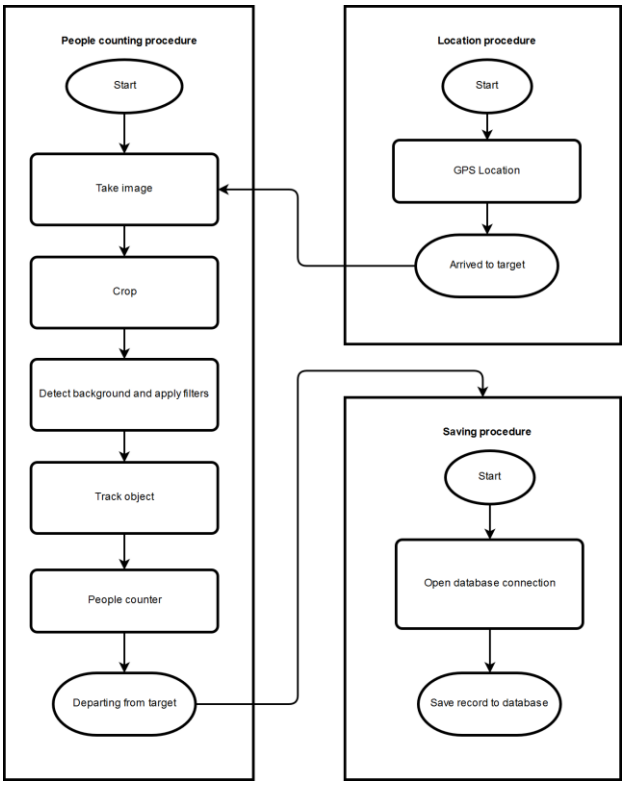

Figure 1. Process chart of the people counting prototype system.

The process chart of the system is presented in Fig. 1. When the prototype is started, the GPS sensor begins to track the location at certain predefined intervals. The prototype system processes the results obtained from the camera when the GPS coordinates are in the range of predefined targets. At first, the image is cropped, then the

background is subtracted and filters are applied. An example image of the detection area is shown in Fig. 2. The area inside the yellow dashed line is the detection area. The red and blue horizontal lines represent the threshold of the count algorithm. The remaining objects in the image are recognized based on their size and shape. Suitable objects are tracked between consecutive images to detect their movement. A selected and moving object which crosses the predefined thresholds is counted as an inbound or outbound passenger based on direction. The collected data record is saved to a database when leaving the target.

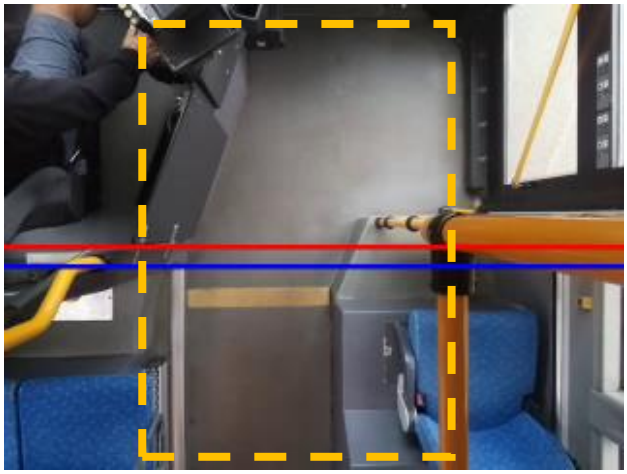

Figure 2. An example of detection area as seen by device.

We had a remote configuration user interface (UI) with the purpose of orienting the camera image, adjusting the set limits, and cropping the image. The UI uses a simple REST API + web page running on Apache Tomcat. The UI requires user authentication and needs to be started every time it is modified. This is a precaution to mitigate the risk of breaking into the device.

IV. Test Process

Our testing method was comprised of actual tests of the equipment and software, and also the verification of the quality of the collected data. The equipment and software tests were conducted in a controlled laboratory environment during a two-month period in a bus running its regular routes.

In-lab trials were performed to make sure that the system really worked and to determine whether it was ready to be transferred to the real environment. The equipment was installed in the ceiling at approximately the same height as it would be on the bus. Also, the geometry of the bus corridor and a bus driver's seat with ticketing machine were made as life-like as possible with typical office furniture. Two persons were then instructed to walk past the detection point as if they were boarding the bus and stopping at the driver's seat to purchase a ticket. To conclude, the system did not have any trouble in detecting the persons even if they walked very fast, very close to each other, or even when they walked in opposite directions. Moving very slowly would make it possible for the system to "forget" the passenger, but it was determined that with a careful setting of detection boundaries the problem could be mostly mitigated.

Verification was done by comparing the data gathered by the equipment to the passenger data provided by the bus company. The data from the bus company included the total number of paying passengers per day and a detailed breakdown of the bus stops where they boarded. It is worth pointing out that the passenger data from the bus company did not include passengers who rode for free nor where they alighted from the bus – and if it had, there would have been no need for our system.

We also conducted some (two during the preliminary tests and two during the event) manual counting of passengers by riding the said bus on its normal route and logging where and when passengers got on and off the bus. Each person that passed through the detection zone in a way that the system should have detected were included in the manual mode counting. All this data helped us to fine-tune the software settings for more accurate detection as well as to define a rudimentary correction coefficient to overcome a systematic error reported by our system.

V. Results

For each bus stop where at least one passenger was detected, the following information was recorded by the system: the GPS coordinates of the bus stop and timestamp of the record, numbers of inbound and outbound passengers, and finally the location of the equipment (i.e., front door or middle door). A record was opened when the bus was near any predefined bus stop (less than 30 meters) where the speed of the bus was below the threshold speed (less than 1 m/s). Once the bus was about to leave the bus stop, and the speed was raised above the threshold speed, the record was finalized and stored with the said information to the database.

Based on two manual passenger count verification runs conducted during the Housing Fair, it was determined that the system was systematically reporting too large a number of passengers. An overall correction coefficient including all bus stops for an inbound passenger count of 0.55 and for an outbound passenger count of 0.68 was determined. A correction coefficient for each bus stop was not calculated due to the sample size being too small.

According to the collected data, the main Housing Fair bus stop had approximately three times more inbound and outbound passengers than the other major bus stops on the route, namely Puuvilla (local shopping mall) and Matkakeskus (travel interchange). The other bus stops between the major bus stops had on average about half as many passengers as the other major bus stops. On the other hand, the total stop count (i.e., a case when any passenger entered or exited the bus) was approximately 400 at both the main Housing Fair bus stop and the Matkakeskus bus stop. The Puuvilla bus stop came in third with approximately 250 stops. The rest of the minor bus stops were stopped at approximately 160 times on average, thus they were utilized significantly less often than the main and major bus stops. The latter, busiest bus stops accounted for 67 percent of total passengers, and 62 percent of total stops.

VI. CHALLENGES

Firstly, because we did not have our own buses to use during the testing period, we were restricted to utilizing the vehicles provided by the local bus company. The primary limitation of this was that we could not make large scale modifications to the buses themselves. All the wiring needed to be done as surface installations, and the camera positions were limited by the structural features of the bus interior. For example, the shape of the ceiling of the bus was in some parts curved, making it more challenging to achieve stable setups. Furthermore, there were a few stanchions inside the bus that could have blocked the view of the camera. Finally, the doors of the bus opened slightly inwards, possibly appearing incorrectly as detected object movement in the camera view. There were no real problems with the installation of the front door camera, but the rear door setup turned out to be more of a challenge, and in the end, less than optimal. In practice, it was possible for the passengers to move about within the view of the rear camera, and to travel through the detection area causing false readings. In a very crowded bus, the problem was much more severe, making the detection process far from reliable.

Secondly, during the trial period, a certain amount of correctly detected passenger movement was later observed to be, in fact, inaccurate. In our case, we did not track individual passengers, and thus, in cases when the same passenger stepped off the bus and immediately returned, duplicate results were obtained. Examples of such cases would be stepping out of the rear door to allow someone else to step in, or the bus driver leaving the bus to help someone on. Additionally, there was a tour guide present on the bus provided by the city, who occasionally stepped off the bus at the stops. During crowded periods these were minor issues, but in the quieter hours, they could appear as significant errors in the detected passenger numbers. In our case, no fool-proof solution for this problem was found, and it is definitely a topic for further studies.

A. Technical Difficulties

In general, the Raspberry Pi proved to have enough processing power for our use case, especially when utilizing relatively simple algorithms. Nevertheless, it was not entirely without problems. One issue was that the device overheated at high load. CPU temperatures exceeding 90 degrees were occasionally observed and during our initial tests the Raspberry Pi would sometimes "hang" or crash, requiring a member of our team to visit the bus to restart the device manually. As a slight oversight, we did not install ambient temperature sensors inside the device casing or around the case during our testing period, which means that we could not obtain accurate temperature readings. Outside daytime temperatures were about +25C during the testing periods, with temperatures reaching over +30C on some days. The bus had air conditioning, but in a crowded bus, the temperatures can still become fairly high. Ultimately, we decided to install custom heat sinks in the Raspberry Pi devices, which kept the device stable during normal operation.

In our use case, all image processing was done on-device. The total amount of video files recorded per day was about 200 MB. The size is not negligible, but neither is it excessive. Thus, it would also be possible to upload the video files to a cloud service for a more resource intensive analysis. This would also require less power from the Raspberry Pi, resulting in lower CPU temperatures.

B. Detection Difficulties

Moving the devices from the controlled laboratory environment to the actual bus resulted in a considerable decline in detection accuracy. The primary problem was with the changing lighting conditions. The ambient lighting varied based on the time of the day and from bus stop to bus stop. Furthermore, people moving in front of the light sources located outside the bus (e.g., the sun, street lamps) caused shadows and/or reflections to appear in the camera view, and these "ghosts" were repeatedly detected as passengers leaving or entering the bus. In rare cases people wearing clothes with colors similar to the color of the bus interior "blended" into the surroundings and were not detected at all or were detected incorrectly.

Because of the fairly northern location of the event - the City of Pori is almost on the 61st parallel north - and the time of year - July-August - there was a reasonable amount of daylight available during the entire day. Based on simple laboratory trials, the detection accuracy should be lower during darker hours, but no specific tests were performed to validate the accuracy in wintertime. Considering the rather long autumn and winter in Finland, a poor detection rate in dark conditions would make the system unusable in practice.

VII. CONCLUSIONS

The tests performed showed significant differences between the laboratory and actual use case conditions. The lighting conditions and the setup of the camera (camera view) play a crucial role in achieving optimal results. Unfortunately, it can be challenging to guarantee stable conditions in real-life scenarios.

Counting people entering and exiting the bus through the front door and the narrower passageway that led to the door was found to be much easier than detecting traffic through the wider area near the bus's rear doors.

In general, the results achieved were acceptable for our use case, though not entirely applicable for very accurate people calculation. The representatives of the City of Pori and the local bus company were primarily interested in estimations of which bus stops people generally entered the bus and where they left the bus, with less focus on the exact passenger numbers. Nevertheless, more studies and improvements to the utilized solution and the detection algorithms would be needed to realize an accurate people counting system usable in a free-to-ride bus in changing conditions.

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Early Forest Fire Detection Using Drones and Artificial Intelligence

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***Abstract* – Forest and urban fires have been and still are serious problem for many countries in the world. Currently, there are many different solutions to fight forest fires. These solutions mainly aim to mitigate the damage caused by the fires, using methods for their early detection. In this paper, we discuss a new approach for fire detection and control, in which modern technologies are used. In particular, we propose a platform that uses Unmanned Aerial Vehicles (UAVs), which constantly patrol over potentially threatened by fire areas. The UAVs also utilize the benefits from Artificial Intelligence (AI) and are equipped with on-board processing capabilities. This allows them to use computer vision methods for recognition and detection of smoke or fire, based on the still images or the video input from the drone cameras. Several different scenarios for the possible use of the UAVs for forest fire detection are presented and analyse in the paper, including a solution with the use of a combination between a fixed and rotary-wing drones.**

Keywords – early forest fire detection platform, drones, UAVs, artificial intelligence, computer vision

I. INTRODUCTION

The most up to date information on the current fire season in Europe and in the Mediterranean area is provided by the European Forest Fire Information System EFFIS [1]. Each year this institution provides annual report on the forest fires in Europe, the Middle East and North Africa. According to the latest report, which they provided for 2017 [2], the dramatic effects of wildfires have caused damages of over 1.2 million hectares burnt natural lands in the EU and killed 127 people, including fire fighters and civilians. Over 25% of the total burnt area was in the Natura 2000 network, which destroyed much on the efforts of the EU countries to preserve key natural habitats and to save the biodiversity of Europe for the future generations. The same report says that these fires caused estimated losses of around 10 billion euros.

Despite these large numbers, EFFIS informs also that the report is showing a decrease in the number of fires, compared to the number of fires, which occurred annually during the last decade. This decrease can be explained with the more severe actions and sanctions to the people that caused the wildfires and with the introduction of more advanced technical solutions for early detection of fires. Obviously, the fight against fires can mitigate the damages, but the numbers, which represent the burnt area and the human lives, are still huge. This reason presents the necessity to constantly develop, implement and upgrade the solutions and systems for fire detection.

The most important factors in the fight against forest fires include the earliest possible detection of the fire event, the proper categorization of the fire and fast response from the firefighting departments.

The aim of the proposed platform is not only to use modern technologies, but also to improve the above-mentioned factors by reducing the fire detection time, by minimizing the false alarms and by issuing of timely responses and notifications to the fire services in case of real forest fires.

In the paper, we discuss the proposed platform for early forest fire detection, which involves two types of UAVs – a fixed-wing drone and a rotary-wing drone. Both UAVs will be equipped with cameras, which will be optical, thermal or both. The fixed-wing drone will constantly patrol the monitored area and will observe the territory below. Since this drone will fly at medium altitude (350 m to 5500 m), it might report false alarms because of the altitude or the lack of clear visibility. If the fixed-wing UAV detects a fire, it will trigger an alarm, which will activate the rotary-wing drone. The rotary-wing drone will then closely inspect the area, where the fire is suspected to have occurred, by using the GPS coordinates provided by the patrol drone. The role of the second drone is to either confirm or reject the alarm bases on its close observation of the area and will then go back to its base station. It will not permanently monitor the targeted area. The reason to use a second drone is to reduce the number of false-positive alarms as the rotary-wing drone will fly at much lower altitude (10 m to 350 m) compared to fixed-wing UAV and will have better and more detailed visibility of the area. If the fire is confirmed, another alarm will be triggered by the rotary-wing drone and the ground level teams and the fire protection departments will be informed.

The platform is completely automated since both drones have on-board computers and processing capabilities. They can detect fires based on the data captured by their thermal cameras and they can process this data without the need for centralized computing engine. In addition and to further improve the platform, we have planned to implement artificial intelligence by allowing the drones to make fire predictions based on computer vision techniques. In order to implement this artificial intelligence solution we will rely on and use neural networks.

The neural networks are currently a very hot topic in the computing systems, because of their ability to "learn" how to perform tasks by considering examples, without being programmed or instructed to follow specific rules. The neural networks are inspired by the biological neural networks that constitute human brains.

II. CONCEPTUAL MODEL OF A PLATFORM FOR EARLY FOREST FIRE DETECTION

This section describes the conceptual model of a platform for early forest fire detection that is going to be implemented under an international project entitled "Forest Monitoring System for Early Fire Detection and Assessment in the Balkan-Med Area" SFEDA. The project was designed with the intention to create a transnational cooperation among the countries in the Balkan-Mediterranean Area and more specifically between Bulgaria, Greece and Cyprus. The goal of the project is to achieve the proof of the effectiveness of the technology and the implementation of a system for early detection and prevention of wildfires targeting a positive environmental impact and climate change resiliency. The purpose of the project is to apply and demonstrate three differently implemented platforms for wildfire detection in three forests in the different countries (Bulgaria, Greece and Cyprus) and by sharing experiences and expertise to promote and strengthen the cooperation of the cross-border partners and improve the infrastructure for fire surveillance. All of the three developed platforms will be part of one system under the name THEASIS. The focus of this paper is to investigated the possibilities and development stages of the platform for early forest fire detection, which is going to be implemented by the University of Ruse on the territory of National Park "Rusenski Lom" near Ruse, Bulgaria.

A. *Model of the platform for early forest fire detection*

Fire detection systems for outdoor environment could be implemented by using specialized cameras, which are able to capture multispectral images. The biggest challenge that arises in these setups is where to place the camera(s) in order to have the best view on the observed territory. Since these systems have their limitations, since they provide stationary point of view, we have decided to investigate a new approach. The platform that is proposed in this paper will use unmanned aerial vehicles, which are going to patrol above the desired territory and will constantly observe for fire-related events. The drones will be equipped with specialized optical and thermal cameras and will be able to capture video or still images. In addition, the drones will also have constant bidirectional connection to the base station and they will be able to provide a feedback about their observations (Fig. 1).



Figure 1. The main part of the platform for early forest fire detection with use of fixed wing and rotatry wing UAVs

The platform will consists of two types of UAVs, which will fly at different altitudes as shown in Fig. 1. The terrain of National Park Rusenski Lom involves a steep canyon along the river covered by very dense forest vegetation. The altitude variates from the ground level (0 meters) at reverbed to 150-170 meters at the highest points of the canyon. This makes the location very difficult for observation. To provide an overall overview of the park and to observe the difficult terrain we have decided to use a fixed-wing UAV with vertical take-off and landing. The drone will fly at medium altitude and will provide long-term observations of the forest area of the national park. The fixed-wing UAV will patrol, following a specific pattern, above the forest area and if it detects increased temperature levels by its thermal camera sensor it will immediately raise an alarm and will send the GPS coordinates of the area to its base station.

In order to reduce the false alarms we are planning to use second drone that will confirm the detection of the fire. For that purpose, smaller drone with rotary wings will be used. It will fly to the location of the potential forest fire by using the GPS coordinates provided by the fixed-wing drone and it will provide close inspection. To have a better view of the observed territory the rotary-wing drone will fly at lower altitude in the range from 10 meters to 350 m.

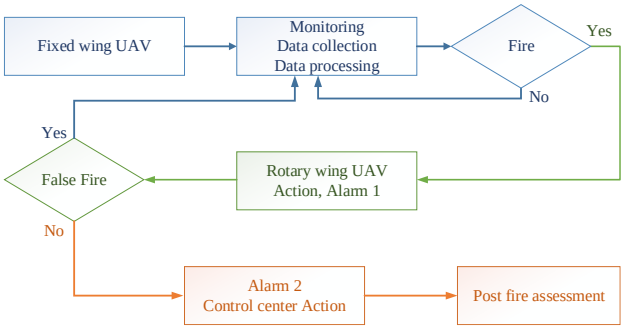

Figure 2. Flowchart of the operating principle of the early forest fire detection platform

The flowchart of the operating principle is provided in Fig. 2. As it can be noticed, the system implements three stages for fire detection. The first stage (coloured in blue) presents the role of fixed-wing UAV. To have a wide-angle view this drone will fly at an altitude from 350 meters up to 5500 meters. If a fire is detected, the rotary wing drone starts its operation (green colour) by inspecting the suspected area from low altitude. Its role is to confirm the fire. If the fire is real then the drone informs the ground level firefighting services (orange colour) and continues its function to assist ground level services. The second drone can be used also for post fire assessment. Since both drones are going to be equipped with specialized multispectral cameras, a thorough analysis could be made. Images captured by multispectral cameras can be processed and used for generating the NDVI (normalized difference vegetation index) maps of the terrain. NDVI is a simple graphical indicator that can be used for fire damage assessments.

B. *Planned equipment*

During the last decades, unmanned aerial vehicles have been widely used in different areas – military,

agriculture, photography, fire service and many others. These aircrafts are mainly classified into two types - fixed-wing UAVs and rotary-wing UAVs with both types having their advantages and disadvantages. Since the developed platform is going to use both types of UAVs, it will also take advantage of their benefits. The fixed-wing UAVs have several advantages, such as higher cruising speed and higher flight altitude, high flight efficiency, long endurance and range. Rotary-wing UAVs on the other hand are more flexible, since they can take-off and landing vertically no matter of the type of environment. Nowadays there are hybrid drones that combine the benefits of both.

After making a thorough analysis, we have decided to use ALTi Transition-F vertical take-off and landing (VTOL) fixed-wing UAV [11], which together with its ground control station are shown in Figure 3. The ALTi Transition-F is class leading VTOL fixed-wing unmanned aircraft, developed as an ultra-compact, efficient and affordable system with the ability to take-off and land vertically almost anywhere with endurance of up to 12 hours and unmatched real world performance, according to its manufacturer [11]. The dimensions of the aircraft are 3000 mm wingspan, 2300 mm length and 525 mm height and its maximum take-off weight is 16 kg. The main wings are removable, which significantly reduces the size and allows for rapid deployment, transport and storage. Depending on the payload, the endurance of the UAV varies, for example with 2.8 kg payload the endurance time is about 10 hours. The high endurance is due to the enhanced aerodynamic design with ultra-lightweight carbon fuselage.



Figure 3. ALTi Transition VTOL aircraft and its ground station [11]

The telemetry and control links between the drone and its ground station are completed using two channels for data communication. One of the channels is duplex for simultaneous bidirectional control and data transfer, while the other is used as radio channel for high definition real time video streaming. The second channel is set to work in simplex mode for downstream video transfer. That video is going to be used for analysis of the observed area.



- Zoom: x20 + x2 digital (total x40);
- HFOV: 60º WFOV – 3º WFOV – 1.5º DFOV;
- Thermal Resolution: 640x480;
- Pitch FOR: -45º to + 135º;
- Roll FOR: -180º to + 180º;
- Weight: 250 grams
- Dimensions: Diameter = 64 mm, Height=94 mm.

Figure 4. The NightHawk 2 camera and its parameters [12]

The high altitude drone will be equipped with NightHawk 2 EO/IR camera with 20x zoom and thermal resolution of 640x480 as shown in Fig.4. This camera is able to capture different temperature levels, and once the UAV detects increased or abnormal temperature levels it will immediately raise an alarm and will send the GPS coordinates of the problematic area to its base station. The camera weighs only 250 grams, which will not cause significant downgrade in the drone performance and will not reduce its endurance.

Since the drone will fly at higher altitude, the view distance from the camera to the ground surface could be significant and this could lead the reporting of many false alarms. In order to minimize their number a second drone with rotary-wings will be used. The use of a rotary-wing UAV will provide the possibility for close inspection. It will be equipped with higher quality camera and it fly at lower altitude for better visibility. To confirm the detection of the fire we have planned to use as rotary-wing UAV the DJI Matrice 210 RTK drone, which is shown in Fig. 5. The advantage of the Matrice 200 series of drones it the fact that they are IP 43 certified, which means that they can withstand humidity and can fly in foggy or rainy conditions.



Figure 5. DJI Matrice 210 RTK with dual gimbal [13]

The reason to choose this drone is its dual downward gimbal, which allows it to carry two cameras. The drone can be equipped with one IR and one standard/zoom camera. We are planning to use the Zenmuse X4S 4K optical camera, which comes with a 20-megapixel 1-inch sensor, with maximum ISO of 12800 and increased dynamic range. The second camera on the drone will be Zenmuse XT2 thermal camera, which integrates a high-resolution FLIR thermal sensor and a 4K visual camera with good stabilization and processing technology for quick transformation of aerial data into powerful insights.

As further improvement of the platform, we have planned to implement artificial intelligence by allowing the drones to make fire predictions based on computer vision techniques. In order to implement image recognition a computing engine is required. Another benefit of the drones is the fact that they can be equipped with high performance on-board computers, which enables their developers to transform these aerial platforms into truly intelligent flying robots that can perform complex computing tasks and advanced on-board image processing. Example of one such high-performance embedded computer, specially designed for the DJI series of drones is the DJI Manifold [14]. The Manifold has the

processing power of a graphics card for PCs and supports DirectX 11 and Open GL 4.4. It also supports NVDIA CUDA, which allows it to be used for processing in many AI applications, including for computer vision and deep learning. This means that the developed aerial platform will perform on-board image recognition and could raise an alarm if it detects smoke or fire in the images, which it captures and processes. This will lead to decreased fire detection and reporting times.

C. *Development stages*

There are three main development stages for bringing the platform for early forest detection in action. They include the planning, the designing and the building of the system. In the implementation process, most of the project team will be involved with distributed tasks. The planning stage involves meetings of the team, discussions and building of a conceptual model, as well as defining the specifications of the equipment that is going to be purchased. The designing stage involves prebuilding tasks, which include clarification of the conceptual model, purchasing of the equipment and additional discussion and talks. The last and most difficult stage from the development process is the actual building of the system. This stage involves actions that are separated in two main tasks: preparation of the system components and laboratory testing of components. These actions must be implemented before the actual use of the system. The preparation of the system components involves tasks as components testing, assembling of the components, camera testing, DSP module testing, GPS module tests and also troubleshooting of the system, while the laboratory testing involves practical tests of the UAVs and their components and laboratory testing of the fire detection system.

In addition, the system could be improved by implementing computer vision (CV) techniques [3, 4, 5 and 6]. For this purpose, we have used artificial intelligence concepts for training a neural network to recognize smoke in images taken from the drone. Before providing more details about our CV implementation, we have included some basic information about artificial intelligence, neural networks, deep learning and the connection between them. Smoke detection using images can be defined as binary classification problem, in which we have as input an image, which has to be classified as containing smoke or not. If it is classified as image, which contains smoke, the reported output value is one. Otherwise, the output value is zero.

III. ARTIFICIAL INTELLIGENCE, NEURAL NETWORKS AND DEEP LEARNING

Artificial intelligence has become extremely popular in the recent years as it has the ability to perform tasks, which are inherent to a human mind. Artificial intelligence, sometime referred to as machine intelligence, is implemented by using neural networks.

The neural networks are specialized computer models, which can be trained to perform different tasks. They are used for classification of images, speech recognition, translation of texts and more complex tasks, like control of autonomous vehicles, etc. There are several types of neural networks, but the most widely used for image detection and computer vision are the convolutional neural networks [7, 8]. They consists of input layer, hidden layers and output layer of interconnected neurons, as shown in Fig.6. Depending on the number of hidden layers, we have machine learning methods (with just one hidden layer) and deep learning methods (with more than one hidden layers), in terms of methods for training the neural networks. For example, Fig. 6 presents a deep neural network, since it has two hidden layers.

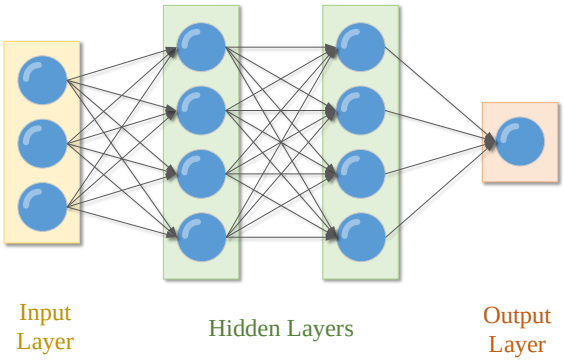

Figure 6. Example of neural network with two hidden layer

Input neurons represent the data, which is going to be used for training. For example, if an input is an image the input neurons might represents the values for each pixel. Neurons hidden in the middle layers usually perform mathematical computations. The links between neurons are parameterized with weights, which dictate the importance of the input value.

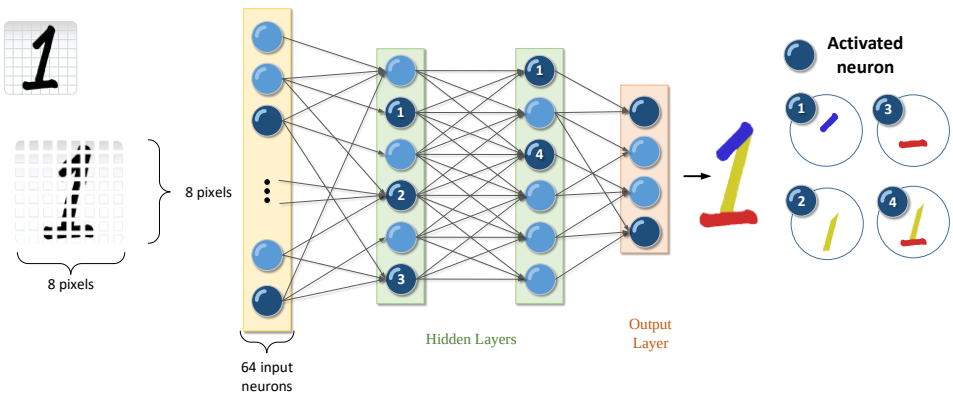

Figure 7. Image detection principle performed by neural network model

All of the weight are randomly set, but during the learning process, they can change in order to fine-tune the loss function. Each neuron in the network has activation function, which is extremely important for the final result.

The image detection principle is shown on Fig.7. This example reveals how neural network can recognize a digit from a given image with resolution of eight pixels by eight pixels (the low resolution is given for simplicity). All of the image pixels are passed to the model as input neurons. Depending on the weights assigned to the links, different sets of hidden layers might be activated. The uniqueness of the activated neuron defines the output. Before performing such complex tasks, each neural network must be trained. The training can be describes as a process of finding the weights of the links between the neurons, where the loss function is minimized. The training could be supervised and unsupervised.

Machine learning systems learn how to combine inputs to produce useful predictions on never-before-seen data. In the supervised learning approach, the machine learning algorithms construct models by examining many examples and attempting to find a model that minimizes the loss. The loss is defined as the difference between the actual value and the predicted output. The loss function is minimized by changing the values of the weight of the links between the neurons. Supervised learning can be used on both structured and unstructured data. Simple machine learning algorithms work well with structured data, but when it comes to unstructured data, their performance tends to be low. This is where neural networks have proven to be so effective and useful. They perform exceptionally well on unstructured data. Structured data is well defined input that has meaningful values, while the unstructured data refers to things like audio and images, where the goal is to recognize what is in the image or what the text is (like object detection). Here the features might be the pixel values in an image and it is not clear what each pixel of the image represents by itself in the image and therefore this falls under the unstructured data.

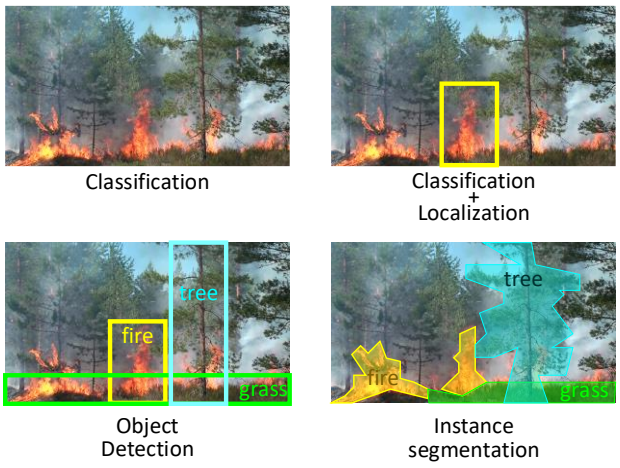

Figure 8. Comparison between image classification, object-detection and instance segmentation

Based on the discussion from above, the system for early forest fire detection can be categorized as binary classification problem. The image classification models classify images into a single category, usually corresponding to the most salient object. In the forest, the most salient object could be a tree, a river, a bush or even the forest itself. For this reason, the image classification as a particular solution could not be effective. Assigning a label with image classification models can become tricky and uncertain. Object detection models are therefore more appropriate to identify multiple relevant objects in a single image or in our case just one the smoke. There is one more advantage of object detection and that is the ability to localize the object in the image. Comparison between image classification, object detection and instance segmentation is provided in Fig.8.

IV. BUILDING OF A COMPUTER VISION NEURAL NETWORK FOR DETECTION OF SMOKE IN IMAGES

In order to improve the platform and to implement the smoke detection functionality from still images it is first necessary to train a network to learn how to recognize the smoke. There are several steps to do that. To utilize the object detection algorithms we first need to define the input data. The input data, also known as dataset is a set of images, in which smoke is present, marked and labelled. The dataset must be separated in two parts – for training and for testing. This is the main requirement to avoid the so-called overfitting. Sometimes after training, neural networks are performing very well with the training data (or very similar images) and not so well on new images. This is called overfitting the model and it is illustrated in Fig. 9. Actually, there are two things to do with the data. The first one is to estimate the parameters for the machine learning methods and the second one is to evaluate how well the machine learning methods work. A bad approach would be to use all of the data to estimate the parameters (i.e. train the algorithm) because then there would not be any data left for testing the method and in that case, the model might become overfitted. Reusing the same data for both training and testing is also not a good idea, because in order to evaluate the model it is needed to know how the method will work on data, which was not used for its training. A good separation of the dataset is about 75% of the images for training and 25% for testing.

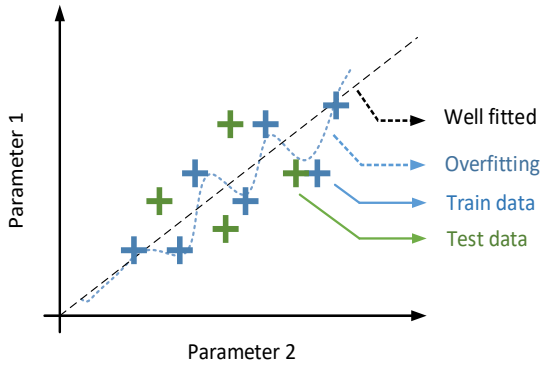

Figure 9. Fine-tuning against overfitting of the model

Fig. 9 reveals the fine-tuning against the overfitting of the model. Assuming that the blue crosses are training data, if the model is trained only on that data, it might become overfitted, meaning that if new data is passed to the model (green crosses) there will be a high loss function.

After collecting many images for the dataset, it is necessary to annotate them all. Annotation includes specification of the object coordinates and a corresponding label. For the smoke detection model, we have collected about 300 images, which include smoke. For their labelling, we have used the LabelImg tool [10], which is a graphical image annotation tool written in Python and uses Qt for its graphical interface. After the labelling of the images, we have used a ready script to convert the XML files to a .csv and then to create the TFRecords. The TFRecord input data is needed because we have used Tensorflow [9] as a training platform. We have separated the input data to be 80% (240 images) for training and 20% (60 images) for testing.

After the creation of the required input files for the Tensorflow Object-Detection API, the model can be trained. For the training, an object-detection training pipeline is needed. Training an object detector from scratch can take days, even when using multiple GPUs. To speed up the training we can take an object detector trained on a different dataset and reuse some of its parameters to initialize the new model. For that purpose, we have downloaded a model named ssd_mobilenet_v1_coco [15]. The model comes with preconfigured pipeline configurations. It is only necessary to adjust the *num_classes* to one (because we only have one class - smoke) and to set the path for the model checkpoints, the training and test data files as well as the label map. In terms of other configuration parameters, like learning rate, batch size and others the default settings would probably be ok.

Training can be done either locally or on the cloud. GPU processing unit with at least 2GB memory is acceptable for local computing. We have started training on a computer with 4GB GPU. At every 10,000 steps of the training, the process is saved as a checkpoint. It is recommended to evaluate the checkpoints from time to time in order to avoid overfitting the model.

After finishing with the training, the model has to be exported to a single file (Tensorflow graph proto), so it can be used for inference. If more images are used for the input dataset, the model could become more accurate, but in that case, there is a tradeoff between the model speed and the model accuracy that one must consider.

V. CONCLUSIONS

The system for early forest fire detection is still in its development stage. We are still waiting for some equipment to be purchased, but we have planned and discussed the actual implementation. We have performed a thorough research and some simulation experiments and we believe that we follow the right way to achieve the goal. We also believe that we apply adequate approach that is also up-to-date. We think that the system could enhance the available platforms for fire detection and we hope that such improvement could significantly reduce the damages caused by untimely or late fire detection.

ACKNOWLEDGMENTS

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Fuzzy Models for Managing a Micro Grid PV System

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***Abstract* - In this paper, models of two fuzzy inference systems for supporting the process of managing micro grid PV systems are presented. The first model is for managing a PV/battery micro grid connected system and uses fuzzy mapping of three input variables: power produced by PV panels, power in battery and consumed power. The output of the FIS, obtained after applying the fuzzy rules, is a decision for choosing which power source is to be used. The second model consists of one additional energy source (diesel generator/fuel cell) and thus the input variables are four. The simulation tests are conducted in MatLab. This research is part of a project for optimizing the energy consumption of a building with the use of independent alternative renewable energy sources. The input test data for the optimization are the amount of used energy for lighting, heating, computers power supply and other needs of one particular building (the building of Burgas Free University) and the corresponding price of each of the used energy sources.**

Keywords - fuzzy inference system, micro grid PV system, smart building management

I. INTRODUCTION

A photovoltaic system (PV system) is an energy system designed to convert solar radiation into usable electricity through photovoltaic elements. The PV system consists of the following components: solar panels for absorbing sunlight and converting it into electricity; inverter for converting electricity from DC to AC; wiring, mounting elements and other elements needed for a working system. Some photovoltaic systems are equipped with tracking devices that detect the change in the sun's trajectory to adjust the position of the panels and thus increasing system's performance. Other photovoltaic systems are equipped with batteries for storing the generated energy.

Photovoltaic systems range from small (roof mounted or built-in) systems with a capacity of several to several tens of kilowatts, to large power plants producing hundreds of megawatts.

At present, most photovoltaic systems are connected to the electricity grid, and stand-alone systems make up a small portion of the market share. The cost of photovoltaic panels is steadily decreasing as a result of technology development and increased production scale. The energy conversion efficiency of the conventional solar panel has increased from 15% in 2004 to 20% in 2018. Financial incentives (e.g. preferential electricity prices generated by solar power) largely support the creation of photovoltaic systems in different countries. The cost of electricity from PV systems is competitive with the cost of electricity generation from conventional sources.

Thus, at present, energy equality is achieved in about 30 countries, and around the world there are several million PV systems (mostly in Europe, with 1.4 million systems in Germany only, 440 000 systems in the United States).

By 2018, the rapidly expanding world photovoltaic market is approaching the 500 GW threshold - about 50 times the installed capacity since 2006 (Fig. 1) [1]. Photovoltaic systems are currently contributing for around 1% to global electricity production. The largest PV system (in terms of capacity) are installed in China, Japan and the United States, while half of the world's capacity is installed in Europe, with Germany and Italy supplying 7% to 8% of their respective domestic electricity consumption. The share of produced energy from PV systems in Bulgaria increased substantially in 2012 and 2013 but after that the rate constantly slowed down. [2-5]

Light energy, measured in [W/m^2], is the total energy obtained from the entire spectrum of the solar radiation, but only a part of it is effective for photovoltaics systems. These are rays with length within 300-1100 *nm*, including

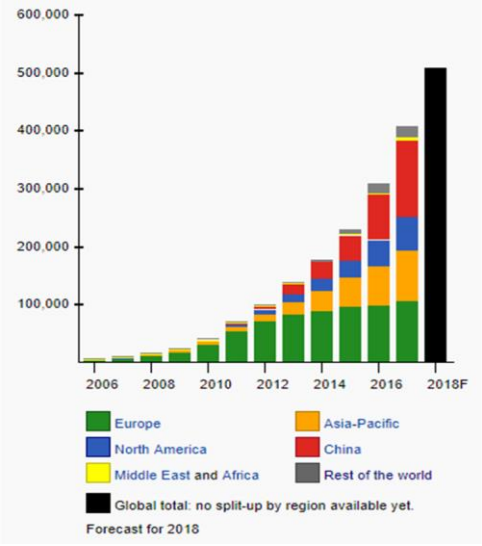

Fig. 1. Worldwide growth of photovoltaics: cumulative capacity in megawatts by regions

the visible light (380-740 *nm*) and the infrared light (>740*nm)*. The sunlight in the visible spectrum accounts for around 45% of the total solar energy, the invisible spectrum (ultraviolet range) - 7% and the largest share - 48% - is due to the infrared light. Unfortunately, infrared rays actually contribute to photovoltaic heating and only a small portion of it can be transformed to electrical energy. [6-8]

The effectiveness of a PV system depends mainly on the following three factors:

(1) annual average solar radiation in hours, depending on the position of the Earth's surface against the Sun and the cloudiness over the area under consideration;

(2) daily fluctuations of solar radiation, analogically depending on the position of the Earth's surface against the Sun and the cloudiness over the area under consideration;

(3) likelihood of sunlight, which directly depends on cloudiness and with likelihood less than 0.2 it is economically unjustified to install PV systems. [9]

For Bulgaria, the annual average duration of solar radiation varies and is approximately 2100 *h* for the Danube Plain and more than 2300 *h* along the sea coast. The total annual energy of the sun distributed over the territory of Bulgaria, varies from *1300 kWh/m*^{2} in the valleys to more than 1700 *kWh/m*^{2} in the highest parts of the mountains. In Bulgaria, during the three summer months the solar radiation from cloudless sky lasts about 10 hours and in the three winter months – around 6 hours.

A general scheme of a PV micro system

The scheme of the system depicts the individual elements and the links between them. It can be divided into three parts: a power source that includes photovoltaic panels and the rechargeable batteries, a controller and an AC inverter, the standard AC consumers and the DC consumers directly from the photovoltaics/batteries (Fig. 2).

The photovoltaic panels are configured in separate blocks in which they are distributed in parallel to achieve operating currents and in series to achieve the required operating voltage. The batteries are similarly configured in parallel to reach a certain current and in series for the working voltage. Loads are divided into two main groups – the consumers from the first group receive energy directly from the batteries and the consumers from the second group - the energy inverted into AC voltage. Each load has specific features to be considered: start current, rated power, peak power, and power supply voltage formats.

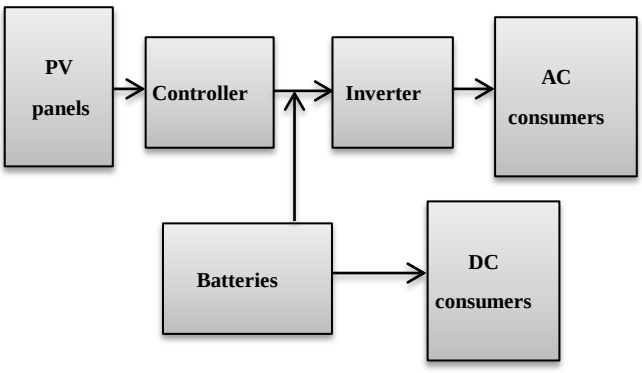

Fig. 2. A general scheme of a micro PV system

For the correct operation of PV panels and the proper coordination with the consumers, the system is provided with a controller for monitoring the proper charging/discharging of the batteries, the operation of the photovoltaic panels and detecting emergency situations. In some applications, the controller also provides optimum battery charge. The controller is the most important element of the system and the proper choice and appropriate software are a key for the smooth operation of the system [11].

The purpose of the batteries is to accumulate the excess energy generated by photovoltaics during the daylight and to give it overnight, keeping the power supply continuous. It is known that direct current consumers can be connected directly to DC buses. These are some types of lights, TVs, radios, refrigerators etc. The batteries in use have to be able to be deeply diluted in order to be fully utilized. For this purpose, lithium batteries are particularly suited, but their cost, performance and safety features for now deter producers from using them massively. Lead accumulators are cheap, but they cannot be discharged completely because they are irretrievably destroyed (the allowable discharge is up to 20% of their capacity).

The role the inverter is to convert the constant voltage into a voltage with an industrial frequency, which allows a direct power supply to all standard consumers. Few systems are limited only to DC consumers without an inverter. Such are, for example, the systems designed to power portable equipment such as illuminated signs, temporary luminaires and more. Autonomous photovoltaic systems without an inverter are the cheapest. The use of an inverter enables the autonomous photovoltaic system to provide energy with indicators identical to those of the general power supply. The quality of the electricity is acceptable, both in frequency and level. However, in the micro power systems the inverters are a major cost factor.

DC loads are usually low-voltage power consumers that can use the power directly and thus the complex converters, which reduce the system's performance, are avoided.

The increase in the use of alternative energy sources naturally leads to an increase in scientific research and development of various methodologies for management and control of photovoltaic as well as different hybrid energy systems - from large PV plants to micro off-grid independent systems. A detailed overview and critical analysis of currently proposed tools and approaches can be found in [10].

The fuzzy approach for managing PV systems, used by different authors is implemented mainly in three directions: fuzzy controllers; interval calculations for managing the energy system and fuzzy rule-based systems with triangular membership functions.

The models, proposed in this paper, differ from already published models in 2 important characteristics: 1) the fuzzy models are Sugeno type and 2) the membership functions of the fuzzy terms are differentiable smooth functions as is described in Section III.

II. FUZZY RULE-BASED INFERENCE SYSTEMS

Following the general structure of a fuzzy system, a fuzzy rule-based inference system consists of a knowledge base (rule base and database) and an inference machine [12-15].

Let N be the number of the input fuzzy variables K_i, $i = 1, 2, 3, \dots, N$, and n_i be the number of terms X_{ij} of K_i for each i with $j = 1, 2, 3, \dots, n_i$. Let S be the number of output fuzzy variables Q_s, $s = 1, 2, 3, \dots, S$, and p_s be the number of terms Y_{sp} of Q_s for each s with $p = 1, 2, 3, \dots, p_s$.

Let $\mu_{ij}(x)$ be the membership function of the term X_{ij} and $\mu_{sp}(y)$ be the membership function of Y_{sp} . Then the overall number of the membership functions in the knowledge base is

$$N.\sum_{i=1}^{N} n_i + S.\sum_{s=1}^{S} p_s . \quad (1)$$

The crisp input values form a vector $x^* = (x_1^*, x_2^*, \dots, x_N^*)$. This vector is fuzzified by calculating $\mu_{ij}(x_i^*)$ for each i and j. At this point there are

$$N.\sum_{i=1}^{N} n_i \quad (2)$$

membership values, stored in the database after that calculation.

The next step is to aggregate. For simplicity let *min* operator be used for the *T-norm* and *T-norm* be used for the *AND* operator. Let M be the number of rules and the m-th rule R_m has the form:

$$if \ \left\{K_{m_1} \ is \ X_{m_1 j_{m_1}}\right\} and \ \left\{K_{m_2} \ is \ X_{m_2 j_{m_2}}\right\} and \ \dots \ and \left\{K_{m_k} \ is \ X_{m_k j_{m_k}}\right\} \ then \ \left\{Q_{m_1} \ is \ Y_{m_1 j_{m_1}}\right\} and \ \left\{Q_{m_2} \ is \ Y_{m_2 j_{m_2}}\right\} and \ \dots \ and \left\{Q_{m_l} \ is \ Y_{m_l j_{m_l}}\right\}$$

and each rule has its weight w_m, $m = 1, 2, 3, \dots, M$.

Once the m-th rule is selected and put into the template, two consecutive calculations are made:

I) $\Theta_m = min\left\{\mu_{m_1 j_{m_1}}(x_1^*), \mu_{m_2 j_{m_2}}(x_2^*), \dots, \mu_{m_k j_{m_k}}(x_k^*)\right\}$

and then

II) ${\Theta_m}^o = \Theta_m . w_m$.

After firing all the rules the corresponding values of the membership functions ${\mu_{sp}}^m = {\Theta_m}^o$ for each term Y_{sp} of the output variables are obtained. The number of these values depends on the number of rules in which they are used.

The aggregation applies after calculating

$$P_{sp} = max \ \left\{ {\mu_{s p}}^1, \ {\mu_{s p}}^2, \dots, {\mu_{s p}}^M \right\} \quad (3)$$

for each Y_{sp}, $s = 1, 2, 3, \dots, S$ and $p = 1, 2, 3, \dots, p_s$.

The last step is defuzzification. For implementing any of the methods for defuzzification, shown earlier, a numerical integration could be applied [16-18].

III. FUZZY MODELS FOR MANAGING A MICRO PV SYSTEM

The quality of the produced by PV system electric power is out of the scope of this paper. In both models it is assumed that the frequency, amperage and voltage are with standard values, thus usable by the consumers.

In advance, the power produced by PV panels, power produced the additional energy source, power in battery and consumed power are measured and the percentage of consumption covered by each of the energy sources is calculated. These percentages become the input variables in the fuzzy systems.

A. Model 1: PV/battery micro grid connected system

In this model there are 2 input variables ($N = 2$). The first one consists of five fuzzy terms ($n_1 = 5$):

$$\boldsymbol{K_1 = Input1}=\{\text{Consumption covered by PV in \%}\}=$$
$$=\{X_{11}, X_{12}, X_{13}, X_{14}, X_{15}\}=$$
$$=\{\textit{Critical low, Low, Enough, High, Excess}\};$$

and the second – of three fuzzy terms ($n_2 = 3$):

$$\boldsymbol{K_2 = Input2} =$$
$$=\{\text{Consumption covered by batteries in \%}\}=$$
$$=\{X_{21}, X_{22}, X_{23}\}=\{\textit{Low, Enough, High}\}.$$

The output is one ($S = 1$)with six terms ($p_1 = 6$):

$$\boldsymbol{Q_1 = Output}=\{\text{Action}\}=$$
$$= \{Y_{11}, Y_{12}, Y_{13}, Y_{14}, Y_{15}, Y_{16}\} =$$
$$=\{\textit{Consume power from PV, Charge batteries from PV, PV to grid, Check Batteries, Switch to batteries, Switch to grid}\}.$$

Thus, the total number of membership functions in the in the knowledge base is 14.

The fuzzy terms of ***Input1*** are shown on Fig. 3. Three of the terms (*Low, Enough, High*) have Gaussian functions with the following formula for the membership

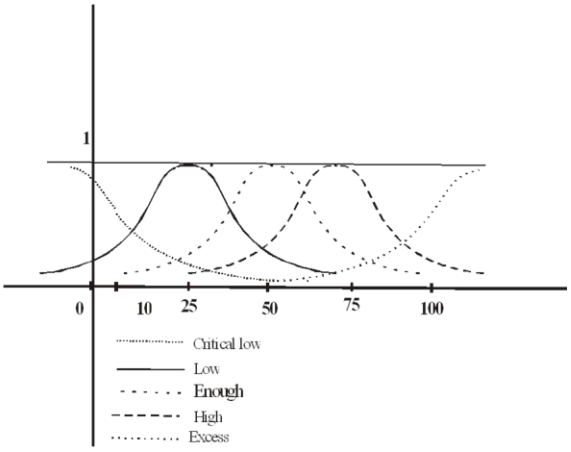

Fig. 3. Membership functions of the fuzzy terms of ***Input1*** for operating a PV/battery micro grid connected system

function:

$$gaussian\ (x,\beta,\alpha) = e^{-\frac{1}{2}\left(\frac{x-\alpha}{\beta}\right)^2},$$

the terms *Critical low* and *Excess* have sigmoidal membership function:

$$sig\ (x,\alpha,\beta) = \frac{1}{1+e^{-\alpha(x-\beta)}}.$$

This model aims at utilizing the power produced by the PVs to the maximum possible extend and therefore the priority is given to the variable ***Input1***={Consumption covered by PV in %}.

The second energy source (in this model - the batteries) plays a reserve role, so the fuzzy terms of the variable ***Input2***={Consumption covered by batteries in %} has only three terms: *Low* and *High* have sigmoidal membership function, while *Enough* has a Gaussian membership function with the corresponding parameters.

The total number of rules, which can be generated in this model is 90, but the proposed rule base consists of 9 rules that combine 21 rules (Table 1).

Some of these rules (Rules 7 and 9) have the form

$$if\{K_1\ is\ X_{1j_1}\}\ and\ \{K_2\ is\ X_{2j_2}\}\ then\ \{Q_1\ is\ Y_{1j_1}\},$$

while the rest are combination of 2 or more rules. For example, Rule 1:

$$if\{K_1\ is\ X_{15}\}\ and\ \{\{K_2\ is\ X_{22}\}\ or\ \{K_2\ is\ X_{23}\}\}$$
$$then\ \{\{Q_1\ is\ Y_{11}\}\ and\ \{Q_1\ is\ Y_{13}\}\}$$

actually combines the following 4 rules:

$if\{K_1\ is\ X_{15}\}\ and\ \{K_2\ is\ X_{22}\}\ then\ \{Q_1\ is\ Y_{11}\}$
$if\{K_1\ is\ X_{15}\}\ and\ \{K_2\ is\ X_{23}\}\ then\ \{Q_1\ is\ Y_{11}\}$
$if\{K_1\ is\ X_{15}\}\ and\ \{K_2\ is\ X_{22}\}\ then\ \{Q_1\ is\ Y_{13}\}$
$if\{K_1\ is\ X_{15}\}\ and\ \{K_2\ is\ X_{23}\}\ then\ \{Q_1\ is\ Y_{13}\}$

Rules 2, 3, 4, 5, 6 and 8 are constructed in an analogical way (Table 1.)

Table 1. Rule base for operating a PV/battery micro grid connected system

		1	2	3	4	5	6	7	8	9
Input1	Critical low									
	Low									
	Enough									
	High									
	Exceed									
Input2	Low									
	Enough									
	High									
OUTPUT	Consume power from PV									
	Charge batteries from PV									
	PV to grid									
	Check Batteries									
	Switch to batteries									
	Switch to grid									

B. Model 2: PV/battery/diesel generator/fuel cell micro grid-connected system

In this model there are 3 input variables ($N = 3$). The first one consists of five fuzzy terms ($n_1 = 5$):

$\boldsymbol{K_1 = Input1}$={Consumption covered by PV in %}=
$=\{X_{11}, X_{12}, X_{13}, X_{14}, X_{15}\}=$
=*{Critical low, Low, Enough, High, Excess}*;

the second – of three fuzzy terms ($n_2 = 3$):

$\boldsymbol{K_2 = Input2}$ =
=*{*Consumption covered by batteries in %*}*=
$=\{X_{21}, X_{22}, X_{23}\}$=*{Low, Enough, High}*

and the third – of three fuzzy terms ($n_3 = 3$):

$\boldsymbol{K_3 = Input3}$ =
=*{*Consumption covered by additional source in %*}*=
$=\{X_{31}, X_{32}, X_{33}\}$=*{Low, Enough, High}*.

The output is one ($S = 1$)with seven terms ($p_1 = 7$):

$\boldsymbol{Q_1 = Output}$={Action}=
$= \{Y_{11}, Y_{12}, Y_{13}, Y_{14}, Y_{15}, Y_{16}, Y_{17}\} =$
=*{Consume power from PV, Charge batteries from PV, PV to grid, Check Batteries, Switch to batteries, Switch to additional source, Switch to grid}*

Thus the total number of membership functions in the knowledge base is 18.

Table 2. Rule base for operating a PV/battery/ diesel generator/fuel cell micro grid connected system

		1	2	3	4	5	6	7	8	9	10	11	12
Input1	Critical low												
	Low												
	Enough												
	High												
	Exceed												
Input2	Low												
	Enough												
	High												
Input3	Low												
	Enough												
	High												
OUTPUT	Consume power from PV												
	Charge batteries from PV												
	PV to grid												
	Check Batteries												
	Switch to batteries												
	Switch to additional source												
	Switch to grid												

The terms of $\boldsymbol{K_1 = Input1}$ and $\boldsymbol{K_2 = Input2}$ are the same as in the first model. The third input $\boldsymbol{K_3 = Input3}$ has three fuzzy terms and they are with the same membership functions as the corresponding terms of $\boldsymbol{K_2}$.

The number of rules that can be generated in this model is 315, but actually the rule base consists of 50 rules, which after combining become 12 rules (Table 2). For example, Rule 12:

$$\begin{aligned} &if\ \{\{K_1\ is\ X_{13}\}\ or\ \{K_1\ is\ X_{14}\}\}\ and \\ &\{\{K_2\ is\ X_{22}\}\ or\ \{K_2\ is\ X_{23}\}\}\ and \\ &\{\{K_3\ is\ X_{32}\}\ or\ \{K_3\ is\ X_{33}\}\}\ then \\ &\{\{Q_1\ is\ Y_{11}\}\ and\ \{Q_1\ is\ Y_{12}\}\ and\ \{Q_1\ is\ Y_{13}\}\} \end{aligned}$$

combines 12 of the 50 rules.

The design of the models of the two fuzzy inference systems for managing micro grid PV systems is based on expert knowledge. Smooth functions (Gaussian and sigmoidal) are chosen as membership function type, because this ensures that the control system is going to function continuously with no jumps or disruptions. The parameters of the membership functions have been chosen by the authors so that symmetry in the fuzzifing process of input data is achieved. The rule-bases have been created after consultation with experts in the field of photovoltaic systems.

IV. MATLAB SIMULATION

After the implementation of the above models in MatLab, experimental tests have been carried out. The tests aim at studying the behavior of the fuzzy system while changing the values of the input variables. One such test is visualized on Fig. 4. The percentage of consumption covered by PV is 85% and the percentage of consumption covered by batteries is 30%, so there is a degree of membership to terms X_{14} and X_{15} of $\boldsymbol{K_1 = Input1}$ and to terms X_{21} and X_{22} *of* $\boldsymbol{K_2 = Input2}$ and therefore the Rules 1, 2, 8 and 9 from Table 1 are fired (in the MatLab simulation these are rules 1, 5, 6, 7, 21, 23 and 24 which are the same but not combined – they are written in detail because of the requirements of the Fuzzy Logic Toolbox). These rules lead to a defuzzified output with value 0.203 which means *Consume power from PV, PV to grid* and *Check Batteries.*

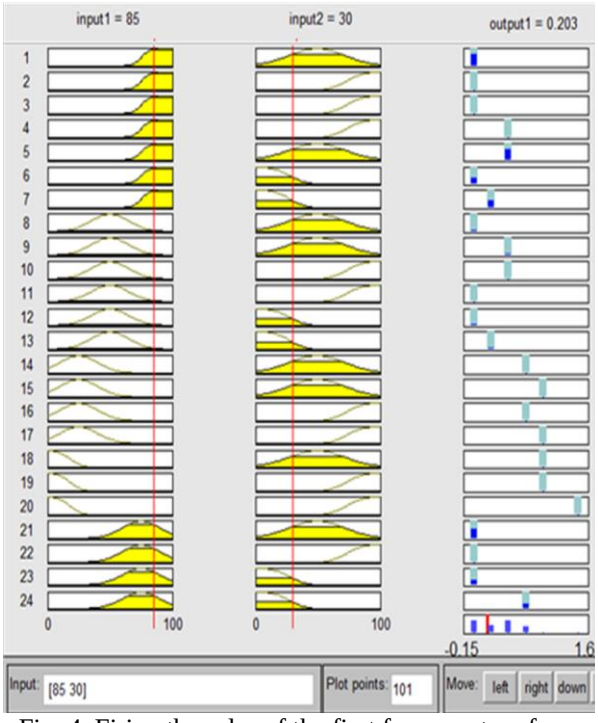

Fig. 4. Firing the rules of the first fuzzy system for operating a PV/battery micro grid connected system with 85% of consumption covered by PV and 30% covered by batteries

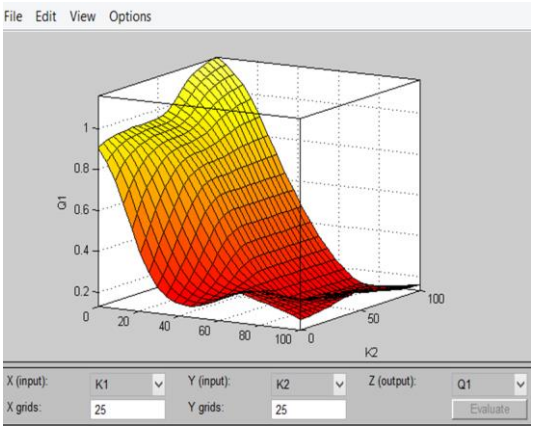

Fig. 5. Surface view of the first fuzzy system for operating a PV/battery micro grid connected system

The surface view of PVsystem1 is displayed on Fig. 5.

Analogically, one of the surface views of PVsystem2 is displayed on Fig. 6 – the surface shows the dependency of the output variable from $\boldsymbol{K_1}$ and $\boldsymbol{K_2}$.

One of the conducted tests of the second system (PVsystem2) is shown on Fig. 7. The input data in this case is 15% of consumption covered by PV, 25% covered by batteries and 85% covered by the additional energy source which fires rules 5, 7 and 11 from Table 2 (which corresponds to rules 14, 15, 18, 37 and 38 in MatLab Fuzzy Logic Toolbox). The defuzzified value of the output in this case is 1.1 and this corresponds to *Check Batteries* and *Switch to additional source.*

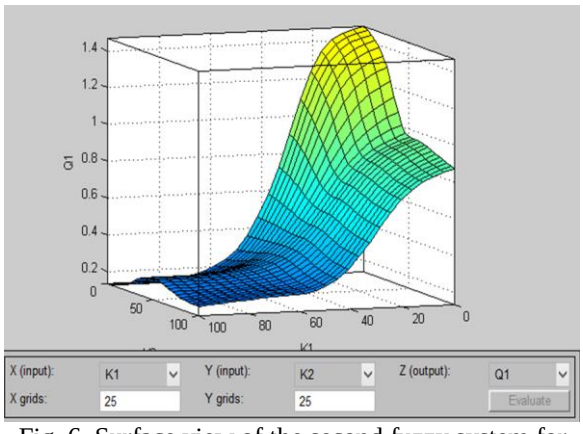

Fig. 6. Surface view of the second fuzzy system for operating a PV/battery /diesel generator/fuel cell micro grid-connected system

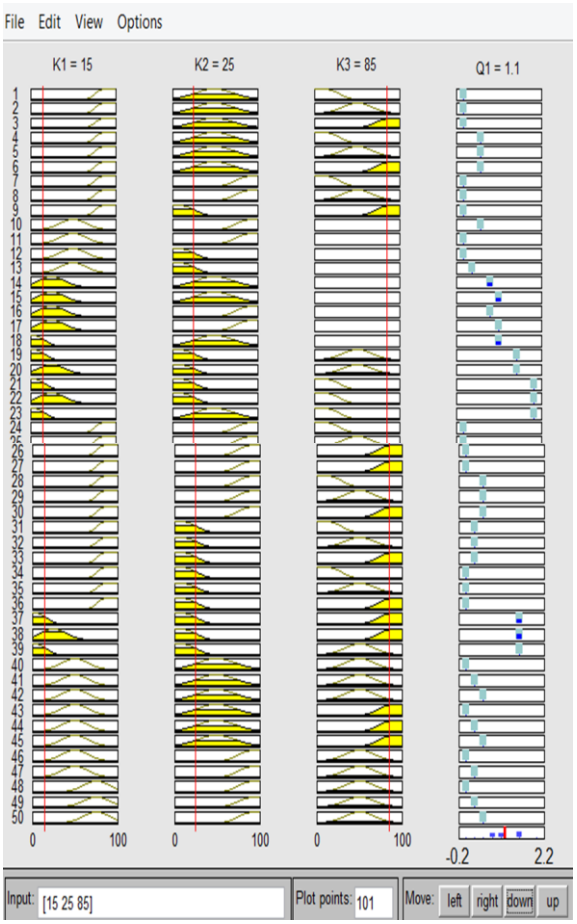

Fig. 6. Firing the rules of the second fuzzy system for operating a PV/battery/diesel generator/fuel cell micro grid-connected system with 15% of consumption covered by PV, 25% covered by batteries and 85% covered by the additional energy source

V. CONLUSION

In this article two models for supporting the process of managing micro grid PV systems are proposed. The first model is for managing a PV/battery micro grid connected system and in the second one is added one additional energy source (diesel generator/fuel cell).

The simulation tests are conducted in MatLab. This research is part of a project for optimizing the energy consumption of a building with the use of independent alternative renewable energy sources. The input test data for the optimization are the amount of used energy for lighting, heating, computers power supply and other needs of one particular building (the building of Burgas Free University).

A useful development of the presented models is to create autonomous software for managing photovoltaic systems. Such a program will be widely used given the pace of development of this technology around the world.

Optimizing PV systems with respect to their cost is another priority in the development of the proposed models.

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Intelligent data service for farmers

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***Abstract* - The agricultural sector in Finland has been lagging behind in digital development. Development has long been based on increasing production by investing in larger machines. Over the past decade, change has begun to take place in the direction of digitalization. One of the challenges is that different manufacturers are trying to get farmers' data on their own closed cloud services. In the worst case, farmers may lose an overall view of their farms and opportunities for deeper data analysis because their data is located in different services.**

The goals and previously studied challenges of the 'MIKÄ DATA' project are described in this research. This project will build an intelligent data service for farmers, which is based on the Oskari platform. In the 'Peltodata' service, farmers can see their own field data and many other data sources layer by layer. The project is focused on the study of machine learning techniques to develop harvest yield prediction and find out the correlation between many data sources. The 'Peltodata' service will be ready at the end of 2019.

Keywords - agriculture; artificial intelligence; platform;

I. INTRODUCTION

This paper is based on the MIKÄ DATA project, which belongs to a European Innovation Partnership (EIP) group. The project is funded by the European Agricultural Fund for Rural Development of the European Union. Generally, the goals of EIP projects are to foster deeper collaboration between farmers and researchers. The problems tackled in EIP projects are suggested by farmers, and the project's aim is provide solutions. For example, the aim of the 'MIKÄ DATA' project is to develop an intelligent data service for farmers, where they can see for example soil variations and nutrient levels. Before the launch of the 'MIKÄ DATA' project, farmers said that there was no such service available in Finland. It also seemed that agriculture in Finland was not developing fast enough from a technological point of view. Farming was focused on the more mechanical development, e.g. the development of larger machines and equipment for them rather than digital precision farming. Data-based management seemed quite distant. Therefore, the project was also designed to raise the importance of data from the agricultural sector's point of view. With open data and its widespread utilization, taking possession of farm data, and with the new value chain thinking, agriculture could take big development steps from a data perspective [1].

This paper focuses on four research questions: 1) What is a good platform for research and farmers' data? 2) Which data is relevant for farmers and research purposes? 3) How to add intelligence to the service? 4) How to improve relevant data quality?

In the second section of this paper we focus on describing different kinds of platforms. The third section deals with the relevant data. The fourth section describes adding intelligence to the service. The fifth section is focused on improving data quality. The concluding section contains a summary and discussion of these research question topics and future plans.

II. PLATFORMS FOR AGRICULTURE

This section focuses on suitable platforms for research and farmers' data. At the beginning of the project, it was unclear which platform would be chosen and what requirements it should have. After a short study, it seemed that there were many potential platforms although it was not essential to find all the platforms. In the spring of 2018 about 150 different possible platforms were listed. The platforms were found from articles, agriculture sector companies' web pages and some were identified during discussions with experts.

The majority of the platforms were commercial. The platforms were divided into three categories. The first category type was data management, where data was mainly introduced in tabular form. The second category was geospatial platforms, where data was introduced in geospatial maps. For example, Farmworks [2] included features of both previous categories. The third category was based on plugins or interfaces, for example Adapt [3]. Some of these platforms were paid and some were free; some were in the cloud and some were local, which made it possible to install them on your own computer. The project was interested in open source solutions, as it would enable its own development work. Only about ten of them were open source, at least partially, for example AgroSense [4] and Tania [5]. The conditions were that the ownership of the data does not change in the service and the user management of the data would be successful in the service. In other words, the service would come under the principles of the MyData concept.

Only open source solutions were researched more closely. Through some lucky coincidences, the Oskari platform [6] was also added to the testing list, although its focus was outside the agricultural sector. Oskari is a front-end service and the default back-end system is a Geoserver [7]. The front-end is based on Jetty [8], which offers a web server and many other components. After short tests of different kinds of platforms, more and more interest was focused on Oskari. Its strengths were strong multi-organizational development work and support in Finland,

which was also very well organized in the Oskari community. The choice of platform could also be partly influenced by the fact that in the very early phases of the project, a Geoserver with leaflet technique was used to show data for farmers. All data in the project was in map form so the project needed a platform that was suitable for maps. Another interesting alternative platform was FarmOS [9], but its focus area did not seem to be maps. FarmOS is specialized for the agriculture sector. Technically, it is a Drupal extension packet including several sub-sector functions [10].

One option would have been to provide farmers with QGIS [11] software and to develop a new plugin there, but farmers wanted an easy service where data processing and analysis had already been done. This kind of plugin has already been developed, e.g. GeoDataFarm [12].

The study of the sign-up and installation was started after it was decided to select the Oskari platform for the 'MIKÄ DATA' project. In the autumn of 2018, the first installation was made. Towards the end of the year, a new version of Oskari was launched, for which a new server was ordered and re-installed in February 2019.

Oskari platform's implementation was named the Peltodata [13] service. The term 'Peltodata' means field data in English and the reason for the Finnish name was to keep our focus in this project on Finnish farmers. The focus of Peltodata is to offer farmers easy access to their own farm data, which is produced by themselves (e.g. harvester yield sensor data) or during the project (e.g. drone data) or collected from outside sources (e.g. maps of the field's drainage systems). The service data is divided into two categories: Public data (which is mainly open data) and Mydata. MyData contains farm data that only the farmer can see unless he has changed the visibility of the data himself. Such data includes, for example, drainage maps and drone data. Open data is more general data that cannot be tied to any single field and such data is openly available for anyone. This data includes for example, weather and European Space Agency satellite data. Oskari enables the addition of data layers from WMS, WMTS, WFS and ArcGIS interfaces. Some of this data comes from the back-end Geoserver database and many open data sources were found from the Spatineo [14] service, which keeps a directory of almost two million different data set sources.

III. RELEVANT DATA

One of the important things about EIP projects is to obtain continuous feedback from farmers. That is why the 'MIKÄ DATA' project has held several workshops and steering group meetings with farmers. Meetings with farmers give for example researchers answers about what data is essential for farmers and why.

However, this has required the presentation of research results to farmers, the introduction of new data sources and the overlapping of data. Data sources have also had to be digitized, such as, for example, drainage maps.

Currently, data has been collected from a variety of sources. The biggest work input is being put into drones for data collection and yield sensor data from combine harvesters. Drone data is important for research purposes because it seems to be the easiest way to collect large amounts of data from different stages of growth throughout the growing season. Satellite data is dependent on satellite movements and cloudiness. In other words, making quality time series with satellite data has been impossible. Yield sensor data is the most important because all research is compared to this data. Up to now, the project has mainly relied on ground data sources, but now it would be more accurate to know about the soil itself.

At present, research utilises drone data, yield sensor data and satellite data. Next, it will be expanded by using weather data to monitor the temperature, solar radiation and precipitation that the crop receives. Later, lidar (light detection and ranging) data, drainage maps and soil samples can be added here.

It is hoped that artificial intelligence will be a solution to finding correlations between different kinds of data, and finding the most relevant data through this. However, researchers and machine learning models might need very different kind of data than farmers. Therefore it is important to consider the data needed for each purpose.

IV. INTELLIGENCE SERVICE

Artificial intelligence (AI) has been used to determine patterns among the features that are available. By using the crop as a system whose functioning (e.g. crop growth) is affected by inputs, it is possible to model crop development to predict the output (e.g. yield). With the prevalence of robust and economical sensor technology, it has become possible to collect large amounts of data by monitoring various aspects of crop development. With AI methods, it is possible to discern the most relevant data sources that can be used to achieve the necessary purpose with only minimal data collection. As an example, crop harvest yield can be estimated with increasing accuracy by collecting time series remote sensing image data. However, if AI can reveal the most significant times for collecting image data, it may be possible to collect images over fewer time points, making data collection less laborious.

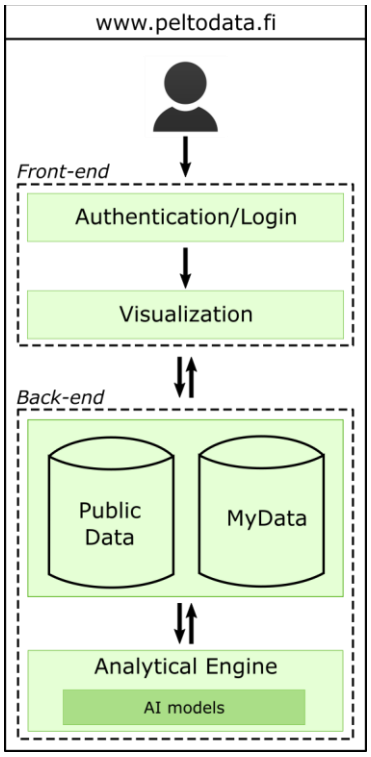

Figure 1. Peltodata service and Analytical Engine.

The analytical engine will include, among other analysis tools, AI models to predict crop harvest yield, which will be continuously developed based on data collected as part of 'MIKÄ DATA' project. [15] When fed with the current remote image of the standing crop the models will be able to return the projected crop yield. In the future, the analytical engine will include tools to monitor, detect and predict factors affecting crop productivity. AI-based methodologies will be employed to increase the farmers'/users' access to the latest developments by keeping the models current, using progressively collected data (with user permission/consent).

V. DATA QUALITY

Yield sensor data from farmers is one of the most important data that all calculations must match. Even in the early stages of the project, several errors appeared in the data. In summer 2018, a workshop was organized for farmers to encourage them to take the initial steps required for yield sensor data quality, including calibrations.

The data errors disturbed the research. The data could have been from several different fields or they may have been wooded in several parts. Varieties were not recorded and the weights were in the wrong format. In addition, the names of the fields were recorded in many versions, which of course the farmer knew well, but could not easily be assigned to the official land register number.

Many errors were found in the data due to either the sensors or some other obscure reason. The summertime of 2017 was very rainy, causing the humidity sensors to be blocked from time to time. When the value of humidity was too high, the sensor cut the value at certain threshold giving wrong values after that.

The detected data problems were resolved by making a python code. The data is from a Trimble yield sensor. First, it is checked (GEOS library, class QqsGeometry, function IsGeosValid()) whether the polygon structure can be repaired, because there are many challenging polygons structure errors [16]. After repair, a new review of the polygons is made. If it is not possible to fix the polygon, it will be deleted. However, the information attached to it is collected separately to assess the significance of the destroyed polygons. Too small polygons have also been destroyed, and one square meter has been set as the limit. Also, polygons whose centroid point (function geometry.intersects ("polycon centroid value")) is outside the polygons will be repaired or deleted. Data does not take into account already wooded areas. In the code, this is corrected so that the polygons shrink the area of the next overlapping polygons. In practice, polygons cannot overlap. For the sake of certainty, the area of the original polygon has been entered into the polygon data. For each polygon, the total field's information has been added, because they cannot be known in the phase of harvesting and when polygons are built. This information is, for example, the total amount of crops in a field. The code has been run in the QGIS program and needs to be improved. It must be checked that it also works with other device vendors. In addition, the code still poses a challenge regarding its reliability so that it does not fall with large masses of data. The challenge is having such a lot of data. Data from farmers concerns over hundreds of hectares in many summers. This corrected data should soon be analyzed by artificial intelligence for better quality data to be available. For machine learning models, it is important that the data is correct, i.e. the model is not developed with false or bad data.

VI. CONCLUSIONS

This paper briefly introduced agricultural platforms and presented the structure of the Peltodata service with the coming AI engine, which will increase the intelligence of the service. Some code tips were also introduced to improve the quality of the most essential data.

Ultimately, this paper answered all four research questions that were introduced at the beginning of the paper. The Oskari platform is a good platform for research and farmers' data if the data are mainly in map format. Its construction and installation are quite challenging, but it is very easy to use for the end user and there are several similar implementations in Finland, so users may already be familiar with it. It is difficult to say what is the most essential data, because there are different needs for farmers and researchers. For example, farmers do not need time series data of drones, but it is very important data when making machine learning models. The project has developed a Python code, which corrects yield sensor data. This data might be the most relevant data for farmers and research purposes. All analyses, etc. are compared with that data. This code improves the quality of the data and hence the accuracy of machine learning models. Peltodata will gain intelligence as machine learning models develop. It is still open how AI is connected to the Peltodata service. For example, the options to connect are a separate cloud service or a separate analyses machine or a code will be executed

directly on the service. Ideas and learning to implement AI can be retrieved from other similar services under development, such as AgroDSS [17] service.

The Peltodata service has many interesting development opportunities. It is already possible for users to download their own map data, which is in geotiff-format. By summer 2019, there will be additional functions that will provide more formats that are extensive. How these can be obtained to Peltodata is still undefined at this stage. Oskari provides a time series tool that allows the display of time-stamped data with a scrollable button. This is, for example, useful for drone data, where data has been taken every week throughout the harvest season. One interesting area of development is also how the farmer could sell or empower his own data. One of the biggest challenges is the fragmentation of data for different services. Can this be improved if the Peltodata service could be connected to service like x-road technologies in Finland and Estonia or company of Cinia Company's data transfer network technology for agriculture? At some point, the goal is certainly to get data out of the Peltodata service, but should it be in some map format or should it already be in some ISOBUS format?

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Short-Term Forecasting of Electricity Consumption Using Artificial Neural Networks - an Overview

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Abstract **- The short-term forecasting of electricity consumption has emerged as an important area of research with the aim of increasing the efficiency and reliability of energy system operation. It plays a very important role in the field of scheduling, load analysis, planning and maintenance of the power system. Artificial Neural Networks (ANNs) are computational techniques which have been successfully applied in a number of different problems, including short-term electricity consumption forecasting. This paper gives an overview of the recently published research papers that deal with short-term electricity consumption forecast based on ANNs. The related papers are evaluated with respect to several aspects, such as applied ANN type, used input variables and obtained precision regarding short-term electricity consumption prediction.**

Key words - Electricity Consumption; Short-term Forecast; Artificial Neural Networks

I. INTRODUCTION

Modern society is highly dependent on the use of electricity because of its many advantages such as convenient form, simple control, greater flexibility, cost, cleanliness and high transfer efficiency, making it more suitable than other forms of energy.

Prediction of electricity consumption implies the prediction of future load and it can be defined as the measure of the difference between the actual and predicted value of future load demand. A better prediction of power consumption can help in avoiding costly mistakes and can be useful in the development strategy of energy supply, financial planning and management of electricity.

Short Term Load Forecasting (STLF), usually refers to the prediction of power load for the next few hours, one day or up to several days ahead [1]. The major objectives of accurate STLF are economic dispatch and reliability, secure and reliable operation of power plants and generation scheduling of power system. Generation scheduling can be carried out with the help of accurate load forecasting to determine the allocation of generation resources, operational limitations, environmental and equipment usage constraints. Another application of STLF is to ensure the security of the power system. Accurate load prediction is an essential tool to determine the optimal operational state of the power system. Furthermore, this information can also be utilized to prepare the power system in accordance with future load state and corrective actions. Another important application of STLF is economic dispatch and reliability of power system. The reliability of power system highly fluctuates with the abrupt variations of load demand. For example, if the load demand is underestimated then the system may face a shortage of power supply. Therefore, it is difficult to manage the overload conditions and overall power system quality. Conversely, if the load demand is overestimated then a lot of available resources would have been spent to generate the overestimated power demand. In such circumstances, the precision of load estimation or prediction has gained tremendous popularity in the last decade [2].

Because of the aforementioned requirements, researchers are constantly proposing new scientific methods to obtain even more accurate forecasting of load consumption since even a small increase in the accuracy of such forecasting can significantly reduce financial losses.

Weather variables such as temperature, relative humidity, dew point, dry bulb temperature, wind speed, cloud cover are the most important factors in predicting load demands. Various types of loads consumed by consumers also creates an enormous impact on load forecasting. However, there is a need to accommodate all factors affecting load demand such as historical load and respective weather data in order to achieve more accurate forecasting results [1].

There is a wide variety of methods for short-term consumption forecasting. All the methods can be divided into two main main categories: traditional (statistical) algorithms and algorithms based on Artificial Intelligence (AI). In this work, emphasis is placed on short-term forecasts using AI based methods which usually outperform classical statistical approach [2]. One of the most famous models in the category of AI is the Artificial Neural Network – ANN.

In ANNs, to get future values, the nonlinear relation between the previous values and some external variables is assumed. Based on collected input-output data and by using an appropriate learning process, the network can learn the nonlinear mapping that exists between inputs and output.

This paper gives an overview of methods based on ANNs for short-term load prediction. The analyzed methods are evaluated regarding different aspects and are summarized for the purpose of easier comparison.

This paper is structured as follows. The details regarding ANNs are given in Section II. The most popular ANN based approaches to short-term electricity prediction are overviewed in Section III while their comparison is given in Section IV. In the end, conclusions are drawn.

II. ARTIFICAL NEURAL NETWORKS

A. ANN Structure

ANN can be defined as a highly concentrated network of elemental processors called neurons. ANN is very similar to the human brain that has a large amount of interconnected neurons arranged in a very complex, highly nonlinear and massively parallel network. A typical ANN is shown in Fig. 1 and consists of an input layer, one or more hidden layers and one output layer. This ANN is also known as the Multilayer Perceptron (MLP). Each layer consists of several neurons, and each neuron in the layer is connected with all neurons in the previous layer. Each connection has a certain weight which is represented by a real valued number. The output of a neuron is obtained by applying an activation function on the weighted sum of all of its inputs. Neural network learning is performed by the cost minimization function, which usually uses the square error output function. The most common algorithm for multilayer networks learning is Back Propagation (BP) algorithm.

An important part of ANN structuring represents input variable selection upon which forecasting is performed. As inputs to ANN, the most influential and highly related input variable must be used to obtain satisfactory forecasting results. However, there is no general rule for selecting the forecast model input data. Appropriate selection of input data can be taken based on engineering expertise or technical experience. Correlation analysis is often used to analyze the relationship between weather variables, historical load data and calendar events on load demand. Highly correlated historical data load, weather variables, and other influential variables dependent on time are considered as inputs of the forecast model to improve the performance of forecast model.

B. ANN Learning

After ANN structuring, it is necessary to obtain the proper values of network weights. The estimation of network weights is based on available data and it is usually called learning since the network is trying to capture the input output relationship that exists between input and output variables based on available data.

The usual approach to ANN learning is supervised learning. Supervised learning is the technique of training ANN in which weights are determined based on data which consists of input output pairs, i.e. for each sample of input variables a true value of output variable is known. Hereby, a objective function is used which defines how well ANN approximates available data. The data set used for obtaining final networks weight values is usually

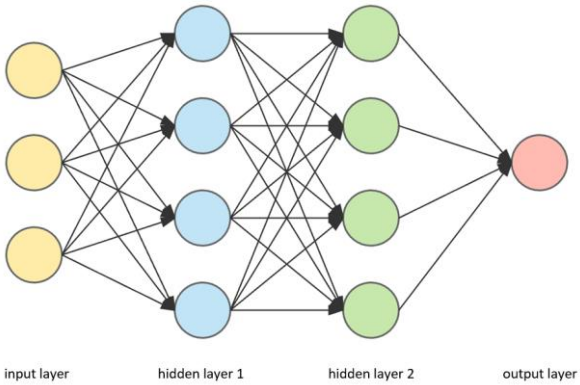

Figure 1. Typical structure of ANN.

called the training data set. Basically, this is an optimization problem where one seeks weight values which correspond to the minimum of the objective function. Commonly, Mean Squared Error (MSE) is used as an objective function which is the sum of squared difference between predicted values $\hat{y}_i$ and true output values y_i for each sample of input variables $\mathbf{x}_i$:

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{1}$$

where n is the number of samples in the training data set.

Usually, the initial weights are iteratively changed in order to minimize the given objective function using an appropriate numerical method such as gradient descent with backpropagation algorithm for gradient calculation.

C. Evaluation

Once the ANN is trained on the available training data set, its prediction performance should be evaluated on another data set from the same distribution as the training data set. This data set is called the test data set. The most common metric is MSE on the test dat set. However, in short-term electricity consumption prediction, Mean Absolute Percentage Error (MAPE) is often used:

$$\mathrm{MAPE} = \frac{100\,\%}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{y_i}\right|. \tag{2}$$

III. SHORT-TERM ELECTRICITY PREDICTION BASED ON ANN

Generalized Regression Neural Network (GRNN) proposed in [3] has proved to be an appropriate method for solving nonlinear problems. The GRNN model is used in various disciplines and engineering fields due to its good capabilities of nonlinear approximation, excellent anti-interference performance, autonomous learning ability and rapid convergence. The biggest disadvantage of this model is the spread parameter, since the value of this parameter highly affects the forecasting performance. Hence, the Fruit Fly Optimization Algorithm (FOA) is

used. FOA is a novel method which uses fruit fly behaviour pattern in order to perform global optimization. By using FOA to determine the spread parameter, stable and better results of the short-term forecast are achieved.

A second method based on evolutionary algorithms is presented in [4] where prediction performance is improved by using Clone Selection Algorithm (CSA) and the ANN machine learning algorithm. The proposed technique also utilizes ANN learning skills to address non-linear and complex problems and CSA population-based algorithms for global and local search. A new self-adaptive modified technique was introduced to enhance local and global CSA algorithm capability and prevent the algorithm to converge too early. The modified technique consists of three sub-modifications to improve population diversity, halve the population average in order to optimize the solution, and establish a balanced local and global search mechanism. In order to improve the training process a new method was proposed, which used the selection of fuzzy features and Self-Adaptive Modified CSA (SAMCSA) Autoregressive Integrated Moving Average ANN method. To demonstrate the supremacy of the proposed hybrid method in relation to traditional load prediction methods, ANN is trained using traditional training algorithms, such as back-propagation, in such a way that the ANN architecture, weight and bias parameters is achieved by experimental path, and then SAMCSA, a modified evolutionary population optimization algorithm is applied to reduce relative errors by tuning weights and biases. In addition to the proposed ANN algorithm training, a selection of fuzzy features is introduced to select only informational features in the data set and to get rid of the data noise in order to keep the prediction accuracy satisfactory. In order to evaluate the performance and the improved system efficiency of the proposed method, a true data set for the daily peak load of the Fars Province in Iran was used. The results show not only that the population-based evolutionary technique can be introduced as a desired alternative ANN learning algorithm, but it also shows that the change made to the CSA method improves the overall efficiency and accuracy of the CSA as an optimization model.

For very short prediction periods, Advanced Wavelet Neural Networks (AWNN) are proposed in [5]. This is a timeline forecasting approach that combines advanced wavelet separation method, Mutual Information (MI) method for feature selection, and ANN as a prediction algorithm. AWNN first separates the load into a variety of Wavelet Packet Transform component groups with the best choice of base that chooses the optimum wavelet component to display data based on the entropy criterion. Then each wavelet component is predicted separately and the results combined. AWNN achieved good predictive accuracy and surpassed a number of methods used for comparison: three Autoregressive Integrated Moving Average (ARIMA) methods, three Holt-Winters exponential smoothing methods, an industrial model, several naive bases and also a single non-wavelet prediction model of ANN, Linear Regression (LR) and Model Tree Rules (MTR).

Likewise, for predicting consumption at the day level, the authors in [6] suggest a Dynamic Neural Network method. The key idea of the proposed methodology is based on neural network with augmented inputs to capture dyanimcs and is trained with Levenberg-Marquardt's back-propagation algorithm. The proposed method gives better and more accurate results in comparison with Holt-Winters exponential smoothing models and Seasonal Autoregressive Integrated Moving Average (SARIMA) model because the proposed method has a better adaptation of the network to the time series variation.

To improve predictive accuracy, the use of Boosted ANN (BooNN) techniques is proposed in [7]. The BooNN technique is based on the iterative creation of numerous ANN models, where the model obtained at each iteration reduces the error between the expected and the obtained output from the trained models in previous iterations. Compared to other prediction models such as single ANN and bagged ANN, similar day wavelet neural network, Autoregressive Moving Average (ARMA) model, hybrid ANN and bagged regression trees, the proposed model obtains better predictive results.

The use of Bagged Neural Networks (BNN) is proposed in [8]. Bagging methods are designed to improve the performance of machine learning algorithms. BNNs consist of generating multiple sets of data by random sampling by replacing, training a neural network on each set of data, and by averaging the results obtained from each trained neural network. The bag process reduces the error estimates and the range of variable errors compared to the use of a single neural network for predicting the load.

In [9], authors propose and compare several approaches to short-term consumption forecast including: GRNN, MLP, Radial Basis Function Neural Network (RBFNN), Fuzzy Counter-Propagation Neural Network (FCPNN) and Self-Organizing Map (SOM), as well as classical statistical models ARIMA and Evolution Strategies (ES). The common feature of these methods is learning from seasonal time cycle series load patterns. Samples used as input and output variables simplify the prediction problem by filtering trends and seasonal variations over a one-day period. The GRNN-based model proved to be the most accurate in STLF compared to other neural models. Based on the results achieved in this work, it can be concluded that GRNN is the simplest among the tested methods. There is only one parameter to be estimated,, i.e. the spread of Radial Basis Functions (RBF). It should be pointed out that dimensions of input and output patterns do not affect the number of parameters to be estimated in GRNN unlike in other methods. The second best model is MLP with slightly worse results.

Forecasting consumption through ANN has its limitations and disadvantages, such as difficulties in determining the ANN structure, neuron type selection, long training period and similar. To overcome these problems, Generalized Neural Network (GNN) were proposed. In [10] authors propose hybrid method which

combines GNN and adaptive genetic algorithm using fuzzy system (GNN-GAF). To further improve the accuracy of predicting short-term load, the GNN-GAF model is combined with wavelet transformation and the resulting model is caled GNN-W-GAF model. The GNN based models are used to forecast the electrical demand of the substation of Dayalbagh Educational Institute, Dayalbagh, Agra, India. The results show that the RMSE of GNN-W-GAF is minimum in comparison different GNN variants trained with BP algorithm.

Another method that uses wavelet transformation is proposed in [11]. The proposed method is based on wavelet transformation, ELM (Extreme Learning Machine) and MABC (Midfield Artificial Bee Colony) algorithm. Wavelet transformation is used to break down the load series into a set of different frequency components that are more predictable. The MABC algorithm selects the optimal set of input weights and hidden impacts on ELM. The ELM-MABC algorithm has a better convergence than the conventional neuro-evolutionary method, which results in a significant improvement in prediction accuracy.

Today's energy network consists of many renewable energy sources. These sources significantly contribute to the level of uncertainty of energy systems. However, traditional forecasting methods cannot handle uncertainties in system operations. Therefore, in [12] authors propose the method based on ANNs for the construction of Predictive Intervals (PI) in order to quantify the level of uncertainty associated with forecast. The newly proposed method is called Lower Upper Bound Estimation (LUBE). The primary multiobject problem is successfully transformed into a constrained single objective problem. The advantages of this new formulation of the problem is fewer number of parameters of the cost function. Particle Swarm Optimization (PSO) is integrated within LUBE method. With improved search capabilities, PSO is then used to address a new problem and to train ANN models. The proposed method gives improved PIs in comparison with classical approaches such as ARIMA or ES.

Similarly to [12], authors in [13] tried to quantify the level of uncertainty associated with the increase of the complexity of power systems by using probability density forecasting method. More precisely, in [13] STLF based on quantile regression neural network using triangle kernel function (QRNNT) is proposed. The advantages of QRNNT are that the complete conditional probability density curve of future load is obtained. The efficiency of the proposed method is evaluated on three different datasets and compared with RBFN.

Hybrid techniques combine superior attributes of two or more algorithms that integrate into the neural network to provide more efficient prediction models with their optimization techniques. One of the hybrid models consists of the Support Vector Regression (SVR) algorithm and the Modified Firefly Algorithm (MFA) for short-term prediction of electric load [14]. Hereby, MFA is used to efficiently determine SVR parameters. The proposed modification increases the diversity of the fireflies in the population and thus reducing the possibility of being trapped in local minima. According to the obtained results, MFA appears as a good candidate for a global optimization problem solving, outperforming standard algorithms such as Artificial Bee Colony (ABC) or original FA. The hybrid SVR-MFA method obtaines better results than ARMA models, standard ANN or SVR models optimized with different algorithms such as GA, PSO or FA.

One way of predicting consumption is based on Gray Models (GMs). However, only the usage of GMs is usually not accurate enough. For this reason, authors in [15] propose a new model that is based on the combination of Wavelet Transformation (WT) and GM which is enhanced by PSO. Weather data including mean temperature, average relative humidity, mean wind speed and load based on past days are used as model inputs. WT is used to remove the high frequency load components of previous days and to improve the accuracy of prediction. The proposed approach is evaluated on two case studies where daily and weekly load forecasting is analysed. By comparing the results of this method using different metrics with all comparable methods on these datasets it can be concluded that the porposed method obtains better results.

Hybrid models that integrate WT with other techniques are used extensively for short-term load forecasting. In these studies, wavelet transformation is effectively used for extracting and analyzing characteristic features embedded in time series of loads at different frequencies. In [16], a hybrid method based on WT, Triple Exponential Smoothing (TES) model and Weighted Nearest Neighbor (WNN) model is proposed. In essence, WT is used to break the load series into fluctuation and deterministic component which are modelled using WNN model and TES model respectively. The proposed approach is evaluated on historical load data from the California and Spain energy markets. Such hybrid approach outperforms the direct use of the Holt-Winters (HW) model, WNN models and Haar wavelets combined with the WNN model in 24 hours ahead forecasting.

TABLE 1. COMPARATIVE CHARATERISTICS OF THE REVIEWED METHODS

Method	Precision	Input Data	Prediction time	Used algorithms	Problem
[1]	MAPE = 1.62%	historical data,	N/A	N/A	N/A
[3]	RMSE = 0.0018	historical data, weather characteristic, environmental temperature	Day	SFOA-GRNN	Disadvantages of learning
[4]	RMSE = 1.9759	real dataset for daily peak load	Day	SAMCSA-ANN	Optimization
[5]	MAPE = 0.27% MAPE = 1.72%	5-min and 60 min electricity load datasets	Minute, hour	AWNN, MI, ANN	Border distortion
[6]	MAPE = 3.27%	load data	Day	DNN, Levenberge-Marquardt	Not specified
[7]	MAPE = 1.43%	historical hourly temperature, load patterns, dry bulb temperature, dew point temparature, hour of the day, day of the week	Day	ANN	Selecting the ANN model
[8]	MAPE = 1.75%	historical hourly temperature, load patterns, dry bulb temperature, dew point temparature, hour of the day, day of the week	Hour	BNN, various ANN	Choose sample size, training time, and performance
[9]	MAPE = 1.38%	patterns of the seasonal cycles of load time series	Day	MLP, RBFNN, GRNN, CPNN, SOM	Not specified
[10]	RMSE = 0.0486	data set of all working days load	Day, week	GNN, GA,BKP, WT	Slow learning time
[11]	MAPE = 1.48%	ISO New England dataset, North American electric utility dataset	Hour, day	ELM, WT, MABC	The noise in the data
[12]	N/A	real electrical load datasets	Day	PI, ANN	Multi-object problems
[13]	MAPE = 1.59%	historical power load data	Day	QRNN	Prediction interval
[14]	MAPE = 1.69%	electric load data	Day	SVR, MFA	Parameters
[15]	MAPE = 1.82%	mean temperature, mean relative humidity, mean wind speed, previous days load dana	Day, week	WT, GM, PSO	Optimization
[16]	MAPE = 1.20%	hourly load data	Day	Holt-Winters, TES, WNN	Load series
[17]	MAPE = 1.13%	two real load datasets, temperature	Hour, day	ELM,ELM-LM, CMIFS	Parameters
[18]	MAPE = 2.17%	one-day-ahead hourly load profile	Day	STAR, SOM, Ho-Kashyap	It does not include weather factors

WT is successfully used for STLF by breaking load data into a set of subcomponents. However, it can play a much larger role in the modeling process. In [17], authors propose a new comprehensive Extreme Learning Machine (ELM) short-term prediction model. In this paper a new, complete scheme that uses WT to generate a collection of individual predictors is presented. Individual predictors were obtained using different combinations of parent wavelets and number of degradation levels. The total output is the weighted average of individual predictors. Weight coefficients were obtained using the Partial Least Squares Regression (PLSR) method. To improve the success of learning, a hybrid algorithm is proposed in [17] that combines the ELM and LM method. The proposed approach is capable of alleviating many difficulties associated with model parameter estimation. In developing the STLF model, determining the appropriate set of input variables from data has a major impact on prediction performance. Generally, multiple input variables carry a greater discriminatory power, but in practice excessive variables can bring many disadvantages. The reason is that some variables are irrelevant or redundant and can act as a source of noise. Therefore, a feature selection method based on conditional MI is used. Compared to other techniques such as MLP or RBFNN, the proposed model obtains better performance.

Statistical methods include linear regression methods, moving average, exponential smoothing methods, autoregressive and moving average models, Box–Jenkin methods and Kalman filtering methods. The biggest drawback of these methods is that they must have some prior knowledge of the relationship between the input and the output and are quite limited due to linear modelling function assumption. However, the load series that is being modelled is a non-linear function of the independent variables. To overcome this problem, [18] suggests a Neuro-coefficient Smooth Transition Autoregressive (NCSTAR) model. The proposed model is based on the flexible Smooth Transition Autoregressive (STAR) model. The described model is a linear model with time-variable coefficients that emerge from a hidden layer of feedforward neural network. Hidden layer is responsible for partitioning input space into multiple sub-space through multivariate thresholds and smooth transitions between substrates. The Self-Organizing Network (SOM) is used to divide the dynamics of historical data into clusters and then use the Ho-Kashyap algorithm to obtain plane spacing equations. A significant advantage of the proposed method is that it can easily handle the lack of data on energy load data, which could

be due to seasonal or market effects. The proposed method of initializing the weight for the NCSTAR model also makes it more robust for initial conditions because the first step of the initialization process involves SOM, which is usually robust against poor initialization.

IV. Comparison Of STLF Methods Based On ANN

In this section, a comparison of discussed methods for STLF is given. For each method, we extracted key informations: MAPE, prediction time frame, used algorithms and the main problems/disadvantages of the proposed approach as shown in Table I. From Table I and reviewed relevant works it can be concluded that a wide range of AI techniques are applied in the area of forecasting the electricity consumption with a certain level of success. Furthermore, we can conclude that the usage of ANN in load prediction often gives better results than conventional methods. Likewise, there are a number of hybrid techniques that take the best characteristics of a particular method and merge them into one method for the purpose of a more accurate load prediction. Usually, wavelet transformation and/or evolutionary algorithm are combined with ANN such as MLP. The accuracy of prediction depends primarily on the efficiency of the neural network training, selection of input data and optimization of network architecture. From Table I it can be concluded that higher MAPE values are obtained if only past load data is used. If additional variables, such as weather characteristics, are used in prediction we can see that more precise predictions are usually obtained with lower MAPE values. Regarding precision of forecasting with respect to the time basis, we can conclude that more accurate predictions are achieved on an hourly basis, followd by daily basis.

V. Conclusion

The decision maker in the energy sector needs accurate forecasts of electricity consumption since most decisions are necessarily based on anticipating future demands. Short-term load forecasting is based on mathematical model and different input variables. Due to the problem complexity, the model structure and parameters are determined based on available data. In this paper, various models based on ANN are reviewed. By looking at the relevant literature, a clear shift toward neural networks is observed and they are achieving promising results in STFL. Moreover, a growing number of hybrid forecasting techniques are being applied to increase ANN accuracy, usually by introducing wavelet transformation or/and evolutionary algorithm. The methods described in this paper show certain ability to predict electrical load, ultimately leading to a reduction in the operating costs of the power system and increasing its efficiency and reliability.

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Semantic Approach in Encoding of the Meanings in Bulgarian Folklore Embroidery in Digital Libraries

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***Abstract* - The purpose of this article is to describe the architectural approach in building a knowledge base for the Bulgarian national embroidery, in which its subjective characteristics are thoroughly presented. There is an opportunity, along with the generally accepted features, to store the characteristics encoded as a negative or hidden element and recognized by historians. Ontology based on subjective semantics would be extremely useful. We list a range of potential uses and offer types of measurements and applications that can be performed to measure the capabilities of the semantic approach. The study lists potential cases of the use of ontology based on subjective semantics, which demonstrates the usefulness of this approach.**

Keywords* - *computational folkloristics, semantic net, folklore archives, folklore symbols.

I. INTRODUCTION

Folklore is the combination of social practices that contains the philosophy, the lifestyle, and the culture of an ethnos. It is an ensemble of music, verbal wisdom and material color, a mirror of the history and mentality of the people, the most direct way to transmit traditions, morals and values to the younger generation.

Researchers of Bulgarian folklore are unanimous that it is one of the best preserved in the world and combines different manifestations of ancient arts that impress with their uniqueness and authenticity. It is one of the main sources of historical artifacts for Proto-Bulgarian pre-Christian beliefs, traditions, artistic perceptions, cosmology. For this reason, the collection and systematization of folk elements in digital libraries are the subject of work of many expert teams from different scientific fields.

An indispensable part of the folk costumes of Bulgarians are the national embroideries. They are not just a decoration, but a coded language that, through image and color, conveys the beliefs of the community. The ornaments embroidered in the Bulgarian national embroideries represent signs and symbols through which the masters of the craft incorporated the cult of the sun and the stars, symbolized ancient gods, transforming their connection with nature. Typically, the embroidery is located along the edges, circularly, closing around the openings of the garment. It is believed that they embody the circle of life and protect the body from evil forces because, in addition to pleasing the eye, these ancient drawings have had the semantics of sacred magical signs for protection, healing and hidden secrets [1]. Within, the craftsmen have invested their hope for protection against disease and envy, and calling for fertility. In the Bulgarian embroidery, there are no classic Christian symbols, there are mainly pagan folklore elements. The symbolism of motives is almost always positive because of the function of the embroidery, which is to protect the wearer [2].

Knowledge of national folklore and lifestyle contributes to building a solid image of ethnic identity and belonging, and therefore respect for the cultural values of peoples. In itself it is a basis for respect for the value of diversity in different countries and in the world as a whole.

The aim of the present study is to create an appropriate formal model of semantic information embedded in the Bulgarian national embroidery, which focuses on its subjective characteristics. Along with commonly accepted forms, the characters are also encoded as positives, negatives or hidden elements (Fig. 1). The knowledge base is organized as a semantic network based on the subjective semantics of the elements.

II. BACKGROUND

In recent years, interest has been intensified in the use of ontologies to present the semantics of data from different areas of knowledge. Their specific advantages, such as simplicity, visibility, clarity and natural way of presentation, favor the formalization of large volumes of factual information. For this reason, semantic digital libraries have attracted the attention of various scientific and educational institutes for more than a decade [3].

Since historical research is an area providing interesting opportunities for the implementation of ontologies, not only computer specialists but historians as well are interested in the promotion of digital libraries preserving the subjective semantic characteristics of individual artifacts. The knowledge of folklore covers the different manifestations of culture in the past. For example, The Danish Folklore Nexus

(http://etkspace.scandinavian.ucla.edu/danishfolklore/) is developed by the University of Washington Press and presents fairy tales and legends from the different geographic regions of Denmark [4]. University of Cyprus, Nicosia, Cyprus, 2014 promotes its initiative to preserve the Cypriot heritage of folk dance. The project aims to create a publicly accessible digital archive of folklore dances, including video recordings often used to document dance performances and aims to preserve this intangible cultural heritage through its digitization [5].



Figure 1. Fragment of a cover with motif of the Red Goddess Mother and the White Goddess Mother (in negative, with the head down and with horns of the head). Photography: M. Georgieva [19]

M. Emadi of the University of Jyväskylä, 2012 presents an ontology of Iranian folklore. The study evaluates several strategies in the digitization and semantic performance of the Ketab-Kuche, an incomplete massive encyclopedia of folklore written by Ahmad Shamlu. The Encyclopedia provides an appropriate case for the difficulties and realities of digitization in developing countries such as Iran. [6] Ramadoss B. and K. Rajkumar, 2007 describe a generic model for presentation of Indian folk dances, where videos of different levels of detail imposed by the components of the accompanying song are used to represent the dance movements semantics. This model includes both syntactic and semantic video features. Examples and evaluation results are presented to demonstrate the effectiveness of the proposed dance video model [7].

Considering the variety of useful properties and characteristics of the repositories of digitized knowledge, their function of presenting the valuable phenomena of Bulgarian folklore is not accidental. There are several popular Bulgarian national studies and projects related to the virtual existence and the digitization of ethnographic and folklore artifacts. More important are: "Digital Libraries with Multimedia Content and Applications in the Bulgarian Cultural Heritage" with Multimedia Digital Library "Virtual Encyclopedia of Bulgarian Iconography" (http://mdl.cc.bas.bg) [8], Digital Library "The Calendar of Saints" (http://www.eslavsanct.net/) [9], the Multimedia Fund with the BellKnow in Bulgaria [10].

As a result of work on the FolkKnow project, developed by BAN specialists, web-based social-oriented applications have been created for the needs of non-formal learning and cultural tourism. Experimental digital archive includes "Bulgarian Ethnographic Treasury" (http://mdl.cc.bas.bg/ethnography/), project "Yuper" (http://yuper.hit.bg/), project "Folklore Motives and Anthologies" (http://liternet.bg/), project "WebFolk Bulgaria" (http://musicart.imbm.bas.bg/EN/Default.htm), project "Living Human Treasures" (http: //www.treasures .eubcc.bg /main.php), project "Virtual Encyclopaedia of Bulgarian Iconography" (http://mdl.cc.bas.bg/), etc. [11]

All these studies confirm the thesis that the well-built, tested and developed semantic basis of the Bulgarian national embroidery would be a valuable resource for future large-scale projects for:

- Folklore analysis;
- Justification of historical theses;
- Computer recognition of folklore images;
- Mathematical and Algorithmic Modeling;
- Generation of L-grammars describing the different elements of the embroidery symbol, and so on.

III. FORMAL PRESENTATION OF THE NATIONAL EMBROIDERY ONTOLOGY

Ontological engineering adapts the philosophical understanding of ontology to the needs of computer science, using different methodologies to create and implement computer ontologies. According to Methontology methodology for the development of knowledge systems, the process of realization of the ontological model for the Bulgarian national embroidery passes through several basic phases (fig. 2).

The generic scientific model on which the theoretical study is based includes:

- Specification - the purpose and scope of the ontology is the national embroidery model, the target group of users are scientists, students, and citizens with interest in this area.
- Acquisition of knowledge: the necessary information for the ontology is gathered from the specialized sources.
- Conceptualization: knowledge is structured as a taxonomy with glossaries of concepts that describe folklore models.
- Integration: the ontology is designed from scratch to be independent.

- Performance: the ontology development environment is prepared to develop the ontology in Protégé` by using OWL.
- Evolution and documentation are the future process of ontology creation. [12]

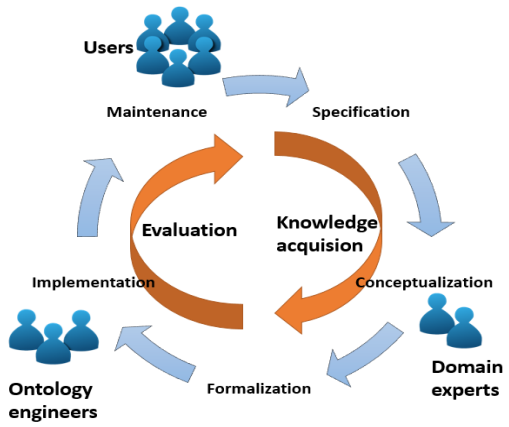

Figure 2. Phases and activities of Methontology and their relation to the actors

According to the accepted ontology, the presentation of an effective annotated knowledge from the studied area requires the use of a format that does not impose semantic constraints on the data, and facilitates complex procedures with them, allowing the algebra of semantic queries. For the current ontology model, Web Ontology Language (OWL) was chosen as the most appropriate. OWL is a dynamic language that provides categorized concepts, reasoning, coherence, information processing, semantic queries. This language allows for a better interpretation of the specified machine content than XML, RDF and RDF Schema, providing additional vocabulary along with formal semantics. The knowledge of the studied folklore area is classified through a rich hierarchy of concepts and relationships between them.

For research on OWL functionalities and ontology building, Protégé 5.0+ OWL Plugin was used. Its specific in a way that if the actual embroidery has a material carrier, then for its digitization an image (picture) is not enough. For this reason, the Class Embroidery correspondent directly with Class Image, Class Stitch, Class Colors, and the relationship is has. The Embroidery class object stores the official name of the embroidery and its specific number as information. The uniquely generated SpecificNumber includes country, folklore, populated area and sequential number.

Depending on the costumes Bulgarian embroidery has formed in more than twenty significant varieties occupying different regions. For a territory with the size of Bulgaria- it is too much. For this reason, Class FolkRegion is required to store this information.

Although the present study is directed only at the Bulgarian national embroidery, it is envisaged that the Class Knowledge Base will also store embroidery of other nations. This organization makes possible the further development of the current theoretical framework and provides a tool for comparing elements from different ethnic regions, which will facilitate and enrich with factual material a number of studies on the human migration.

The description of each embroidery as a museum exhibit also includes the tailor's stitch used on the artifact, so Class Stitch is also included for completeness of the description.

The identification of the groups of symbols encoded in the national embroidery is used in the studies of I. Koev, and they are classified in the following groups: zoomorphs, plants, people, sun signs, old Bulgarian symbols, compositions, deities, geometric shapes [13].

Figure 3 shows the diagram of the classes described and the links between them.

IV. METADATA

According to J. Fray [20], metadata can be used to record different types of descriptive information at different levels of detail. The project defines the following levels:

Dataset level, which combines information about the number of artifacts, the number of images that describe them, number of registered system users, included in the information system.

Resource level is a level where the same meta information is shared for all objects. These are digital images (photos) and commentary texts as well as additional information about the source of the photos, the embroidery owner, and so on [15].

At the Triple level, metadata is stored for each statement or triple. It is required to store meta information at a triple/statement level in order to use the metadata for filtering or fusion algorithms.

Cultural institutions and organizations as well as non-professionals will be able to find information about the semantically connected complexes of folklore objects based on starting points such as "Location", "Symbols", as well as searching for specific "Colors".

Ontology allows us to describe the semantics of folk content and use new knowledge management services such as semantic search in sets of diverse and complex subclasses and objects in a stable, rich and user-friendly way, custom search, context-based search, multicriteria search, metadata management, etc.[16]

Semantic annotated objects can also be used as a basis for eLearning course development, for example, folklore objects can easily be found and grouped into lessons and modules [17] [18].

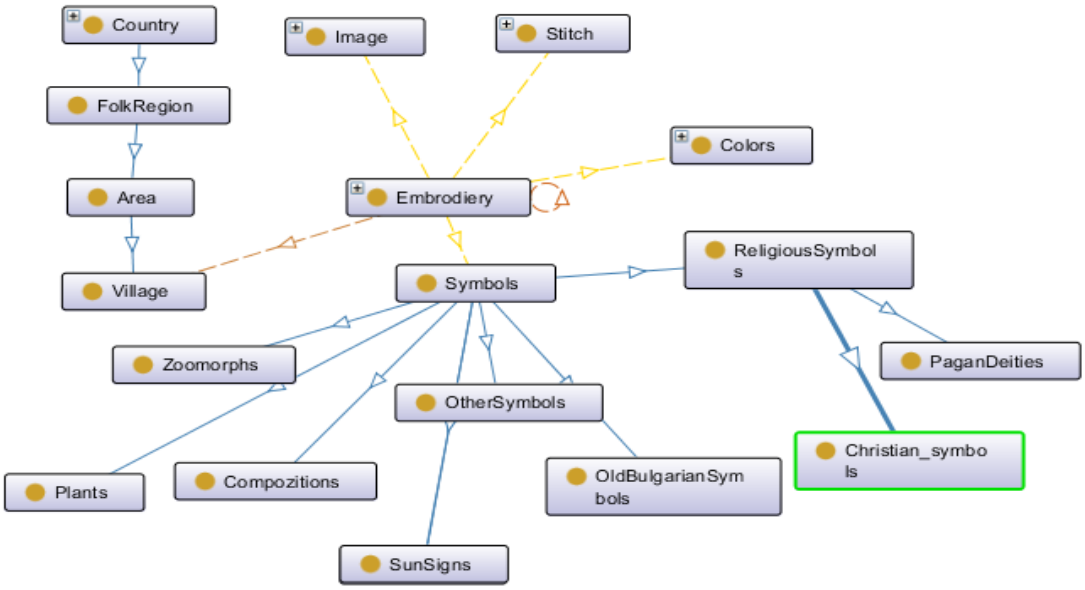

Figure 3. The ontology OntoGraph in Protégé

V. CONCLUSION

1. Since folklore is a social phenomenon, determined by the environment in which its artifacts are created, it is necessary for the folklorists to work together with cultureologists, ethnographers, ethnologists, sociologists, linguists and historians, which also requires the interdisciplinary character of the approaches to observing and preserving folk art.

2. In the field of artificial intelligence and computer science, ontology-building methodologies are used in designing formal models from different areas and aspects of reality by building a knowledge base, conceptualizing the world of interests, and offering definitions of sites and relationships that allow the accumulation of specialized knowledge, accessible and shared between different audiences and communities. Methontology is one of the most comprehensive and used ontological methodologies that allows to design and development of zero-level ontologies or the use of existing ones. It is compliant with the IEEE 1074-2006 standard for project lifecycle development. The phases of the process of designing, developing and evaluating the release of the ontological model for the Bulgarian national embroidery are several: acquisition of knowledge. conceptualization, integration, performance, evolution, documentation.

3. As the Web Ontology Language (OWL) is a knowledge representation language for authoring ontologies or knowledge bases it was chosen as most suitable for the ontological model.

4. Although the present study is directed only at the Bulgarian national embroidery, there is an opportunity for the knowledge base to store embroidery of other nations. This organization makes possible the further development of the current theoretical framework and provides a tool for comparing elements from different ethnic regions, which will facilitate and enrich with factual material a number of studies on the human migration.

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Deep learning advancements: closing the gap

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***Abstract* - This article explains how recent development in the field of Artificial Intelligence (AI) makes gap between human and machine smaller than ever before, by explaining and comparing traditional approach user in development of AI systems with new approach that has been used by AI system AlphaZero, developed by DeepMind. Traditionally AI systems have been tested in chess and the same has been done to demonstrate the power of AlphaZero. But, instead of playing against human, it played against the best (at the time) chess program Stockfish. While chess programs (before AlphaZero), were using powerful hardware and embedded built-in formal knowledge about the game, AlphaZero is using completely new approach, running on standard hardware and using deep learning. It learned about the game by playing a large number of games with itself, learning in the process. Article will also explain what is so revolutionary in AlphaZero approach to AI and how this new approach can be used in different areas of processing visual information, bio-medicine, autonomous driving, robotics and AI generated images/videos of humans.**

Keywords – artificial intelligence; deep learning; AlphaZero; bio medicine; autonomous driving; GAN; generated image; video synthesis;

I. INTRODUCTION

The idea of artificial intelligence as a concept that would be able to somehow emulate the functionalities of human brain has been fascinating mankind for a long time. We have been (and, for the most part, still are) wondering what exactly the difference between the inner workings of a brain and a very advanced machine is. These days, or at least from 1950, the machine really means a computer of some kind.

For a long time, the question did not have much practical value because computers could not really compete with humans in almost anything, but that was only a consequence of available "firepower" or the sheer computing power. However, things have gradually started to change, hardware was more and more powerful and mathematical formalism used to approach the topics of artificial intelligence has also advanced to the point where question began to make sense.

II. ARTIFICIAL INTELLIGENCE (AI)

A. Setting the stage

At the same time people realized that there are also many other important questions that were (and many still are) waiting to be answered. As the computer's capabilities increased, the number of different important areas have also increased and natural language processing, handwriting recognition, speech recognition, image recognition, games playing, advanced robotics, evolutionary systems, autonomous driving and many other problems were elevated to the level where we started looking for a well-defined, logical and mathematical answers. And so, the discipline of AI (artificial intelligence) has been officially established.

Despite big promises, things were not always smooth and the society (even very qualified parts of it) did not always recognize that this is yet another new technology and it should, therefore, follow the similar development and adoption path as other important technologies do. This is nicely explained in the following Gartner's image from 2017, Figure 1:

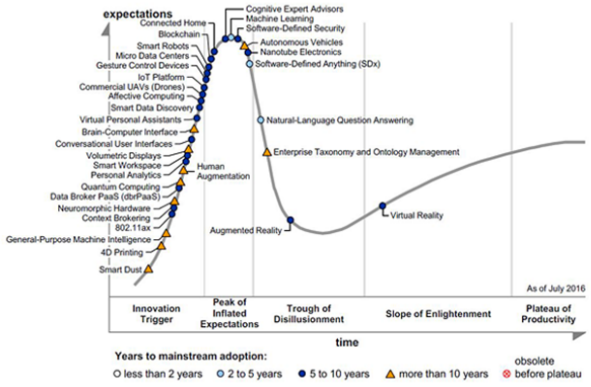

Figure 1: Gartner, 2017

AI did not exactly follow this pattern. Instead, it moved along this one, Figure 2:

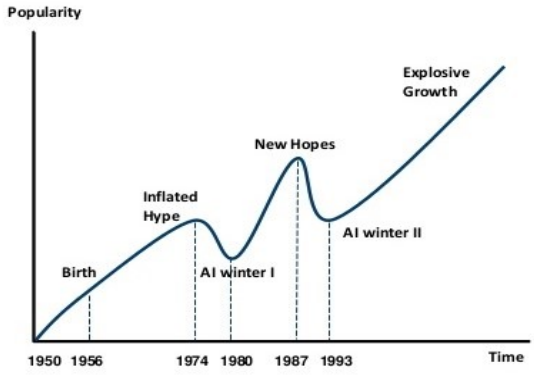

Figure 2: Team Finland Future Watch Report, 2017

If you take a good look at the above image, you will be able to see that it looks like there was not one but two starts

(inflexion points) instead and, very important, that the rapidly rising curve is much steeper than Gartner would predict. But otherwise, the pattern is there, and we should be able to analyze it in a rational manner.

In a sense, for a long time (more than 60 years, actually) AI has been a victim of our reduced capabilities and it simply means that we did not have enough computing power to investigate the theoretical possibilities and, therefore, we were very far from being able to build important commercial level applications that would benefit from AI promises. To be completely fair about this, there were quite a few important and even impressive steps, like IBM's DeepBlue that won the first chess match against Gary Kasparov in 1997. That marked the end of an era of human domination in probably the most beautiful logical game that human race ever invented.

But these successes were still very limited and were certainly still far from becoming a part of our standard productivity applications. The hardware was still too expensive, the solutions were too specialized for a certain task and something was clearly still missing.

In this period many reputable teams were working on natural language processing and speech recognition, and some have also started to develop image recognition techniques because these were the areas that seemed to promise the most at the time. Some important examples that even entered the commercial stage were Roomba (the first autonomous cleaner that is widely available today) in 2002 and Apple's Siri (speech recognition intelligent assistant) in 2011. The time difference between these two was very typical for AI struggles in those days.

At the time, IBM was still a very strong player in the field of AI (they would surely argue that they still are, but not everyone agrees with that) and they proved it by building yet another specialized machine that was able to beat men in the jeopardy game in 2011 and that was an important step towards fulfilling Adam Turing's three criteria for comparing AI to human brain.

B. Deep learning revolution

Waiting for more capable hardware lasted for another 15 years and new ideas have been boiling. If you look back at those years at the beginning of 2010's, two very important things were emerging and the other one really played a key role for rapid development of AI and deep learning in particular. That other thing was, of course, Big Data based on Hadoop and other new related technologies. From the very beginning Big Data (compared to AI) had a clear commercial value and very soon it became the main topics in analytics everywhere. It brought two important breakthroughs to the table: the ability to process very large (petabytes and even more) data sets and, also extremely important, the ability to work with and analyze unstructured data like text, speech and images.

The important new page for AI has been turned when Geoffrey Hinton (and his colleagues David E. Rumelhart and Ronald J. Williams) have promoted an old idea of multi-layer neural networks, which opened the field that is today known as deep learning [1]. But the real breakthrough came when Alex Krizhevsky designed the innovative solution for the Imagenet challenge in 2012 that helped to revolutionize the field of computer vision [2].

Now, the stage was finally ready for the most important breakthrough in AI: deep neural networks and deep learning concept. In other words, the idea that a machine can be programmed to learn from its own experience and not something that has been somehow preloaded, such an idea has become the most important path of development to come.

Deep learning has been developed as the extension of ordinary neural networks and the idea of another concept called "unsupervised learning". Basically, the idea is to supply a minimum number of parameters, feed a significant amount of representative data and then let the computer go through a process called "training" to build a model that can then later be used with other production data to predict some aspects of future behavior of the real-life system. The beauty of this concept is that, while training and building a model usually still require very significant computing power, using a model (once it has been trained) can be very effectively done on ordinary, commodity hardware. And that, of course, makes it extremely interesting for a variety of commercial applications.

Many different algorithms are used in deep learning coupled with some of the most advanced mathematical concepts such as tensor analysis, and they are not trivial. Tensors happen to be a good foundation for multi-layered neural networks. That is because, at the very basic level, neural networks consist of these layers:

- Input layer
- A series of hidden layers, and
- Output layer

This is represented on the following image, Figure 3:

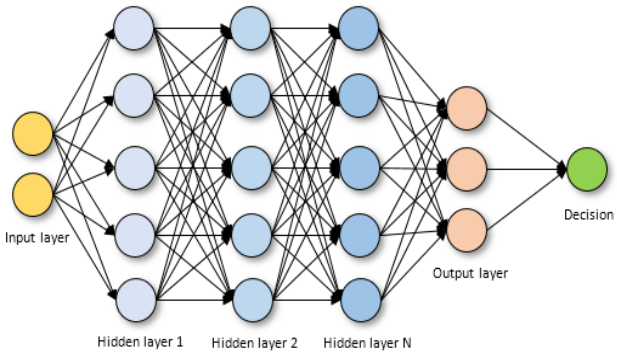

Figure 3: Multi-layer processing in neural networks

The number of hidden layers can be very high, depending on the number of different characteristics and the overall complexity of the problem (process) that we want to solve.

Once you have trained your model, it can be put to work and, in principle, the process starts with the most basic elements, like identification of individual pixels, colors and shapes. After that, each of the subsequent layers processes higher-level (more complex) elements until enough information has been collected to calculate the output probabilities in the output layer and make the final decision.

The following image represents this process in some detail, Figure 4, [3]:

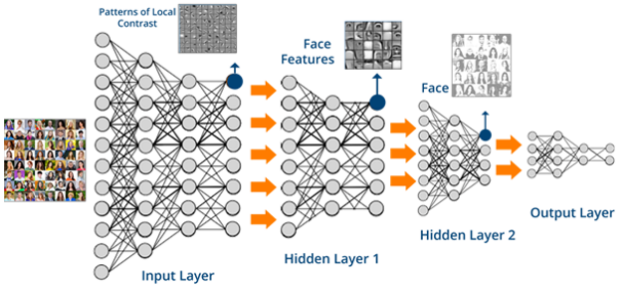

Figure 4: Multi-layer image processing

Deep learning has quickly gained popularity for two important reasons:

- Models were able to work with huge amounts of data and still keep high performance levels
- People discovered that the very same (or at least very similar) models could be applied to a wide variety of entirely different problems and still get very good results

Here we can immediately see the link to Big Data developments, something that will quickly become one of the cornerstones of deep learning developments. It is not difficult to understand the importance of Big Data for AI because:

- Most of the data that AI needs to analyze is usually not structured but instead, AI works with pictures, sounds, text and similar data types
- The amount of data available for describing practically important problems tends to be extremely high, not only in training phase, but also in the production phase

Some examples of such problems are complex games, autonomous driving, mixed and simulated reality, processing of LHC (Large Hadron Collider) images, chemical and bio-medical problems, evolutionary based systems and many others.

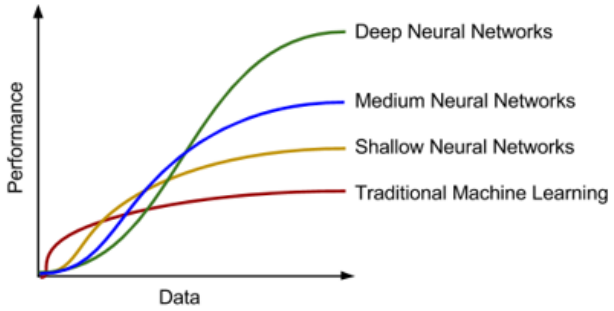

Figure 5: Performance vs Data Volume

There is another very important characteristic to be noticed here. There are many different types of neural networks and not all of them are equally friendly to large amounts of data. Common sense might lead you to the conclusion that the best performance should be expected from the simplest neural networks, or at least from those with least number of hidden levels. Interestingly enough, this is not the case. In fact, it is exactly the opposite, as described on the previous image, Figure 5 [4].

This unexpected result shows that more complex, deep neural networks, actually favor huge amounts of data. The more data you supply, the better performance you get! Obviously, this type of behavior immediately makes the deep neural networks everybody's favorite for solving complex problems.

C. AlphaZero and Leela

It is almost impossible that you have not heard of AlphaZero and its chess match against Stockfish in 2018. Stockfish was practically undisputed world chess champion (among computers; humans cannot compete with them for quite some time now) and it has been built using totally different approach, not based on AI.

Chess world has a concept called ELO rating, an official mathematical system that allows objective classification for all players, including computers! Stockfish 8 was rated at 3300, far above human world champion. And what about AlphaZero? Well, based on this extremely narrow sample of games, it has been estimated to be at least 4100 points, but more likely to be much higher than that.

Just consider this fact for a second: the difference between best human and best machine is roughly 400 points and humans cannot compete with computers. The difference between AlphaZero and one of the best machines seems to be at least 800 points, possibly even several times more.

If you are interested to learn more about AlphaZero, there are many articles about that match available on the internet and a good place to start with is here [5].

DeepMind released the paper soon to be followed by with initial 10 games, very detailed statistics about all played games and revealed the underlying technology used in AlphaZero [6].

Although there were only 10 games originally released, it instantly became clear that something really extraordinary has happened. Although AlphaZero was superior in that match, the main point was not the result itself. Instead, it was how some of the games were played and the general consensus around the world was that it played not like a computer, but like a super-human instead. That really meant that the style was like a human but a very, very advanced one. How advanced, exactly? Well, final score in the 100 games match was: 28 wins for AlphaZero, 0 losses and 72 draws and the rough ELO estimate was set to 4100 points or higher.

This level of supremacy made some people very suspicious and some of them still are! Although the very same program previously defeated human champions in Go and Shogi (two most complex games invented by humans), this was something very different because the defeated party was another computer program. And this other program was so superior to humans that it has been considered as practically invincible.

So, what is it so outstanding about the chess match between two machines?

First of all, there is a difference in how the two programs work. Stockfish 8 (like practically all other programs of its kind) uses a lot of built-in formal knowledge (opening theory, endgame tables, specific chess

related knowledge) and combines all that together while playing a game.

AlphaZero does something completely different. The only thing that it knows about the game (Go, Shogi or Chess) is the complete set of game rules. Nothing else whatsoever. No theory, no principles, no endgames… nothing at all! The only thing that it had to do is to somehow "learn" how to play good chess and it does so by first playing a large number of games with itself. This was the training process and AlphaZero took only 9 hours to train itself from zero to demonstrated strength!

So, what is the big deal about that?

To start with, that it is not about the processing speed. In fact, AlphaZero is analyzing roughly 80 thousand positions per second, while Stockfish 8 was analyzing much higher number, over 70 million. Normally, this should give Stockfish 8 significant advantage, but the reality was completely the opposite. So, if it is not about the processing power, it must be about the principles of processing. The two programs are clearly not "thinking" the same way. In other words, they do not share the same level (even not the same type!) of intelligence.

Today we have more than 100 published games and it is very clear that initial conclusions were right on the target.

But, the real test for AlphaZero technology came from different side after the results have been published. The key question was: can the same principles be successfully applied using commodity hardware instead of super-expensive Google TPU (tensor processing unit) processors?

It did not take long and, based on the information published by DeepMind, Gary Linscott have created special version of AlphaZero for ordinary PC's. The new program was named Leela Chess Zero (or simply: Leela) and it started with zero games played. He did not have powerful machines to do the training so instead, he asked people around the world to play with Leela and create the necessary large number of training games. In December 2018, the AlphaZero team published a new paper in Science magazine revealing previously undisclosed details of the architecture and training parameters used for AlphaZero. These changes were soon incorporated into Leela Chess Zero and increased both its strength and training efficiency.

In February 2019, Leela scored first major tournament win in the second TCEC cup, an unofficial world championship for chess computers. She defeated the reigning champion Houdini in the final match of 8 games. Even more important, Leela did not lose a game throughout the entire tournament!

This really was a definitive empirical proof that deep learning methodology introduced by DeepMind in their AlphaZero was one of the most important achievements in the history of AI and history of deep learning in particular. Important point here is that very similar implementations can be used for entirely different types of problems that have nothing to do with chess at all.

It brings us to summarize our conclusions about the state of deep neural networks today, which can be simplified to these three key points:

1. Hardware has become powerful enough and even the commodity hardware can support quite advanced AI scenarios
2. Data is being generated very fast, in many different forms and places and in huge volumes; Deep neural networks love this and are able to keep-up with this very successfully
3. Algorithms and tools are being developed using very advanced mathematical constructs that dramatically improve the power of AI

Old questions about the AI and its potential have risen again, this time often in a much more serious formulation. While it is true that machines still don't have human's general cognitive capabilities, it is not at all clear where the limits might really be. In fact, many reputable people seriously think that. If not handled properly, one day AI might become the greatest threat to mankind in general. On the other hand, many believe that it will help us solve many complex problems that our brains cannot solve today.

The gap is closing…

D. What is next

There are several areas where AI can be used. Potentially the most interesting applications are in the field of real-time, or near real-time image or video processing and intelligent decision making. This paper has been focused on the state-of-the-art advancements in the area of computer-generated images and videos, that can be used in exciting new disciplines like autonomous driving, various bio-medical applications of deep learning, processing extremely large volume of images generated in physical experiments in LHC (Large Hadron Collider) or creating humanoid avatars and robots.

Computer vision is one of the most advanced area of usage for deep learning, especially in the 2017-2018, when number of scientist, including research team led by DeepMind experts, have written/published several scientific papers about application of deep learning in the area of bio-medicine.

One of the papers that has been written by DeepMind researchers (and their collaborators) is about their AlphaFold AI powered system that has been used to predict 3D protein structure, based on the knowledge from previous researches and huge quantity of genomic data, more accurate than any that have come before [7]. The importance of determining the right 3D sequence of how the proteins are folded is important because it can help in diagnosis and curing diseases that has been suspected to be related to misfolded proteins like Alzheimer's, Parkinson's, Huntington's and cystic fibrosis. The other area of usage is design of new proteins that can be used, for example, in the plastic waste management, where proteins can help develop biodegradable enzymes that helps to fight pollutants like oil and plastics. Artificial intelligence, namely deep learning makes the process of determining the 3D structure of proteins faster and chipper, as previous methods were based on trial and errors using different experimental technics. In their paper [7], DeepMind team explained how they prepared their submissions to the global competition called the Community Wide Experiment on the Critical Assessment

of Techniques for Protein Structure Prediction (CASP), marked as A7D. For purpose of producing submissions to the CASP, three variants of an automatic free -modelling structure prediction system were used that has been relying on scores computed with deep neural networks [7]. For the purpose of this paper, most important facts are that they *"... didn't use any templates or server predictions and no manual intervention was made except for domain segmentation of T0999 and final decoy ranking in a handful of cases"* [7].

The second paper published by team of scientists led by DeepMind researchers explains applications of deep learning in field of diagnostic imaging [8]. DeepMind researchers focused on achieving performance in three-dimensional diagnostic scans, namely three-dimensional optical coherence tomography (OCT) scans from eye hospital patients. In their research, DeepMind team used small number of manually selected segmented tissues for training purposes that resulted in fast and very reliable diagnosis very close to what the human experts are capable to provide. Furthermore, they removed dependency on the type of devices that has been used for image tissue segmentations that, in the past, required modification of the model used for tissue segmentation. This alone can help human experts today and speed-up diagnostic process, but future use of this or similar methodology and technology promises to solve the "second step": to achieve expert performance of the proposed AI solution in providing referrals decisions.

Another big area of deep learning application is in the field of autonomous driving, either cars or drones or commercial jets.

In the past two years number of announcements about self-driving cars, beside Tesla, has been made by Swedish car maker Volvo that hopes to introduce a fully autonomous commercial vehicle in 2021 [9] and BMW & Daimler [10]. Other leading car-makers and IT companies in self-driving car industry have recognized the importance of self-driving cars for the future of transport [11].

Self-driving cars has been in the focus of the researchers for the long time, especially in last few years when so called "human-centric" approach has been emphasized as the promise of fully autonomous driving has not been reached yet. Another reason for taking "human-centric" approach is question of ethics and broad discussion in the society related to the first (human) fatal incidents by Tesla [12] and Uber [13] self-driving cars. In contrast to the human-centric autonomous driving, traditional approach would be to completely ignore human as a driver and concentrate on solving technical and planning problems.

Human centric approach to the autonomous driving represents so called shared-autonomy, in contrast to ideal fully autonomous vehicles. Several talks and papers have been published about this topic, among them two that are talking about symbiotic autonomous vehicles (SAV) *"... which can work with human users in a safe way, leveraging the human/machine perception, decision making and action when needed.*" [14] and Human-Centered Autonomous Vehicle Systems (HCAVS) [15] where humans and machines interact during the driving.

Authors define HCAVS with seven principles of shared autonomy: Shared Autonomy, Learn from Data, Human Sensing, Shared Perception-Control, Deep Personalization, Imperfect by Design, System-Level Experience [15]. Although the responsibility to control the vehicle stays on the human driver, about 30% (Tesla Autopilot is a good example here) of automated tasks and actions can be done by AI. HCAVS uses AI, namely supervised learning to achieve further improving to level 50% of automated response, going to semi-supervised and unsupervised learning formulations [15]. Data from human driver sensing, like gaze, hand position and pose are part of the decision process too. HACVS can enable better results in today-ready semi-autonomous vehicles, while we wait for fully autonomous one.

Another interesting area of using AI is creating completely new video based on existing video, so called video-to-video synthesis problem "*... as a distribution matching problem, where the goal is to train a model such that the conditional distribution of the synthesized videos given input videos resembles that of real videos.*" [16]. Video-to-video synthesis is used in several areas, including: generation of a high-quality video from an input segmentation map, edge-two-face video generation, pose-two-body video generation and frame prediction. All of them are built on Generative Adversarial Networks (GAN). GAN are two separate neural networks, one is generator, used to produce realistic synthetic data, and the other one is discriminator, used to analyze videos syntheses by generator. If discriminator is fooled by generator (can't differentiate synthetic generated frames from the real ones), then the process is successful. New video-to-video synthesis method proposed by [17] use conditional video generation with GAN's [17] that allows flexible control over the output of the model, that "… *synthesizes photorealistic videos conditioning on manipulable semantic representations, such as segmentation masks, sketches, and poses."* [16].

Research results that have been gathered from video-2-video syntheses can be used in generation of new virtual human characters. Recently, very popular application is to create virtual humans on television as TV anchors. Those virtual humans represent completely new persons, use gestures and creates stories.

Finally, humans like to communicate with other humans. Because of that, some of the most active research of AI applications are in robotics. In spite the fact that event the self-driving cars are robots, and that robots are used in industry/manufacturing, the most advanced uses of AI, at the moment, is for development of human-like robots.

III. CONLUSION

The beauty of AI specifically deep learning is that it is applicable to the broad range of problems. If you implement enough number of layers and methods, it's possible to solve huge number of different complex problems. In contrast to the traditional machine learning, deep learning is performing better with more data available for training the model/learning. On the other hand, deep learning performs well even in cases when unsupervised learning is used for training the model.

Also, deep learning exhibits new capability that is close what humans call “intuition” that helps in solving problems with better efficiency. In spite of number of breakthroughs and advancement in AI when we are speaking about deep learning, generally success of AI application in specific field depends on the fact how well the problem that we want to be solved is defined and if we have chosen the right problem to solve.

Yet, if we have well defined the problem and we had chosen the right tools for solving the problem, then we need to set the right goals that we want to achieve. For example, when researchers started to work on developing autonomous vehicles, most of them have been focused on full self-driving cars. In the meantime, another approach has been receiving more and more support – human centric approach that is focused on understanding how human thinks, behaves and reason. That leads to the recent AI development that has been focused on improvement of human-to-machine collaboration and communication in symbiotic way.

In the field of bio-medicine, problems are better defined, goals are set, and results are better, but they still need to pass clinical testing. On the other hand, when human-centric approach is applied, meaning AI collaborates with humans, the best results are achieved. This conclusion has ground in example of using AI to produce device-independent scanning diagnostic of tissue so human medical experts can establish referral to diagnosis, with important additional tools: ethics and empathy.

Using AI to create virtual humans that are not avatars, create fake videos, by using video-to-video synthesis, or even make robots more human makes “real humans” anxious and afraid what the future AI development will bring. Because of that, it’s important to promote further discussion about ethics, regulations and law’s in all areas where AI is about to be used.

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A Method for Estimating Variations in Speech Tempo from Recorded Speech

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***Abstract* - In this paper we describe a method for measuring variations in speech tempo from speech samples recorded from Croatian news channels, where the text of what was spoken is available through subtitles. For speech recognition we use a feed-forward neural network trained with about 150 seconds of speech. To extract word boundaries, we created a speech-to-text aligner capable of finding an acceptable match between text and sequence of phonemes classified by the neural network. The aligner takes into consideration certain categories of phonemes for which the neural network has higher accuracy. Preliminary experiments show average alignment miss of about one to three phonemes, depending on the speaker, the content, and recording quality.**

Keywords – speech recognition, text-to-speech alignment, speech tempo, neural network.

I. INTRODUCTION

Two frequently used measures of speech tempo are

1. Words per unit of time.
2. Syllables per unit of time.

Syllables per unit of time provide more granularity because syllables are less dependent on the length of the word. For example, one can say three short words slowly and three long words quickly in the same time interval and by measuring number of words in that time interval it would appear there was no difference in speech tempo because three words were uttered in each case. If we ignore pauses in speech, duration of words primarily depends on the duration of vocals. Therefore, it is important to capture not just which phoneme was uttered at a certain point in the recording, but also what its duration was. Two main components of a system for automatically measuring speech tempo are

1. Phoneme classifier (speech recognition)
2. Speech-to-text aligner

The phoneme classifier can be built in various ways, depending on whether we need a fully automatic speech recognizer (ASR) or one for which a partial recognition suffices. By "partial ASR" we mean a system that cannot be used for automatic conversion of speech to text, but it can correctly classify enough phonemes to make it possible to align speech to text (assuming the text of what was spoken is available). The purpose of speech-to-text alignment is to obtain information on where each word begins and ends in the recording. One difficulty in using a partial speech recognizer is that many phonemes might be incorrectly classified (how many depends on the amount of training data and the model of the classifier), so the job of the aligner is to map each letter of the text to an appropriate phoneme. There are some previous relevant works in this area. In [1] the authors describe an alignment algorithm using dynamic programming with a matrix of approximate phoneme-to-text matching. In [2] a method for forced alignment using hidden Markov models (HMM) is described. Automatic alignment with error correction of manual transcription is described in [3]. Some other approaches to text-to-speech alignment are described in [4], [5], [6], and [7].

Automatic speech recognition using neural networks is described in [8] and [9]. There are some previous works related to the study of Croatian speech. In [10] the authors describe a method for modeling basic intonation forms using analysis by synthesis. In [11] the author analyses how the vocal emphasis and duration affect the frequencies of formants. In [12] a model for time structure of the standard Croatian speech is described. In [13] the results of acoustic analysis of spoken vocals and vocals synthesized in 3-dimensional space F1xF2xF3 of Croatian standard speech are described. However, none of these works attempt to automatically measure speech tempo.

II. GOAL

The aim of this study is to answer the following questions: 1) How precise can the automatic alignment between the text and corresponding recorded speech be without using a complete

automatic speech recognition system? By "complete" we mean an ASR that is designed as a user interface for speech, thus supporting a large vocabulary and is speaker-independent. Although such systems are well developed for English and readily available, in this study we used Croatian, so the language and acoustic models are different from those for English. For this study our approach to speech recognition was simplified because there was no need to find out what was spoken, but rather where in the recording it was spoken. 2) By using this approach is it possible to measure variations in speech tempo when the text of what was spoken is provided? Our assumption is that it is possible to get enough information from the phoneme classifier about the phonemes, especially vocals, such as their temporal positions in the recording and their duration to determine the duration of certain speech segments by which the variations in speech tempo could be deconstructed and measured.

III. MATERIALS AND METHODS

This section describes the tools and methods used for conducting the study. For all sound analysis we used Praat software [14] and for neural network we used Scikit-Learn library for Python and its MLPClassifier module. The process consisted of four general steps:

1. Speech segmentation on individual phonemes and neural network training.
2. Speech recognition.
3. Text-to-phonemes alignment.
4. Speech tempo analysis.

The input for the process were three types of data:

- LTAS[1] values obtained from a speech recording of about 20 or 30 seconds in length.
- The text of the speech part we wanted to analyze (one or two sentences).
- The approximate interval where that text begins and ends in the recording.

For speech recognition we used feed-forward neural network with three hidden layers of sizes 120, 120 and 160. For neural network training only male voices were used, but for recognition we used both male and female voices. Croatian TV news channels were used for speech recordings, with most of the speech originating in a studio setting.

[1] LTAS stands for *Long Term Average Spectrum.*

Segmentation and Neural Network Training

The recordings selected for training were partitioned into smaller parts on which speech segmentation was performed. The total length of the sound used for training was about 150 seconds. Although this does not constitute a large quantity of training data, we emphasize that the goal here is not speech recognition but speech alignment, supported by the speech-to-text alignment algorithm described later. To train the neural network, for each phoneme identified in the segmentation phase its LTAS was computed and stored together with the designated letter representing the phoneme. The LTAS bandwidth used was 100 Hz, where only first 120 LTAS values were kept (to correspond to the upper frequency threshold of 12 kHz). These values were further normalized using the feature scaling method to bring them into the [0, 1] interval. The values were additionally transformed to prevent intensity from influencing the training efficiency where phonemes with similar spectral shape, but different intensity appear too different to neural network. This data was then used as a training set and fed into the neural network, where each LTAS segment of 100 Hz was used as one input parameter (out of 120) for the input layer of the network. During training, pauses in speech that were bellow some specified threshold were skipped.

Speech Recognition

The recognition part was performed in two steps. First, the input sound was divided into consecutive segments of 10 milliseconds and for each such segment the LTAS was computed. In the second step the sound was marked at positions where glottal pulses were present and for each such position a segment of 10 milliseconds was taken (5

1. iii	['i']
2. ssssssss	['s']
3. aaaaaaaaaaaaaao	['a', 'o']
4. ndf	['n', 'd', 'f']
5. ooaaaoo	['o', 'a']
6. mnnmm	['m', 'n']
7. oaooaaaoaaao	['a', 'o']

Figure 1: An example of classification by neural network. The phonemes are grouped by their category.

TABLE 1: CLASSES OF PHONEMES USED FOR GROUPING THE PHONEMES RECOGNIZED BY NEURAL NETWORK.

Vocals	*i, e, a, o, u*
Fricatives 1	*č* (tʃ), *š* (ʃ)
Fricatives 2	*c, s, z*
Fricatives 3	*đ* (dʒ), *ž* (ʒ)
Other	All other phonemes

milliseconds before and after the position) and for each such segment the LTAS was also computed. This second step was done to avoid "accidental" skipping over an important part of the sound in the first step. We also note that the second step did not capture any fricatives because they do not contain any glottal sound, so for those types of phonemes we relied exclusively on the first step. The data from the two steps was then merged based on the time of occurrence (i.e. the time position of the sound segment) and used as an input set for classification by the neural network. The recognition process resulted in many phonemes being consecutively repeated (due to the duration of most phonemes being greater than 10 milliseconds and the merging of previous two sound segmentation steps). Such phonemes were grouped together by equality and the class of phonemes they belonged to. The classes of phonemes consisted of four groups shown in TABLE 1. The output of the neural network was thus transformed into a sequence of groups of phonemes ordered by the time of appearance in the recording. The listing in Figure 1 shows an example where in interval 1 the neural network classified the phoneme as *i* in three consecutive segments of 10 milliseconds, and in interval 2 it classified the phoneme as *s* in the same way. However, in intervals 3 and 5 it classified the segments as two different phonemes, *o* and *a* (in the last segment), and since these two belong to the same group of phonemes they were grouped together. Also, in interval 4 the phonemes that don't belong to any of the first four groups above were grouped together.

One important aspect of this kind of phoneme classification is that it preserves the duration of phonemes, most importantly vocals, so that after the alignment step the duration of syllables and words is measurable. For example, in TABLE 2 in the time interval [22.95, 23.08] the phoneme was classified as vocal *a* or *o* and its duration was a bit longer than the vocal in interval [22.15, 22.21].

TABLE 2: SAMPLE LISTING OF SEQUENCE OF PHONEMES CLASSIFIED BY THE NEURAL NETWORK. EACH INTERVAL (ROW) REPRESENTS ONE GROUP OF PHONEMES AS DESCRIBED IN THE TEXT. THE SEGMENT IN BOLD IS THE INTERVAL OF THE WORD „OPROŠTAJA" (CROATIAN FOR *FAREWELL*) WHOSE START AND END TIMES (IN SECONDS) ARE ESTIMATED AT 22.39 AND 22.82, RESPECTIVELY.

INTERVAL	PHONEME GROUP
22.15-22.21	aoooaaaaaao
22.21-22.23	mml
22.24-22.25	aaao
22.26-22.36	ooooooooooooooooooo
22.38-22.38	n
22.39-22.43	**ouuouooooou**
22.43-22.43	**v**
22.45-22.49	**uoooaaaaaa**
22.50-22.52	**aaaeo**
22.53-22.56	**ščšč**
22.57-22.59	**sss**
22.66-22.77	**aaaaaaaaaaaaaaaaaaa**
22.78-22.80	**aaaoa**
22.81-22.82	**aoa**
22.83-22.84	tv
22.85-22.94	zcszsssscs
22.95-23.08	aaaaaaaaaaaaaaaaaaaooooooooo
23.10-23.10	m
23.10-23.12	aaaaa

Alignment

Since many phonemes were not correctly classified by the neural network, an algorithm for aligning the neural network output to the text was developed. The purpose of the algorithm was to estimate the beginning and end of a sound interval where a specific word was spoken. For example, given the sequence of phonemes *czsonmoaea* and word *soba* (Croatian for *room*), the algorithm would match s-s, o-o, m-b and a-a, as shown in Figure 2. Additionally, the algorithm was configured so that the gap between two matched phonemes cannot be larger than two phonemes. This was done to avoid some unrealistic alignments where the gap between two phonemes would be too large to be realistic in normal speech. The algorithm takes as input a text (usually fifteen to twenty words) and a list of phoneme groups classified by the neural network (like the one in TABLE 2) and it returns an estimated alignment for all letters in the text with the group of phonemes. The aligner does not always find an optimal alignment, depending on the combination of letters and phonemes. One minor detail that was done before the alignment step was to transform the text itself to correspond better to the speech regarding coarticulation and assimilation. One problem with the algorithm is the alignment accuracy when there are fewer phonemes than letters. In that case the algorithm "borrows" phonemes from the next word, so after that point the alignment can be significantly off.

Tempo Analysis

The time interval occupied by each word was obtained from the alignment of the text with the phonemes. To analyze speech tempo those words were merged together and split into segments (in the order in which they appeared in the text) such that each segment contained at least five syllables. Since the word time boundaries were estimated by the alignment the tempo was calculated as the number of syllables per time interval of the segment. Syllables rather than words were chosen to measure speech tempo because they provide for better granularity than just words. For example, in time interval of two seconds one can utter three short words slowly or three long words quickly, so just

counting words per time interval would not be precise enough.

phonemes	c	z	s	o	n	m	o	a	e	a
text			s	o		b		a		

Figure 2: An example of aligning a word to a sequence of phonemes.

IV. RESULTS

This section presents the results of speech-to-text alignment and speech tempo detection using recordings of three male and three female speakers from Croatian news channels. The speech duration for male speakers was 6.2, 6.1 and 5.3 seconds, respectively. For female speakers the duration was 6, 5.3 and 7.4 seconds, respectively. None of the voices were used for neural network training. Also, as stated before, the neural network was trained using male speakers only.

A. Word Alignment

It was expected that speech-to-text alignment will not be entirely accurate because the neural network didn't recognize all phonemes correctly. Also, it recognized some classes of phonemes better than others. For example, it recognized phonemes *s*, *c*, *š* and *č* much more accurately than some other classes of phonemes, like oclusives or nasals. The alignment algorithm tried to find a match between a letter of the text and a group of phonemes using a scoring system that considered the fact that the neural network recognized the first four groups of phonemes in TABLE 1 better than others. The matching algorithm assigned greater score when matching, for example, phoneme *s* to group like ['s', 'c', 'z'] than when matching it to a group like ['d', 'm']. The example listing in TABLE 2 illustrates how the alignment algorithm estimated where the word *oproštaja* (Croatian word for *farewell*) is positioned in a sequence of phonemes classified by the neural network using one of the test recordings. The sequence of phoneme groups for the word as estimated by the aligner is written in bold.

In case of whole-word alignment the algorithm is less accurate than when larger segments were aligned. This was expected because when a small amount of text (like one word) is searched for in a long sequence of phonemes it is more likely that more than one subsequence will produce an acceptable match because there are no enough elements that would make the right segment more unique. TABLE 3 shows alignment results on six speech samples (three male and three female), each with a different speaker. For each speaker there are two columns: *from* and *to*. Each row in these columns represents one word of the uttered sentence (different sentence for each speaker), with numbers representing the estimated alignment offset of the word against the correct alignment (as determined by listening). The *from* and *to* columns contain the start and end time of the word, respectively, i.e. the estimated alignment of the word. A negative value means the estimated alignment is off to the left (begins too early), while positive value means it is off to the right (ends too late) for the given amount in milliseconds. The data shows that on these six samples the average deviation was about one to three phonemes, assuming the average duration of phonemes in Croatian is as described in [15] and [16], which is about 76 milliseconds. One of the factors that influenced the accuracy of the recognizer (and thus the aligner) was the fact that neural network had a poor recognition of occlusive phonemes, like *p* or *t*. Although the neural network wasn't trained with female voices the results show that the recognition of phonemes can still be reasonably good for such speakers, depending on the recording quality and clarity of pronunciation. This was expected because in average the spectrum of a female voice is moved slightly to the higher frequencies and is somewhat more rounded, but the overall shape is the same. In the case of sample 5 in the table the average deviation was less than one phoneme, though it was more pronounced in samples 1, 2 (male voices), and 6 (female voice).

B. Detection of Variations in Tempo

Figure 3 shows estimates of variations in speech tempo as detected by the program for the same six sample recordings and speakers. Each bar represents the time duration of a group of words calculated as *number of syllables / time interval*. These diagrams show that most of the speakers had balanced speech tempo on the sample recordings, with diagrams *a*, *e*, and *c* showing slight variations in the middle part. All these variations are rather small and hard to notice while listening.

TABLE 3. RESULTS OF AUTOMATIC WORD ALIGNMENT ON THREE SPEECH SAMPLES WITH A DIFFERENT SPEAKER ON EACH. EACH ROW OF A SAMPLE REPRESENTS A DEVIATION (IN MILISECONDS) OF THE CORRESPONDING WORD FROM THE CORRECT INTERVAL (AS DETERMINED BY LISTENING). NEGATIVE VALUE MEANS THE ESTIMATE IS OFF TO THE LEFT (BEGINS TOO EARLY), WHILE THE POSITIVE VALUE MEANS THE ESTIMATE IS OFF TO THE RIGHT (ENDS TOO LATE). LAST ROW IS THE AVERAGE DEVIATION OF THE ABSOLUTE VALUES IN THE CORRESPONDING COLUMN.

1 (male)		*2 (male)*		*3 (male)*		*4 (female)*		*5 (female)*		*6 (female)*	
FROM	*TO*	*FROM*	*TO*	*FROM*	*TO*	*FROM*	*TO*	*FROM*	*TO*	*FROM*	*TO*
15	-58.8	0	215.4	20	52.6	0	109.4	9.5	136.5	29.1	234.4
-25.6	-115	222.3	166	130	136.7	123.4	105.4	131	149.8	237.2	-3
-119.1	-286.6	194.1	131.3	188.7	176.6	110.4	89.3	198.5	1.9	-50	59.1
-275	-187.4	90	28.6	180	320	10	26.6	85.9	-4.1	180	259.8
-283.7	14.6	39.2	-10.8	320	350	0	-12.4	0	-3.2	214.3	260
15	-5	100	0	120.3	-0.4	-81.8	-8.1	-42.8	-50	261	204.2
14.6	-5	10	60.6	100	67.5	9.1	-207.8	56.8	0	136.8	194.9
15	-18.3	80	55	79	20	-191.8	-3.7	20	57	141.6	-114.7
-35.9	-49.6	37.2	-15.2	70	4.6	53.4	-13.6	63.4	41.7	-118.6	-26.2
-37.2	-30.7	20	79	10	70	-108.6	130	40	40	18.2	50
-28.6	305	28.7	182.1	10	-65.6	132.7	161.7	10	5	-360	-6.7
211.4	412.6	230	226.8	0	-3.7	156.7	-14.8	20	10	20	-5.7
72	11.3	235	67.5	5.1	13.9	-3.9	214.1	11.9	-14	-48.8	-21.9
35	-10.3	41.2	205.4	23.3	30	150	-84.8	71.6	135.1	10	8
24	-8.8	140	276.1	16.2	-27.4	-80	-108.9	55.5	-4.8	10	-38.3
4.2	-81.3	300	395	10	-0.6	-16.6	77.9	-19.7	-7.7	-41	-230
-85	-210.6	377	60	8.6	-22	83.7	20.3	70	-9.2		
-196.8	-184.9			-12.3	85.2	-67.3	-60.8	-51.7	-4.8		
-192.8	-220.2			90	335.5			15.6	-93.1		
-207.4	-245							-90.5	50		
-268	-262.9							128.5	10		
-115	6.4							10.6	-54.3		
103.47	**124.1**	**126.16**	**127.93**	**73.34**	**93.81**	**76.63**	**80.53**	**54.7**	**40.1**	**117.29**	**107.31**

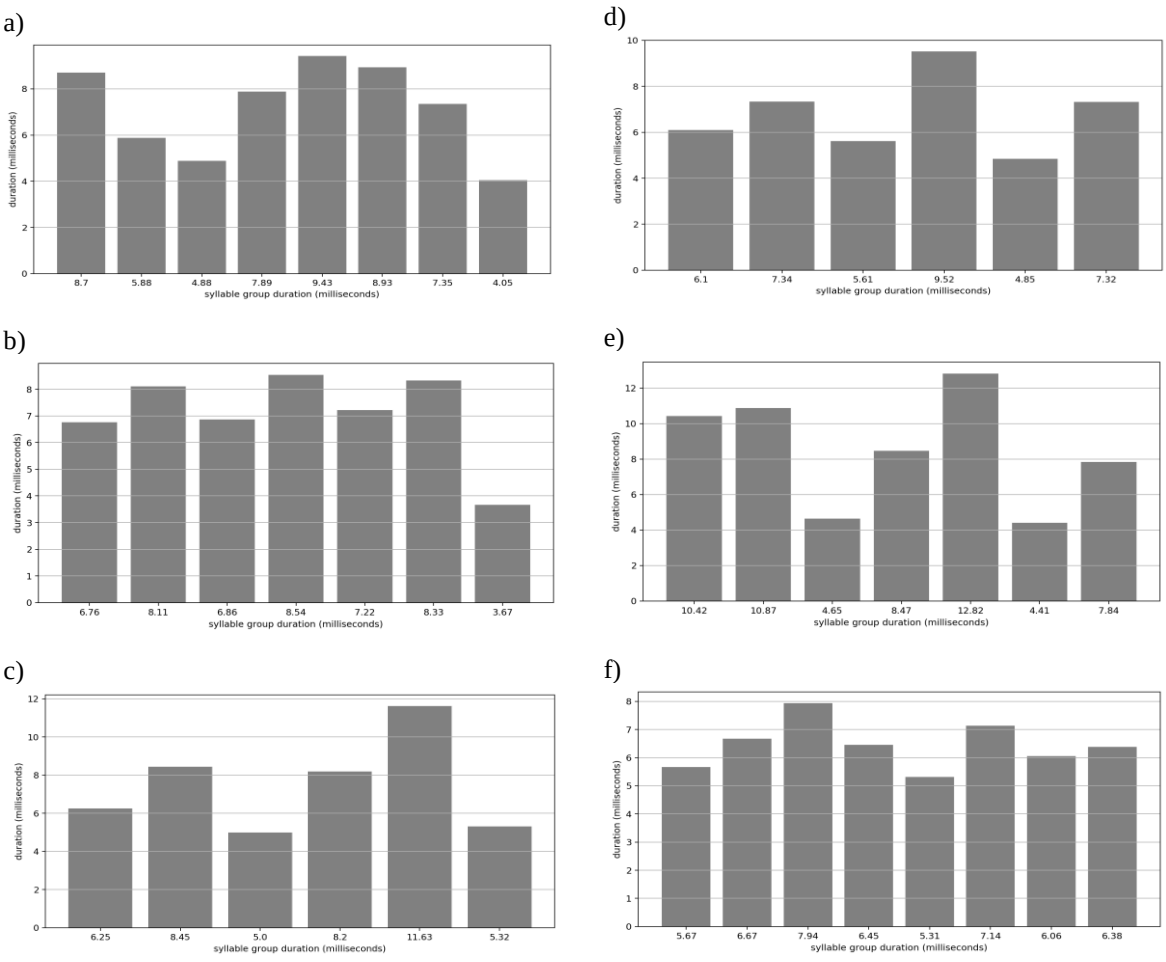

Figure 3: Estimated variations in speech tempo based on speech recordings of six speakers – three male (a, b, and c) and three female (d, e, and f). Each bar represents speech tempo calculated as *number of syllables / time interval*.

V. CONCLUSION

The results suggest that for measuring speech tempo in the presence of the text of what was spoken it is possible to create a reasonably accurate partial speech recognizer for Croatian with relatively small amount of training data. This can be useful for some languages that are not as supported in commercial speech-recognizers as English, such as Croatian. The speech-to-text aligner can be used to approximate word boundaries based on the recognition results of the speech recognizer. Although various algorithms could be used to perform partial string matching between the given text and the recognized sequence of phonemes (like *Edit distance*), an algorithm that takes into consideration the fact that the speech recognizer detects certain groups of phonemes better than others probably performs better, although no direct comparisons were made in this study.

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Crowd Motion Pattern Detection at the Microscopic Level

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***Abstract* – In this paper we present a common-sense reasoning model for crowd motion pattern detection and behaviour analysis at the microscopic level. Information about the trajectories of individuals is represented with fuzzy predicates. The characteristic motion patterns and the behaviour of groups of individuals are described with fuzzy predicates and fuzzy functions, respectively. The usability of the proposed model is tested on a simulated crowd scenario. The obtained results show that the model supports the efficient representation of expert knowledge and detection of motion/behaviour patterns. The main contribution of this paper is a proposed model for motion pattern detection and classification based on fuzzy knowledge which can imitate common-sense reasoning.**

Keywords: crowd, motion pattern, fuzzy logic, common-sense reasoning

I. INTRODUCTION

Video surveillance plays an important role in our information society in ensuring security in public and semi-public places where large numbers of people are gathered. Recently, one of the most active research areas in computer vision has been crowd analysis [1-3], where a crowd can be defined as a mass of people or a large group of individuals gathered in the same physical environment, sharing a common goal. Research on crowd analysis is of interest to social and technical disciplines [3-6]. The research results are applicable in the following main areas:

i) visual surveillance to ensure safety in public and semi-public places by the automatic detection of the abnormal behaviour of individuals (or groups) and tracking individuals/groups in a crowd;

ii) the development of crowd management strategies to avoid crowd related disasters during sport matches, public demonstrations and music festivals;

iii) public space planning to provide guidelines for public space design to increase the efficiency and safety of public buildings, airport terminals, railway stations, and shopping malls;

iv) virtual environments where the models of crowds are used to provide more accurate simulations of crowd phenomena. The results of the simulations can be used in computer games and in the film industry.

In general, an analysis of a crowd may be conducted at: i) macroscopic levels, where the global motions and behaviours of a mass of people are the focus of interest; ii) microscopic levels, where the analysis concerns the movements and behaviours of any individuals in the crowd; and iii) mesoscopic levels which are based on combinations of intrinsic characteristics of microscopic and macroscopic levels. Crowd analysis is composed of four main processes: crowd motion detection, crowd tracking, crowd density estimation, and crowd behaviour. Many survey papers relevant to the topic of crowd analysis have been published in the last decade [6-11].

In this paper, we deal with the detection of crowd motion patterns and a crowd behaviour analysis at the microscopic level. Generally, motion patterns include any recognizable spatio-temporal regularity of moving objects. Crowd motion patterns are important for understanding and predicting the behaviour of groups of people, for example small or medium groups in pedestrian crowds or even large-scale crowds. Crowd motion detection and motion information are the basis for crowd analysis.

Crowd behaviour analysis deals with the classification of crowded scenes manly in two categories: normal and abnormal. Some approaches to crowd behaviour analysis refine crowd behaviour into categories such as direction and different crowd events, and motion patterns such as bottlenecks, lines, fountainheads, and blockings. Crowd behaviour analysis is usually based on two approaches: the holistic and object-based approaches. The holistic approach treats the crowd as a single entity, while the object-based approach treats the crowd as a collection of individuals. The holistic approach is appropriate for highly crowded scenes where objects acquired by sensors appear small, and very few features can be extracted from the individual object. In the paper, we deal with an object-based approach where behaviour analysis is usually based on segmentation and on the detection of each individual in the crowd. However, we are aware that the approach has a drawback in that it suffers from the computational complexity needed to isolate individuals and extract features.

This paper presents a fuzzy knowledge-based approach to crowd motion pattern detection, classification, and crowd behaviour analysis. The paper is organized as follows. Section II describes the relevant research work, section III deals with motion pattern analysis for an individual and a group of individuals. A set of fuzzy predicates and heuristic procedures for their evaluation is proposed. Section IV describes examples of motion pattern analysis, fuzzy knowledge and inference procedures in an attempt to represent human common-sense knowledge. The results of the proposed approach are given. Finally, section V summarizes the results and gives several directions for future research.

II. RELATED WORK

Typical motion patterns extracted from video scenes are important for automatic video surveillance and are used in high-level analysis (e.g., detection of events and anomalies that occur in the scene, predicting disasters, etc.). Depending on the level of crowd analysis, there are three basic approaches to crowd motion pattern analysis and classification. One approach is based on algorithms for the microscopic level of a crowd where a crowd is regarded as a collection of discrete individuals or small groups. Robust multi-object detection and multi-object tracking, the generation of trajectories/tracklets of the objects, as well as the grouping of the detected objects based on sociological models are characteristics of this approach. The second approach is defined at the macroscopic level where there is no need to segment each individual in a crowd. Here, algorithms based on optical flow and particle and streak flow features are used to represent motion patterns in crowded scenes.

Recently, attempts have been made to develop methods for the detection of motion patterns at mesoscopic levels where multi-target tracking is applied in combination with pieces of information of the target in the form of appearance and motion, as well as context cues in the form of neighbourhood motion, spatial proximity and grouping [12].

The detection and classification of motion patterns has been one of the fundamental problems in crowd analysis in the past twenty years. Boghossian and Velastin [13] proposed motion-based computer vision techniques that detect the circular flow paths of a crowd, crowd flow diverging from a point to all directions, and obstacles in the flow paths. Detection of the motion patterns was based on the Hough transform.

Ge et al. [14] described a vision-based analysis of small groups in pedestrian crowds. The approach used methods of detection and multi-object tracking, and sociological models of human collective behaviour, for the automatic detection of small groups of individuals walking together. The groups were discovered by bottom-up hierarchical clustering using a generalized, symmetric Hausdorff distance defined with respect to the pairwise proximity and velocity of the pedestrians in a crowd. Based on the tracklets of moving objects and the assignment of trajectories to the tracklets, the corresponding linear assignment problem (LAP) was solved using the Hungarian algorithm.



a) b) c) d) e)

Fig 1. Five motion patterns for identifying crowd behaviours [15]: a) blocking; b) lanes; c) bottlenecks; d) arches/ring; and e) fountainheads.

In [15], Solmaz et al. proposed five motion patterns (Fig.1) for identifying crowd behaviours. The approach treats crowds as collections of mutually interacting particles (using a Lagrangian particle model). The method combines low-level local motion features, computed by optical flow, with high-level information, obtained by analysing regions of interest in the scene [15].

The authors applied a fluid-dynamic-like model and used a stability analysis of linear dynamical systems and a Jacobian matrix defined by optical flow to define crowd flow, i.e. motion patterns. Based on the values of the determinant $\Delta = \lambda_1 \lambda_2$ and trace $\tau = \lambda_1 + \lambda_2$ of the Jacobian matrix, where λ_i, i = 1, 2 are the eigenvalues of the Jacobian matrix, the motion patterns are categorized as follows [15]: i) blocking ($\Delta < 0$); ii) line ($\Delta = 0$); iii) bottleneck ($\Delta > 0$; $\tau < 0$; iv) arch/ring ($\Delta > 0$; $\tau = 0$); and v) fountainhead ($\Delta > 0$; $\tau > 0$).

In [16], the authors used a spatio-temporal viscous fluid field model for large-scale crowds. Based on the so-called characteristic of a spatio-temporal variation matrix they classified the crowd motion patterns in five categories: circle; disperse; gather; disperse in an arch form; and gathering in an arch form.

In recent work [17], the authors proposed the scalable detection of crowd motion patterns. They combined tracklet information, the spatial clustering of these tracklets into motion clusters, and temporal clustering where concatenation of the motion clusters is performed. The proposed approach was evaluated in different scenarios for the following motion patterns (Fig. 2): curved lanes; parallel lanes; intersecting lanes; and divergent lanes.

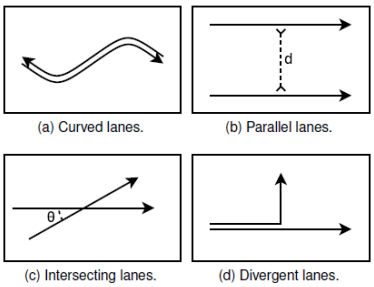

Fig 2. Types of motion patterns [17].

As far as we know, no approaches have been made to motion pattern detection and classification based on fuzzy knowledge and inference procedures which can imitate common-sense reasoning. There have been some initial attempts [18] which are used in video games and animated movies for the description of individual and collective character behaviours. In [19], an ontology and a set of fuzzy rules, which provided crowd classification according to a sociological theory, were proposed, but the authors did not present concrete solutions or a classification of motion patterns.

III. MOTION PATTERN ANALYSIS

The position of each tracked individual o_i, $i = 1, \ldots, n$, at discrete time point t_j, $j = 1, \ldots, k$, is depicted with space points (x_i^j, y_i^j), where n is the number of tracked individuals and k is the total number of frames in a video. The positions of all tracked individuals in the video (x_i^j, y_i^j), $i = 1, \ldots, n$, and $j = 1, \ldots, k$, are obtained by multi-object detection, tracking and re-identification algorithms [20].

A. Motion Patterns for an Individual

In general, a fuzzy predicate is a mapping: O×T×R → [0,1], called an assignment (or assignment function), which maps each element of **s** ∈ O×T×R to a degree of fulfilment, where O is a set of *n* tracked individuals: $\{o_1, o_2, \dots, o_n\}$, T is a set of *k* time points $\{t_1, t_2, \dots, t_k\}$, and R is a set of *n* trajectories of individuals: $\{r_1, r_2, \dots, r_n\}$. Each trajectory consists of corresponding position points, i.e. trajectory r_i contains *k* position points $\{(x_i^1, y_i^1), (x_i^2, y_i^2), \dots, (x_i^k, y_i^k)\}$ of an individual o_i. A heuristic function is used to compute the actual truth value to which a sample **s** fulfils the given predicate. In our case, the domain of the mapping is restricted to samples **s** represented by triplets (o_i, t_j, r_i), where $i = 1, ..., n$, and $j = 1, ..., k$.

1) Direction fuzzy predicates

Direction motion patterns for an individual are described with fuzzy predicates: Inline, Turn_left, Turn_right, and Circle. A heuristic procedure is used to obtain degrees of fulfilment for each of these fuzzy predicates.

The degrees of fulfilment for the Inline(o_i, t_j, r_i), Turn_right(o_i, t_j, r_i), and Turn_left(o_i, t_j, r_i) predicates are determined based on a subset of *m* time points ($2 < m < k$), $\{(x_i^{j-m+1}, y_i^{j-m+1}), (x_i^{j-m+2}, y_i^{j-m+2}), \dots, (x_i^j, y_i^j)\}$ from the set r_i. The value of *m* is experimentally determined based on a learning dataset, and it defines a time window (*m* frames in the past, starting from the current frame with index *j*) for an individual movement estimation.

The connection of the first $(x_i^{j-m+1}, y_i^{j-m+1})$ and the last (x_i^j, y_i^j) position points define a line l_i.

The truth value estimation procedure for the Inline(o_i, t_j, r_i) predicate is as follows:

INPUT: Line l_i and *m* position points from the subset of r_i.

STEP 1: The mean of distances of *m* position points to the line l_i is determined.

STEP 2: Estimated truth value of the Inline(o_i, t_j, r_i) predicate is obtained by mapping a mean of distances to an interval $[0, 1]$ with an experimentally determined assignment function (Fig. 4. (a); first column, second row).

A small value of the mean of distances indicates high degrees of fulfilment that the object is moving inline.

The truth value estimation procedure for the Turn_right(o_i, t_j, r_i) predicate is as follows:

INPUT: Line l_i and *m* position points from the subset of r_i.

STEP 1: The mean of signed distances of *m* position points to the line l_i is determined.

STEP 2: The estimated truth value of the Turn_right(o_i, t_j, r_i) predicate is obtained by mapping the mean of signed distances to an interval $[0, 1]$ with an experimentally determined assignment function.

The truth value estimation procedure for the Turn_left(o_i, t_j, r_i) predicate is the same as that for the Turn_right(o_i, t_j, r_i) predicate. High positive mean signed distances indicate a high degree of fulfilment that the object is moving to the right, while high negative average signed distances indicate a high degree of fulfilment that the object is moving to the left.

The truth value estimation procedure for the Circle(o_i, t_j, r_i) predicate is as follows:

INPUT: A subset of *m* position points from the subset r_i.

STEP 1: The mean of *m* position points, i.e. centroid c_i, is calculated. It corresponds to the estimation of a circle centre.

STEP 2: The variance of the distances of these *m* position points to the circle centre c_i is calculated.

STEP 3: The estimated truth value of the Circle(o_i, t_j, r_i) predicate is obtained by mapping the variance of distances to an interval $[0, 1]$ with an experimentally determined assignment function (Fig. 4. (a); second column, second row).

A small value of variance indicates a high degree of fulfilment that the object has a circular movement.

2) Velocity fuzzy predicates

Velocity of movement for an individual is described with the predicates: Standstill_individual, Slow_individual and Fast_individual.

The truth value estimation procedure for the predicate Standstill_individual(o_i, t_j, r_i) is as follows:

INPUT: Two time points $\{(x_i^{j-m+1}, y_i^{j-m+1}), (x_i^j, y_i^j)\}$ from the subset of r_i.

STEP 1: A distance between $(x_i^{j-m+1}, y_i^{j-m+1})$ and (x_i^j, y_i^j) position points is determined and then divided by the value of *m*-1, i.e. the average velocity per frame is obtained.

STEP 2: The estimated truth value of the Standstill_individual(o_i, t_j, r_i) predicate is obtained by mapping the average velocity per frame to an interval $[0, 1]$ with an experimentally determined assignment function.

The truth value estimation procedures for the Slow_individual(o_i, t_j, r_i) and Fast_individual(o_i, t_j, r_i) predicates are the same as that for the Standstill_individual(o_i, t_j, r_i) predicate, except that in **STEP 2** appropriate experimentally determined assignment functions are used.

The assignment functions for Slow and Fast are depicted in Fig. 5, second row.

Note that, in general, a time window, defined by *m*, can be different for each predicate.

B. Motion Patterns for a Group of Individuals

The described predicates, together with the introduction of new fuzzy predicates for a group of individuals (for example, Dispersing, Gathering), can be used for building fuzzy functions suitable for making inferences about complex crowd behaviour. Characteristic

crowd events of interest can be described with functions of fuzzy predicates. These functions are application specific and their truth values are obtained with a composition of fuzzy logical operators [21]: negators, conjunctors (t-norms), disjunctors (t-conorms) and implicators, and fuzzy predicates. Humans, based on expert and common-sense knowledge, build these functions [21, 22].

In general, each fuzzy predicate for a group of individuals is $\mathcal{P}(\mathrm{O})\times\mathrm{T}\times\mathcal{P}(\mathrm{R})\rightarrow[0,1]$ which maps each element of $\mathbf{g}\in\mathcal{P}(\mathrm{O})\times\mathrm{T}\times\mathcal{P}(\mathrm{R})$ to a degree of fulfilment, where $\mathcal{P}(\mathrm{O})$ is a power set of tracked individuals $\mathrm{O}=\{\mathrm{o}_1,\mathrm{o}_2,\ldots,\mathrm{o}_n\}$, $\mathrm{T}\in\{\mathrm{t}_1,\mathrm{t}_2,\ldots,\mathrm{t}_k\}$ is a set of time points, and $\mathcal{P}(\mathrm{R})$ is a power set of trajectories of objects, i. e. $\mathrm{R}=\{\mathrm{r}_1,\mathrm{r}_2,\ldots,\mathrm{r}_n\}$. A heuristic assignment function is used to compute the actual truth value to which a sample **g** fulfils the given predicate. In our case, the domain of the mapping is restricted to samples **g** represented by triplets $(\mathrm{O},t_j,\mathrm{R})$, where j =1, ..., k.

For a group of tracked individuals, we can use distance predicates such as Next_to, Near_to, Faraway, and the velocity predicates Standstill_group, Slow_group and Fast_group, and dynamics predicates Gathering and Dispersing. For illustration, let us describe truth value estimation procedures for the Gathering and Dispersing predicates. Similar procedures can used for the other above-mentioned predicates.

The truth value estimation procedure for the Gathering$(\mathrm{O},t_j,\mathrm{R})$ predicate is as follows:

INPUT: n position points for time interval t_{j-m} and n position points for time interval t_j, $\{(x_1^{j-m},y_1^{j-m}),\ldots,(x_n^{j-m},y_n^{j-m}),(x_1^{j},y_1^{j}),\ldots,(x_n^{j},y_n^{j})\}$ from the set R, where n is the number of objects in a group.

STEP 1: At time point t_{j-m} for a set of corresponding n position points $\{(x_i^{j-m},y_i^{j-m})\}_{i=1}^{n}$ the average value of $n(n\text{-}1)/2$ distances between all possible point pairs is determined. The same procedure is performed at time point t_j and corresponding n position points $\{(x_i^{j},y_i^{j})\}_{i=1}^{n}$.

STEP 2: The difference of the average value of distances for time point t_j and the average value of distances for time point t_{j-m} is calculated.

STEP 3: The estimated truth value of the Gathering$(\mathrm{O},t_j,\mathrm{R})$ predicate is obtained by mapping the difference of the average value of distances to an interval $[0,1]$ with an experimentally determined assignment function.

Truth value estimation procedures for the Dispersing$(\mathrm{O},t_j,\mathrm{R})$ predicate is the same as that for the Gathering$(\mathrm{O},t_j,\mathrm{R})$ predicate except that in STEP 3 an appropriate experimentally determined function is used.

A high positive and negative difference of the average value of distances indicates a high degree of fulfilment for the Dispersing and Gathering predicates, respectively.

Let us describe in the context of common-sense knowledge a scenario of an anomaly detection of crowd behaviour at the microscopic level in surveillance applications. A runaway scenario occurs when several individuals that are close to each other (i.e. a group of people) suddenly start to run away. The group is dispersing, and the individuals are becoming more and more distant. The formal fuzzy function named Alarm_ runaway is defined as follow:

Alarm_runaway (t_j) = Near_to$(\mathrm{O},t_{j-l},\mathrm{R})\wedge$ Fast_group$(\mathrm{O},t_j,\mathrm{R})\wedge$ Dispersing$(\mathrm{O},t_j,\mathrm{R})\wedge$ Faraway$(\mathrm{O},t_j,\mathrm{R})$, where $j>l$, and $\wedge$ is a conjunctor and it corresponds to minimum value of fuzzy predicates.

Note that due to limited space, we introduce the above predicates (except Dispersing) without a formal description.

IV. Examples of Motion Pattern Analysis

The feasibility of the proposed motion pattern analysis scheme will be demonstrated in a simulated scenario. The scenario simulates the movement of five individuals for the duration of 20 time points. It simulates a "runaway" scenario (Fig. 3). The active area for movement is represented by 1024×1024 pixels. In the scenario, the units used to express distances are pixels. The value of the parameters m is 10 (see Sections III).

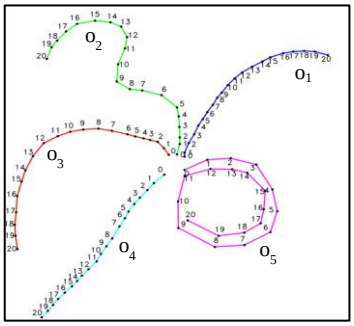

Fig 3. Simulated scenario of motion patterns at a microscopic level.

An illustration of the truth evaluation procedures (see section III) for four direction fuzzy predicates and three velocity fuzzy predicates are depicted in Fig. 4 and Fig. 5, respectively. Fig. 4 and Fig. 5 relate to fuzzy predicates for five individuals. The first row of Figures 4 and 5 represents input values for the assignment functions at time points from 10 to 20. All input values are distances, except for the Circle predicate which uses variance. The input values for Fig. 5 are velocities expressed as pixels per time point. The second row in both figures represents the assignment functions. The third row in both figures depicts the predicate value at each time point. The truth values of the fuzzy predicates for motion patterns and velocities are calculated as described in section III. In short, for the selected seven fuzzy predicates, the positions of the tracked individuals in each frame are first transformed into distance values or the variance of distances (only for the Circle predicates), or velocities.

The obtained results are in accordance with an expert's expectation and common-sense reasoning. For example, at time point 19 (Fig. 4 (a); second column, third row) we can see that individuals o_2 and o_5 have circular movement patterns (the values of the fuzzy predicates are 0.87 and 0.97, respectively).

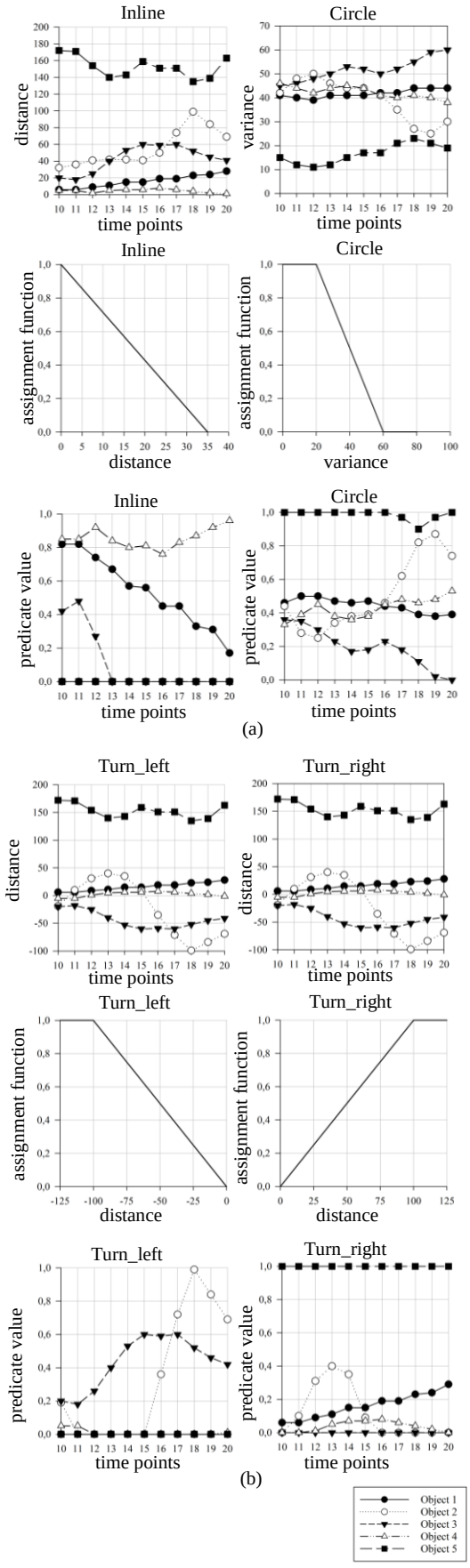

Fig 4. Illustration of the truth evaluation procedures for four direction fuzzy predicates for five individuals at each time point (n = 5, m = 10 and k = 20): a) Inline and Circle; b) Turn_left and Turn_Right.

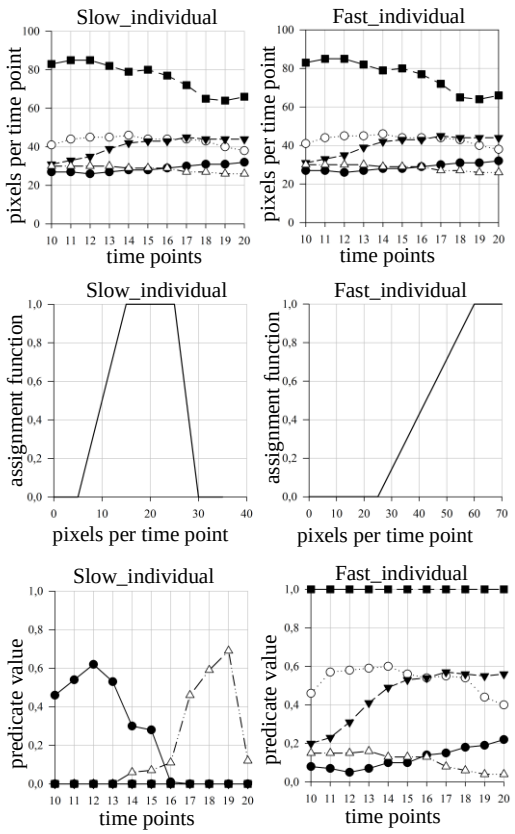

Fig 5. Illustration of the truth evaluation procedures for two velocity fuzzy predicates for five individuals at each time point (n = 5, m = 10 and k = 20) Slow_individual and Fast_individual.

V. CONCLUSION

This paper presents an approach to the detection of crowd motion patterns at the microscopic level. The approach uses fuzzy knowledge-based methods and fuzzy predicates. The fuzzy predicates are inspired by common-sense human knowledge. The fuzzy predicates are divided into the following classes: i) direction and ii) velocity. A simulated crowd event is used to evaluate the model. The obtained results of the preliminary experiment show that the model supports the simple and efficient representation of expert knowledge and the detection of motion patterns of interest.

Our future research work will be directed to include: i) the development of a robust multi-object tracker and trajectory generator based on a combination of head-and-shoulder-shape-based methods and optical flow; ii) an extension of motion patterns to medium- and large-scale crowds for the detection of different types of anomaly behaviour; iii) the introduction of fuzzy functions for the classification of complex crowd behaviour patterns; iv) exhaustive testing of the proposed method in real crowd scenes.

We believe that the presented model can be used to solve many application-specific problems in the domain of computer vision and multiple object tracking, such as the automatic recognition of actions and activities in video content in the domain of sports [23].

ACKNOWLEDGMENTS

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Reverse Engineering of the MMORPG Client Protocol

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Abstract— **Massively Multi-Player On-Line Role-Playing Games (MMORPG) represent a computer game genre where the human player is able to assume the role of a game character and control its actions in a well defined virtual world; the prefix "massively" denoting the vast number of players playing the game simultaneously. Cheating in such games is a fairly common occurrence and presents a major concern in network games as it is able to degrade the experience of "honest" players, with cheat prevention being considered as a subset of security issues for online games. In this paper we have presented a form of a network-level game cheating based on the MMORPG client reverse engineering method within the game Mana World, an MMORPG with client/server architecture. We have used the network protocol vulnerability of a non-encrypted data traffic in order to reverse-engineer the original data packets sent by the original game client, and replicated these packets in our own AI-based game client which enabled us complete control of the game character via Python code.**

Keywords*— *reverse engineering, mmorpg, network protocol, computer games, cheating, security

I. Introduction

One of the most popular ways of spending time on the Internet is playing online games. According to [1] over 40% of Internet users play online games regularly and worldwide online gaming traffic reached 915 petabytes per month in 2016 and is expected to grow by 79% more in 2019. The most popular genre of online games are Massively Multiplayer Online Role-Playing Games (MMORPGs). Lee et al. [2] define them as follows: "In an MMORPG, each player creates a character in the virtual game world to perform various activities including combating other players, socialising with other players and collecting game items. "Item-pay" is a primary business model that offers financial incentives for game developers." Chen et al. [3] define MMORPG as a series in which players pay a network connection fee for operating their virtual character while accumulating game play and virtual properties. Different definitions exist, but they define the same characteristics for MMORPGs [4]: network connection (connected to a server through Internet), player authentication (username and password), game objectives (accumulate virtual property to achieve game objectives), number of players (large number of players competing) and payment for use (payment for network connection).

Chen et al. [3] state that the real-world sales of virtual properties in MMORPGs have surpassed 100 million dollars worldwide. The increasing popularity and monetisation of such games has made them very popular for malicious users and many cheating problems and criminal behaviour has emerged that can influence the development of online gaming.

The idea behind this paper is to present a form of a network-level game cheating based on the MMORPG client reverse engineering method within the game Mana World. Mana World is an MMORPG with client/server architecture. The network protocol vulnerability of a non-encrypted data traffic was used to reverse-engineer the original data packets sent by the original game client, and replicate these packets in our own AI-based game client which enabled us complete control of the game character via Python code. Chapter 2 gives an overview of cheating in online games along with the most frequently used taxonomies of online cheating. Chapter 3 describes the Mana World game protocol and architecture, while chapter 4 explains the reverse-engineering process used to imitate human player by recreating and managing network packets being sent between the game server and the client.

II. Cheating in Online Games

The increasing popularity of MMORPGs has made them very popular for malicious users who can influence the development of online gaming. According to [3], most of the criminal cases relating to online games belong to MMORPGs. Different types of criminal and fraudulent behaviour causes legitimate players to stop playing the game and discourages them from playing in the future. This, in term, decreases the profit in the gaming industry. Limelight [5] states that gamers are concerned about online security and 57% will not continue to make purchases or play games on a website that has previously suffered a security breach.

Many different definitions of online cheating have emerged. However, the definition by Yan et al. [6] is the most extensive and defines cheating as "Any behaviour that a player uses

to gain an advantage over his peer players or achieve a target in an online game is cheating if, according to the game rules or at the discretion of the game operator (i.e. the game service provider, who is not necessarily the developer of the game), the advantage or the target is one that he is not supposed to have achieved." In order to better understand the magnitude of cheating and its influence and consequences on online games, Chen et al. [3] define seven influences of online cheating: (1) undermining the development of online gaming, (2) increasing criminal cases pertaining to theft, fraud, robbery, counterfeiting, vandalism, threat behaviour, (3) causing unfair competition among players, (4) gaining an illegal advantage over other players or vendors by using cheating programs, (5) harming victim's finances, mental well being, or social relationship, (6) adding burdens and resource wastage on vendors (network bandwidth, server processing), (7) affecting the validity of the gaming server's log record as digital evidence. For this reason, cheating in online games has become an important field of research.

Yan and Choi [7] created one of the first taxonomies of cheating in online games. They categorise online cheating in 11 categories: cheating by collusion, cheating by abusing procedure or policy, cheating related to virtual assets, cheating by compromising passwords, cheating by denying service to peer players, cheating due to lack of secrecy, cheating due to lack of authentication, cheating related to internal misuse, cheating by social engineering, cheating by modifying game software or data and cheating by exploiting bugs or design flaws. They did not only classify online cheating, but also introduced security techniques for cheating prevention.

Ki et al. [8] classified known attacks in online games by objectives and methods. When classifying attacks by objectives, they identified four types of objectives: user ID and password theft, hidden information exposure, data modification and advantage gained from cheating. Moreover, when classifying attacks by methods, they categorised the attacks into four layers: client, server, network and environment. Attacks in client layer can be: memory scan and modification, software modification, bug or flaw in software, malicious code or backdoor. Server layer attacks include: server environment weakness, ID and password dictionary attack, security holes in the operating system and internal misuse. Attacks on a network layer are: packet sniffing, packet inserting, deleting and modifying, pretending game Web page, Denial of service. Environment attacks include: hack, abusing procedure or policy and social engineering. Other than classifying the attacks, they proposed security solutions for each attack.

Another systematic classification of cheating in online games has been published by [6]. They summarised the various known methods of cheating and created a taxonomy of online cheating with respect to the vulnerability, consequence and cheating principle. They expanded and modified their previous research [7] and identified fifteen common cheating forms: cheating by exploiting misplaced trust, cheating by collusion, cheating by abusing the game procedure, cheating related to virtual assets, cheating by exploiting machine intelligence, cheating by modifying client infrastructure, cheating by denying service to peer players, timing cheating, cheating by compromising passwords, cheating by exploiting lack of secrecy, cheating by exploiting lack of authentication, cheating by exploiting a bug or loophole, cheating by compromising game servers, cheating related to internal misuse and cheating by social engineering. Their three dimensional taxonomy can be seen in Figure 1. This is the most extensive and detailed taxonomy to date.

Chen et al. [3] expanded on taxonomy by [7] and to the previously defined eleven categories, added six of their own: fraud by trade or exchange, fraud by identity, cheating the online gaming vendor, fraud by sharing user id and password, fraud due to lack of secrecy and fraud by faking official website. Most of these categories were also identified by [6].

Yee et al. [4] researched MMORPGs from the security aspect and examined what crimes could have been avoided if the games were designed to be secure. They created the attack trees and discovered potential new threats and their countermeasures.

Another review on cheating in networked computer games has been done by [9]. They classify cheats into four levels: game, application, protocol and infrastructure. Game level cheats include bugs and real money transaction. Application level cheats are information exposure, bots/reflex enhancers and invalid commands. Protocol level cheats include suppressed update, fixed delay, inconsistency, timestamp, collusion, spoofing, replay, blind opponent and undo. Protocol level cheats are information exposure and proxy/reflex enhancers. The authors also discussed countermeasures for those cheats and benefits of peer-to-peer architecture for online games.

Woo and Kim [10] identified six major threats in online games: game bot, in-game hack, gold farming, private servers, system or network hacking and identity theft. They also categorised those threats by severity and their effect on game service providers and effect on users.

The most recent research on online games cheating, especially in MMORPGs revolves around the usage of bots and their prevention. Thawonmas et al. [11] propose the bot-detection methodology. The methodology consists of two steps. First step is detection of a bot if its frequencies of actions are higher than those of human characters. The second step is classification of the rest of the characters by using support vector machines. Lee et al. [2] propose a framework that detects game bots through machine learning techniques. They use real-world MMORPG to evaluate their framework. Chen et al. [12] proposed a new way of bot detection by using plug-in detecting technology that can be applied to all kinds of games, not only just one type of games.

The bots have been recognised as a great threat to honest users in online games. Network layer cheating, as identified by [8] is essential for bots. In that regard, next chapters describe one way of network layer cheating.

Classification of the various types of cheating	Vulnerability (-ies)				Possible Failure(s)					Exploiter(s)			
	Inadequacy	System Design	People		Fairness Violation	Masquerade	Integrity Violation	Service Denial	Theft of Information or Possessions	Independent		Cooperative	
	In Underlying Systems	In Game System	Player	Game Operator						Single Player	Game Operator	Multiple players	Operator and Player
A) Cheating by Exploiting Misplaced Trust		●					●		●	●			
B) Cheating by Collusion		●			●				●			●	
C) Cheating by Abusing the Game Procedure		●			●					●			
D) Cheating Related to Virtual Assets			●		●					●			
E) Cheating by Exploiting Machine Intelligence		●			●					●			
F) Cheating by Modifying Client Infrastructure	●						●			●			
G) Cheating by Denying Service to Peer Players	●	●						●		●			
H) Timing Cheating		●			●		●			●			
I) Cheating by Compromising Passwords			●						●	●			
J) Cheating by Exploiting Lack of Secrecy		●					●		●	●			
K) Cheating by Exploiting Lack of Authentication		●				●				●			
L) Cheating by Exploiting a Bug or Design Loophole		●			●					●			
M) Cheating by Compromising Game Servers	●						●			●			
N) Cheating Related to Internal Misuse				●			●				●		●
O) Cheating by Social Engineering			●						●	●			

Fig. 1: Taxonomy of online game cheating by Yan and Randell [6]

III. The Mana World Game Protocol

The Mana World is an open source 2D MMORPG with client-server architecture, where players are able to connect to one of several officially available game servers, or with the option to install a customised local game server. The architecture of The Mana World builds up from the three different functional servers and a client. Login server is managing accounts and connections to character server, and this is the first server a client is connecting to. The character server is managing characters, saves and loads character data, and connects characters to the map server. The map server manages monsters, items, maps and other game-related content, and also manages interaction of such contents with players.

When interacting with a server, official game client is sending and receiving network packets to and from the server. Both the client and the server are acting according to the finite state machines that are able to change their states in response to the payload contained within network packets.

Some packets are defined with fixed length binary fields, but others contain variable length fields. Only several packet types are fully documented, and the others merely defined by their name and pointed to the locations of source code where they should have been implemented. The first few letters of the packet label indicate the packet direction; packets prefixed with SMSG are server packets sent to the client, and packets prefixed with CMSG are client packets sent to the server. This simple, but crucial piece of information helped significantly in the reconstruction of the finite state machine-

Offset	Length	Contents
0	2	Packet ID
2	2	Packet Length (47 + (32 * ServerCount) + 0)
4	4	Session ID (Part 1)
8	4	Account ID
12	4	Session ID (Part 2)
16	4	*Unused* - Always set to 0x00000000
20	26	*Unused* - Currently set to account.lastlogin for some reason.
46	1	Character Sex
		WorldInfo Sub-packet (Repeated for each world)
X+0	4	Address
X+4	2	Port
X+6	20	Server Name
X+26	4	Online Users (Count)
X+30	2	*Unused*

Fig. 2: Login Data ("SMSG_LOGIN_DATA"): an example of a well-documented server packet [13]

based communication.

The most common packet in the game protocol includes 2 main fields: packet identification and payload. For some packets, the second field relates to the packet length in bytes, which in certain cases helped in separating individual packets when capturing them on the network.

IV. Reverse Engineering the Network Packets

The main idea behind the reverse-engineering process described hereafter was to imitate the actions of the real human player by re-creating and managing network packets being sent between the game server and the client. Should the packets be recreated according to the dynamics regulated by the finite state machines, the server would not discern the actions performed by the official game client from the ones generated by our artificial Python client.

Several basic functions were implemented at the beginning of the process, such as character creation, server login request and connection, character choice, etc. Connecting to the Mana World server with Python script was a straightforward process, as these initial packets are well documented on the TMW wiki page [1] as discussed in the previous chapter.

As such, they could easily be recreated and sent to the server, resulting in the successfully executed player login process without the need of having an official game client.

In order to create a functional set of player commands to be implemented in our Python client, first we had to define all the actions a human player would need to successfully complete game quests. This step required playing the game as a regular human player, experimenting with player abilities in completing game quests, but also analysing the publicly available list of network packets that were to be sent from the game client to the Mana World game server. The empirical analysis revealed the list of 32 actions needed for the further implementation of the Python game client. The list included the basic navigation commands of the player, attack and stop attack commands, whisper command, pick and equip items, several actions regarding player parties (create/invite to/leave/join/response/send message), inquiries about other players, walking towards certain items, walking towards certain players, talking to the NPCs, several actions regarding the trading of the items, follow player/monster, several actions regarding the interactions with NPCs, etc.

In order to implement these actions in Python client, there were 3 steps to be carried out beforehand:

1) Identify the network packet(s) involved with the specific player action (1 or more packets per action).
2) Identify and/or reverse engineer the structure and the content of the network packet.
3) Implement the packet in Python, resolve the interoperability, send to server, observe possible further exchanges.

The main challenge of first two steps arose due to the fact that most of the packets were not well documented (or not documented at all), and certainly not documented in relation to specific player actions. To establish a sufficient level of certainty regarding the action - packet set relation, we had to create atomic game scenarios with isolated actions for collecting and analysing data. In a trivial example, to analyse a simple interaction between a player and an item, such scenario required the following steps:

1) Login to the server, enter the game.
2) Walk to the coordinates +-1 step next to the item.
3) Start recording network traffic.
4) Pick-up item.
5) Stop recording network traffic.

With this simple technique, most of the traffic overhead was avoided, and it was easier to discern between targeted packets.

Luckily, the network packets exchanged between server and client were not using any kind of encryption, and were transported as streams of bytes within TCP segments. In order to reverse-engineer the packet structure, the first step was to employ the Wireshark network analyzer, capture the packets, and establish some form of a semi-automated parser in spreadsheet processing applications for quicker packet analysis.

Another challenge arose in separating individual packets, since more than one TMW network packet can arrive in the same TCP segment, and also one packet can be separated into multiple TCP segments. Based on the value at the beginning of the packet, corresponding to the packet ID, the type and the structure were inferred. Especially challenging were messages that do not obey byte boundaries, for example 12-bit integers.

Some more simple packets were initially analysed in order to provide the proof of concept. For example, this string was caught with Wireshark: a1:00:02:00:00:00

The first 2 bytes are packet identifiers, identifying this packet as SMSG_ITEM_REMOVE packet (0x00A1), with a length of 6 bytes. The bytes are apparently arranged in a little-endian order.

The next several bytes proved to refer to the so-called item index, which in this case had value 2. Item indexes were somewhat troublesome, because they would not represent a

[1] https://wiki.themanaworld.org/index.php/Archive:TmwAthena_Packets

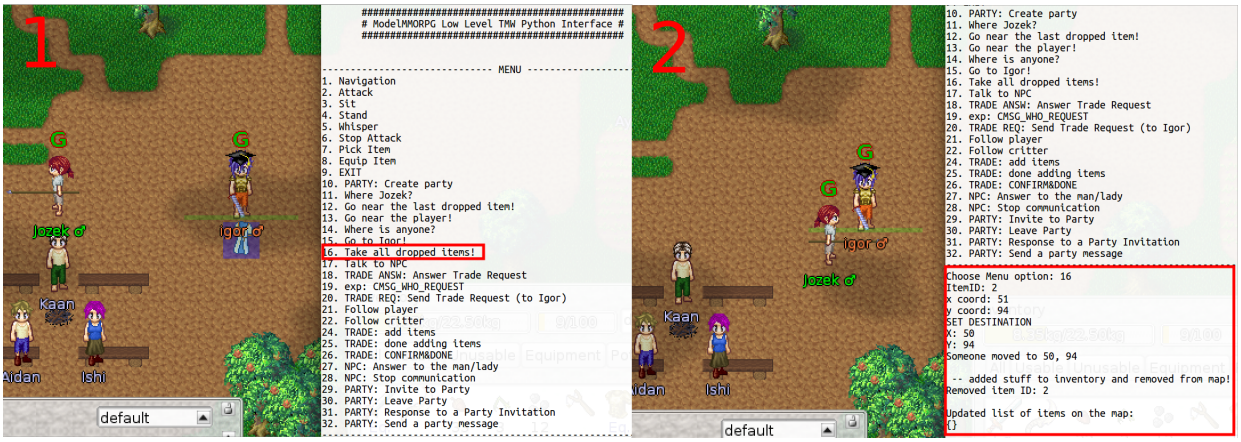

Fig. 3: Python interface/client - an example of player manipulation [14]

unique and consistent item identifier, but merely a temporary item pointer which was identifying in respect to the current player inventory, and stored locally.

An example of a slightly more complex TCP segments contained streams of bytes as follows.

```
b4:00:12:00:57:99:8e:06:5b:54:61:6e:69:
73:68:61:5d:00:b4:00:38:00:57:99:8e:06:
22:54:68:65:73:65:20:79:75:63:6b:79:20:
6d:61:67:67:6f:74:73:21:20:54:68:65:79:
27:72:65:20:65:61:74:69:6e:67:20:6f:75:
72:20:67:6f:6f:64:73:21:00:b4:00:45:00:
57:99:8e:06:4e:6f:20:6d:61:74:74:65:72:
20:68:6f:77:20:6d:61:6e:79:20:6f:66:20:
74:68:65:6d:20:79:6f:75:20:6b:69:6c:6c:
2c:20:74:68:65:79:20:61:6c:77:61:79:73:
20:63:6f:6d:65:20:62:61:63:6b:2e:22:00:
b4:00:13:00:57:99:8e:06:53:68:65:20:73:
69:67:68:73:2e:00:b4:00:12:00:57:99:8e:
06:5b:54:61:6e:69:73:68:61:5d:00:b4:00:
25:00:57:99:8e:06:22:44:6f:20:79:6f:75:
20:68:61:76:65:20:61:6e:79:20:71:75:65:
73:74:69:6f:6e:73:3f:22:00:b7:00:35:00:
57:99:8e:06:59:65:73:2c:20:63:6f:75:6c:
64:20:79:6f:75:20:65:78:70:6c:61:69:6e:
20:61:62:6f:75:74:2e:2e:2e:3a:4e:6f:2c:
20:74:68:61:6e:6b:73:2e:3a:00
```

The above example contains fused game messages with variable length, non-player character (NPC) identifiers, packet metadata, and plaintext coded in HEX format. It is an example of a communication between the player and the NPC, and is one of the less challenging packet exchange, mainly because of the clear byte boundaries, metadata providing information about packet size, straightforward packet structure, and easily reconstructible plaintext coding.

Besides FSM-governed packet exchange, there was one more challenge to be addressed: local player data consistency. In the default game playing, local player client not only manages game message exchange, but also keeps locally relevant information regarding the player itself, such as inventory lists, item amounts and local index numbers, crucial for identification and manipulation with specific items. Functions for local player information were implemented within our Python interface for this purpose.

For an artificial agent to receive game quests, to extract specific pieces of information, and to be able to communicate with NPCs, various methods of text parsing were implemented, relying mainly on regular expression rules.

Testing and evaluating our Python client (low level Python interface) was first manually conducted by executing various scenarios via simple text interface developed within the client (see Figure 3), and observing the game via official, nearby game client concurrently. Client errors were caught either by program exceptions, or by suspicious and unexpected scenario development, which mainly pointed to the broken FSM communication caused by unallowed network packet structure and/or payload.

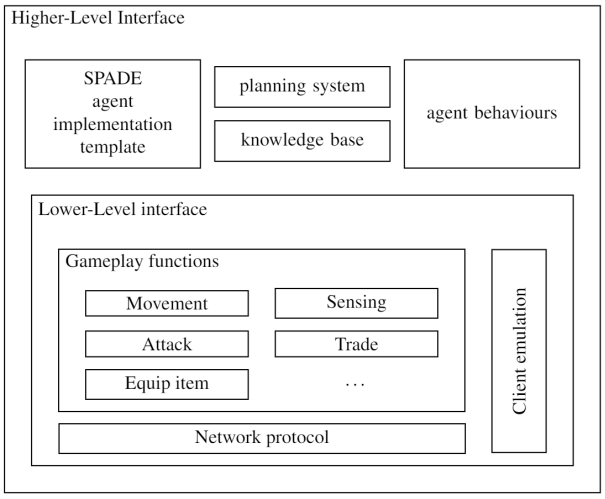

Fig. 4: A possible architecture for an agent-based game cheating model [15]

With the described functional game interface, available at GitHub service [2], there are various possibilities on game cheating methods; from simple automation of "boring" character building actions which could be implemented within the Python client itself, to employing the full AI-based manipulators in resolving game quests, such as described in [14], [15] and [16]. Figure 4 represents one of the possible implementations of the AI-based cheating model, relying on the STRIPS-based planning system and SPADE (Smart Python Agent Development Environment) knowledge-base system for software agents. As for the former, the cheating player could gain significant advantages in building the character in an automated way (collecting items, fighting monsters, discovering the game world, etc.). As for the latter, the AI-based cheating player, using the proposed Python interface, could do all of the above, but also resolve complex game quests, interact with NPCs and/or other players, join parties, etc.

V. Conclusion

In this paper we have presented a reverse engineering approach to re-create the Mana World game client via Python interface, which can enable further implementations of game-cheating models on top of our Python low level plug-in. The model described within this paper included mostly network-layer cheating (network packet analysis, packet re-creation and manipulation), and cheating by exploiting lack of secrecy (non-encrypted data traffic).

Our methodology included several key methods:

- Identification of player actions needed for successful completion of game quests (empirical analysis).
- Identification of network packet(s) involved with the specific player action.
- Identification and/or reverse engineering of the structure and the content of the target network packet.
- Implementing the packet in Python, sending to server, analysing possible further exchanges.
- Scenario development for the targeted package exchange analysis.
- Implementation of the client-side data consistency.
- Text parsing methods for game-related information extraction.

By providing the means to manipulate the game client, various forms of game-cheating models could be implemented; from the basic, character building ones, based on the simple game actions (collecting, fighting), to more complex, quest-resolving processes which could employ AI methods on top of our Python interface.

Acknowledgement

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A clustering model for time-series forecasting

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***Abstract*—In this paper we consider a novel Integer programming approach for the cluster-based model used for time-series forecasting. There are several approaches in literature that aim to find a set of patterns which represent similar situations in the time series. In order to predict target variable, different types of fitting methods can be applied to set of data that belongs to the same pattern. We propose method that uses clustering of patterns and prediction of target value as the mean of values in the same cluster, in order to minimize total squared deviation between predicted and real values of target variable. We also propose a heuristic method that achieves good solution in practice. Our approach is applied to short-term prediction of airborne pollen concentrations. We give experimental results about comparison of our method to some common approaches.**

***Keywords*—Integer programming, clustering, k-means algorithm, heuristic, time-series forecasting, short-term prediction of airborne pollen**

I. Introduction

In this paper we give a novel approach for time-series forecasting that is based on finding similar patterns in time series. Although our approach can be applied on arbitrary time-series, we give an example of time series that consists of average daily airborne pollen concentrations. We give a model that catches some irregular patterns that do not fit well in classical statistical models.

There are several papers that deal with pattern matching in time series. Singh et al. [1] propose Neural Net-PMRS hybrid for forecasting time-series data. More recently, [2] gives a pattern-matching method for time series prediction that is based on finding k-nearest neighbours prior to the interval to be forecasted. Our method is similar to [2], while it uses additional features to find patterns in data. On the other hand, we propose integer programming model and heuristic approach to find a good solution in practice.

The rest of the paper is organized as follows: in section II brief summary of what the model is used for is given, in section III Integer programming (IP) formulation of a problem is devised. Section IV explains heuristic approach which solves given problem. In section V numerical and graphical results of a model are shown. Finally, section VI concludes a paper.

II. Application: Short-term prediction of airborne pollen concentrations

Short-term prediction of daily airborne pollen concentrations becomes one of the most important factors in the public health system. Forecasting of these concentrations, along with real-time measurements, substantially improves life quality of persons who suffer from allergic rhinitis. Good forecasts, for a few days in advance, help people to plan their activities such that exposures to high concentrations are avoided.

We focus on three type of pollen: *Ambrosia*, *Betula* and *Poaceae*. Indeed, according to Bousquet et al. Betula and Poacea cause the majority of allergical reactions in Europe [3], while Ambrosia is the second most important allergen with the significantly increased clinical relevance [4]. There are several approaches in predictions of airborne pollen concentrations. One of the most simple, and the most common approach in practice, is a long-term method that presumes a preparation of predictions based on means/medians of concentrations in previous years. This method is commonly known as a pollen calendar. A standard approach gives a prediction for the particular day in the season as a mean/median of concentrations on the same day in previous years that are available in the dataset. Spieksma's model introduces a preprocessing by 10-day means that remove short-term shifts during the pollen season. The most recent result improves a standard and Spieksma's approach by introducing moving mean/median in the preprocessing phase, and calculating of means/medians on daily and 10-day resolutions [5].

We apply our model to short-time forecast of time series that represents average pollen concentration in geographical area that is considered by RealForAll project[1]. The main contribution is an improvement of predictions that are reported in [5]. We use the same pollen dataset along with the meteorological data.

III. Integer Programming model

Assume that each time unit $i \in \{1, \ldots, T\}$, $T \in \mathbb{N}$ in our model is represented by scalar y_i and vector $\mathbf{x}_i$. y_i represents a realization of time-series (dependent) variable to be predicted and $\mathbf{x}_i \in \mathbb{R}^n$ vector of realizations of n independent variables used in prediction of y_i. Before we give a prediction model, we pre-process a dataset such that the patterns consisting of several consecutive time units are found with respect to the domain specific knowledge about the time-series forecasting problem. These patterns represents some common situations visible in data or some deterministic patterns that are known in advance. For example, if we focus on application in pollen prediction where time unit is a day, visible pattern of data contains consecutive days where concentrations of

[1]Interreg IPA CBC project: Real-time measurements and forecasting for successful prevention and management of seasonal allergies in Croatia-Serbia cross-border region, more detail can be found in acknowledgment

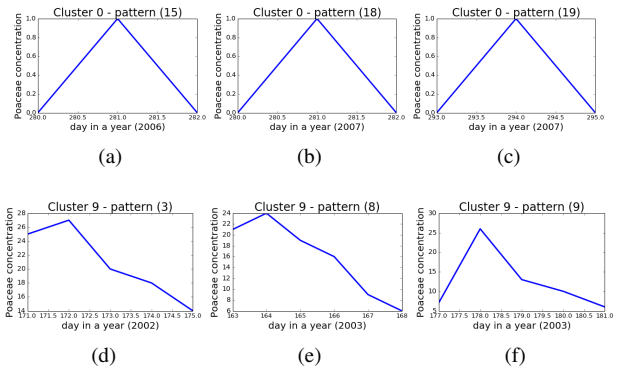


Fig. 1: **(1a)-(1c)**. Three-day patterns discovered in 2006 and 2007 show very similar situations with respect to target value. Even more, we observe that these patterns occur relatively close to each other during the season. **(1d)-(1f)**. Although pattern **(1e)** consists of 6 days, it exhibits similar trend as the one observed in **(1d)** and **(1f)**.

pollen grows to the local maxima and falls down until the end of pattern (see Figure 1a-1f). These patterns can also be represented by some features such as minimum and maximum concentration in pattern, index of day with maximum concentration, etc.

In this paper, we introduce integer programming model for clustering of patterns P_j, $j \in \{1, \ldots, p\}$, $p \in \mathbb{N}$. Each pattern represents one observed situation in time series. Each time unit i is assigned to exactly one pattern $P_{j(i)}$, where $j(i)$ denotes an index of cluster that contains pattern P_j. $d(i)$ is an index of time unit i in its pattern, while $y(l, j)$ is a value of target variables in l-th time unit of pattern P_j.

We introduce integer variable z_{jk} that is set to 1 if pattern P_j is assigned to cluster k, 0 otherwise.

$$\text{minimize} \quad \frac{1}{T}\sum_{i=1}^{T}(y_i - \hat{y}_i)^2 \tag{IP}$$

subject to

$$\sum_{k=1}^{K} z_{jk} = 1, \quad j \in [p], \tag{1}$$

$$\sum_{j=1}^{p} z_{jk} \geq 1, \quad k \in [K], \tag{2}$$

$$\hat{y}_{ik} = \frac{\sum_{j=1}^{p} y(d(i), j) z_{jk}}{\sum_{j=1}^{p} z_{jk}}, \quad i \in [T], k \in [K], \tag{3}$$

$$\hat{y}_i = \sum_{k=1}^{K} z_{j(i)k} \hat{y}_{ik}, \quad i \in [T], \tag{4}$$

$$\hat{y}_{ik} \in \mathbb{R}, \quad i \in [T], k \in [K],$$

$$\hat{y}_i \in \mathbb{R}, \quad i \in [T],$$

$$z_{jk} \in \{0, 1\}, \quad j \in [p], k \in [K].$$

In this IP we minimize average squared euclidean distance between predicted values $\hat{y}_i$ and known realization of target values y_i, for $i \in [T]$. Constraints (1) ensure that each pattern is assigned to exactly one cluster. Each cluster should be non-empty due to constraints in (2). The prediction of target values are calculated for each time unit and each cluster. If time unit i is assigned to cluster k then prediction of target value $\hat{y}_{ik}$ is calculated as a mean of target values in time unit $y(d(i), j)$ in all patterns that are assigned to cluster k. This calculation is done due to constraints in (3). The final prediction $\hat{y}_i$, in time unit i, is equal to the prediction $\hat{y}_{ik}$ such that $z_{j(i)k} = 1$. In other words, we select prediction for time unit i for cluster k, such that the pattern which contains time unit i is assigned to it.

Due to the size of real datasets, it is hard to solve this non-linear integer programming. Because of that, we do not deal with solving this problem exactly, but try to find good heuristic solutions.

IV. Heuristic Solution

Our heuristic approach consists of two phases. In the first phase, we used centre-based clustering approach [6], [7] to find clusters of patterns that model similar situations. We do not incorporate objective function IP, but find cluster with respect to pattern features. In the second phase, we use clusters to make a prediction of unknown target value for a given time unit as follows. First, we make a pattern from all known features until the time unit we want to predict. It is assumed that day for which one wants to predict target values is the last day of that new pattern. The new pattern is then assigned to the nearest cluster. Based on values in that cluster, a target value is estimated. To be able to achieve that, after initial clustering, in every cluster the longest pattern is found. Suppose that length of the pattern is d time units. For every time unit $l \in \{1, \ldots, d\}$ in the pattern and every cluster $k \in \{1, \ldots, K\}$, a mean of target values on time unit l among all patterns in cluster k is calculated. In that way, a mean of a target value on specific time unit is obtained and those values will be predictions we are looking for. If a time unit for which target value should be evaluated is e.g. fifth day in its pattern, the estimated value for target variable of that day is the fifth mean value of target values of a cluster to which this pattern belongs. If it happens that a new pattern is longer than the longest pattern in an appropriate cluster then the mean value of a last day in cluster is used as a prediction for target value of a new day.

V. Experimental Results

For experiments three data sets for the city of Novi Sad were used. First data set considers *Ambrosia* pollen concentration, second data set considers *Poaceae* pollen concentration and the third set considers *Betula* pollen concentration. For Ambrosia and Poaceae, concentrations are available for periods from year 2001 to year 2016, and for Betula, concentrations are available also from year 2001 to year 2016, but with exception of years 2009, 2010 and 2011. First, data is cut off so that only those days where concentration of given pollen is greater than zero are considered. From that data two data sets were made

TABLE I: Pattern Attributes

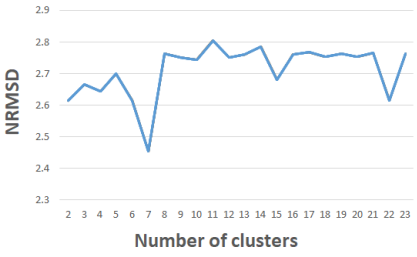
Name	Description
Len	length of a pattern (number of days in pattern)
PattNoYear	ordinal number of pattern in current year
DayNo	ordinal number of day in the year on which the pattern started
MinConc/MeanConc/MaxConc	minimal/mean/maximal pollen concentration in a pattern
MaxDay	ordinal number of a day in pattern on which the maximal pollen concentration is reached
RainNoDay	number of days in a pattern that had rainfall
MinRainDay/MaxRainDay	ordinal number of a day in pattern on which the minimal/maximal rainfall value is reached
MinRain/MeanRain/MaxRain	minimal/mean/max rainfall value in a pattern
MinTempDay/MaxTempDay	ordinal number of a day in a pattern on which the minimal/maximal mean temperature value is reached
MinTemp/MeanTemp/MaxTemp	minimal/mean/max mean temperature value in a pattern
Year	a year from which this pattern comes
AreaBeforeMax/AreaAfterMax	area under the pollen concentration line in a pattern before/after maximal value of concentration
RelAreaBeforeMax/RelAreaAfterMax	relative area before/after maximal concentration in a pattern (minimal value of concentration is subtracted from all concentration values)
ConcBegMax/ConcMaxEnd	concentration values of a day exactly half way from the beginning of the pattern to the maximal value of the pattern and a day exactly halfway from the maximal value of a pattern to the end of a pattern

for Ambrosia pollen concentration and for Poaceae pollen concentration in a way that all the patterns before the maximal value of concentration in an entire given year are put in one data set and all the patterns that come after maximal value of concentration are put in the other. The reasoning for this distinction is that patterns from the beginning of the pollen season and from the end of pollen season are mainly different and it would not be good if the pattern from the beginning of the season has influence on behavior of the pattern from the end of the season. For the Betula pollen data that distinction was not made because the maximum is reached almost always in the first pattern and there are not so many data points in general, so this distinction was not needed here. After that, for every data set patterns were made in the sense that one pattern starts when concentration is growing, then it reaches its peak and starts to fall. When the concentration stops to fall then the pattern is finished, as already described in section III. Examples can be seen in Figure 1a-1f.

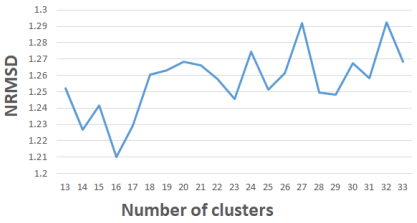
For every pattern in each data set, a set of attribute values was calculated and different subsets of them were used for experiments. Attributes whose values were calculated can be seen in table I.

For each data set, three test cases were considered: test case one contains only attributes regarding pollen concentration (except minimal pollen concentration and mean pollen concentration), test case two contains attributes regarding pollen concentration (same as in the first test case), attributes regarding rainfall and mean temperature and three additional attributes: length of a pattern, ordinal number of current pattern in a current year and ordinal number of day in the year on which the pattern started, and test case three contains all attributes as the second one but without attributes regarding pollen concentration.

For every data set and for every test case clustering was made using kMeans algorithm in order to group similar patterns into groups. In order to determine number of clusters, in all three data sets, years 2013 to 2016 were excluded and clustering was done using data from years 2001 to 2012 (for Betula pollen, years 2009 to 2011 are also excluded because that data is not available) for different number of clusters. After that, data from 2013



(a)



(b)

Fig. 2: **(3a)**. NRMSD curve for Betula in test case one. **(3b)**. NRMSD curve for Poaceae in test case three for data after the maximum.

and 2014 were used as a validation set, i.e. for every day in those two years, prediction was made for every number of clusters (as described in section IV) and normalized root-mean-square deviation (error) - NRMSD was calculated in order to see which number of clusters yields minimal error. NRMSD is calculated by dividing root-mean-square deviation (error) - RMSD by average of known realization of target values y_i, for $i \in [T]$ where RMSD is error obtained by taking square root from average squared euclidean distance between predicted values $\hat{y}_i$ and known realization of target values y_i, for $i \in [T]$ which is, also, an objective function of IP model. Figure 2 shows how NRMSD changes for different number of clusters for some test cases. For first case, 7 clusters are used for further experiments and in the second case 16 clusters were used.

When number of clusters is determined, then the predictions were made for data in test set which consists of

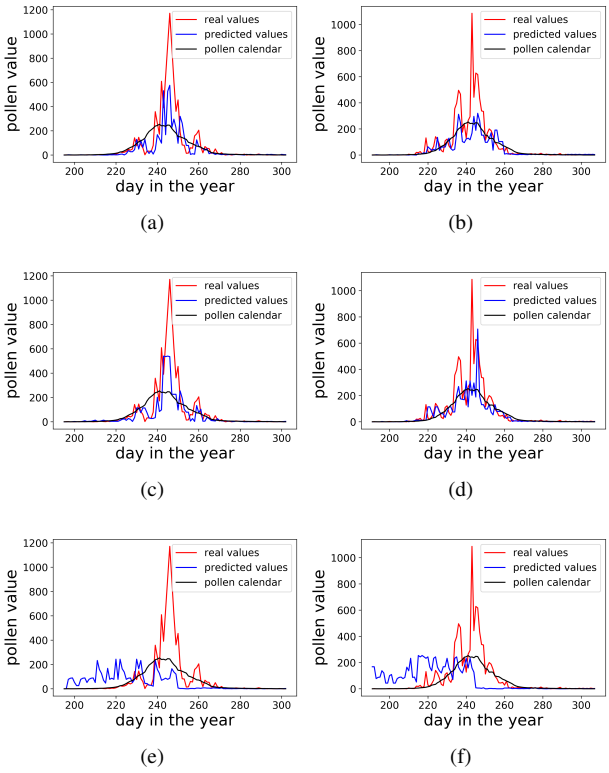


Fig. 3: Ambrosia concentration for: test case 1 for 2015 **(3a)** and 2016 **(3b)**, test case 2 for 2015 **(3c)** and 2016 **(3d)**, test case 3 for 2015 **(3e)** and 2016 **(3f)**

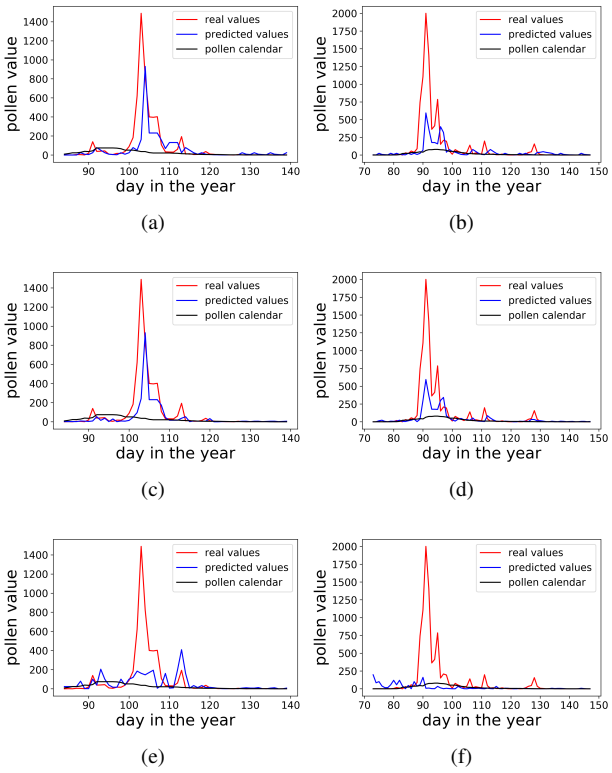


Fig. 4: Betula concentration for: test case 1 for 2015 **(4a)** and 2016 **(4b)**, test case 2 for 2015 **(4c)** and 2016 **(4d)**, test case 3 for 2015 **(4e)** and 2016 **(4f)**

data from years 2015 and 2016.

Results achieved by model described in this paper can be seen in Tables II - IV. RMSD and NRMSD are reported for years 2015 and 2016, and comparison with values achieved by pollen calendar was given. Also in Figures 3-5 graphs of real pollen concentration, predicted pollen concentration and values given by pollen calendar separately for 2015 and 2016 can be seen.

From tables II - IV it can be seen that given model has smaller RMSD and NRMSD than pollen calendar for all three types of observed pollen concentrations. Also, for Ambrosia and Betula test case 2 has the smallest RMSD and NRMSD which means that information about pollen concentration and its appropriate values as well as meteorological data have influence on predicting pollen concentration in any given day. For Poaceae test case 1 has the smallest RMSD and NRMSD which means that in this case meteorological data are not so important in predicting concentration of pollen. Figures 3-5 show that predictions obtained by this model follow pollen concentration trend really well (in a sense that peaks in predictions happen in the same time as peaks in real values) for test case 1 and 2. For test case 3 the situation is not so well, but it only means that one cannot predict concentration of pollen by using only meteorological data, the pollen concentration data should also be used.

VI. Conclusion

In this paper a clustering based method for predicting pollen concentration was proposed. This method uses pollen concentration data for previous known days as well as additional data (e.g. meteorological data) to find clusters of similar patterns whose mean target values on specific time unit are taken as a forecast of unknown value. Although our method outperforms advanced calendar approach, we believe that it doesn't use all knowledge available from data. We focus our future research on approaches that train our model with all features and implicitly select the set of most predictive ones. One of the most interesting challenges is to find clusters of patterns that enable the best fitting of target variable with the most predictive features.

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TABLE II: Experimental results for Ambrosia

Method	RMSD 2015	RMSD 2016	RMSD Both	NRMSD 2015	NRMSD 2016	NRMSD Both
Heuristic solution - test case 1	1.568339	1.486571	1.530611	0.597347	0.095406	0.290987
Heuristic solution - test case 2	1.499938	1.440932	**1.472883**	0.544118	0.10415	**0.266733**
Heuristic solution - test case 3	2.287196	2.090123	2.196069	2.872484	2.385183	1.854562
pollen calendar	1.795675	1.397128	1.617169	0.651955	0.119353	0.319033

TABLE III: Experimental results for Betula

Method	RMSD 2015	RMSD 2016	RMSD Both	NRMSD 2015	NRMSD 2016	NRMSD Both
Heuristic solution - test case 1	2.108565	2.290662	2.241765	0.694087	0.633266	0.468491
Heuristic solution - test case 2	1.978329	2.173093	**2.119745**	0.221541	0.377668	**0.236053**
Heuristic solution - test case 3	2.348061	2.878849	2.72552	0.656588	1.999024	1.178395
pollen calendar	2.643745	2.794911	2.758008	0.78778	0.1068	0.342267

TABLE IV: Experimental results for Poaceae

Method	RMSD 2015	RMSD 2016	RMSD Both	NRMSD 2015	NRMSD 2016	NRMSD Both
Heuristic solution - test case 1	1.305439	1.550134	**1.427614**	0.107341	0.064374	**0.06174**
Heuristic solution - test case 2	1.220976	1.685547	1.460438	0.140311	0.088914	0.082047
Heuristic solution - test case 3	1.47779	1.575929	1.526313	0.136176	0.225758	0.133667
pollen calendar	1.554004	1.482002	1.521725	0.180552	0.111577	0.104771

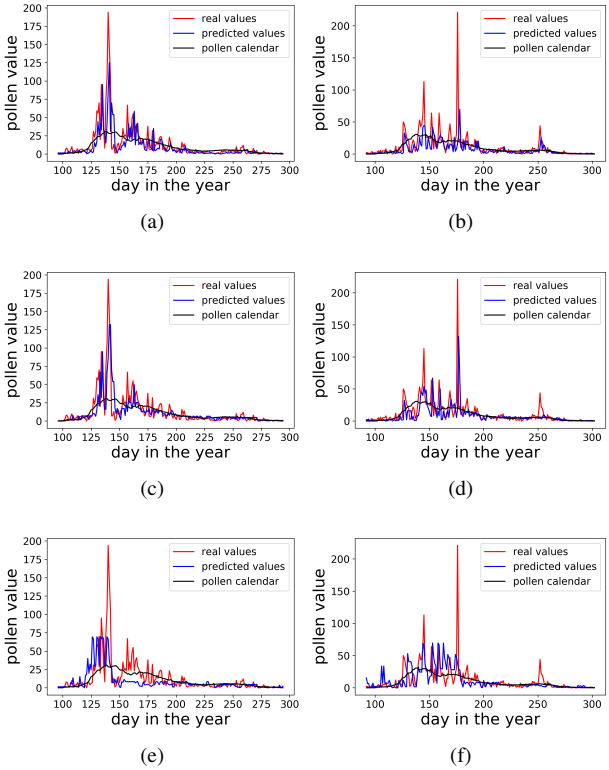

Fig. 5: Poaceae concentration for: test case 1 for 2015 **(5a)** and 2016 **(5b)**, test case 2 for 2015 **(5c)** and 2016 **(5d)**, test case 3 for 2015 **(5e)** and 2016 **(5f)**

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Towards reusable process-based models of dynamical systems: A case study in the domain of aquatic ecosystems

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***Abstract*—Storing metadata about models of dynamical systems in a machine readable form is one of the key steps towards their accessibility and reusability. In the domain of process-based modeling of dynamical systems, the task is to construct an explanatory model of a dynamical system from domain knowledge and data. In this paper, we present a workflow for annotation, storage and querying of process-based models specifically in the domain of aquatic ecosystems. To provide the vocabulary of key terms about the process-based modeling paradigm, we use the Ontology for Process-Based Modeling of Dynamical Systems (OntoPBM). Next, to capture the domain-specific characteristics, we extend OntoPBM with terms specific for aquatic ecosystems. The annotations for each process-based model are stored in an RDF triple store. This enables us to execute SPARQL queries on facts asserted in the annotations, as well as facts inferred from the domain knowledge encoded in the ontology. Finally, by following the proposed workflow, we generate the minimal information about a model, which takes us one step closer towards reusable research.**

***Index Terms*—dynamical systems, process-based modeling, ontologies, knowledge representation, querying, reusability**

I. Introduction

Modeling dynamic systems is an omnipresent task that occupies a major portion of work of mathematical modelers in various fields of science and engineering. In machine learning (ML), the area of equation discovery studies methods for automated discovery of equations in collections of quantitative data [1]. Process-based modeling (PBM) is an approach to equation discovery, where the resulting models comprise system variables represented as entities and their interactions that define the underlying model structure represented as processes [2]. The PBM approach and its software implementation ProBMoT [3], [4] have been successfully used to model dynamical systems in a variety of domains, including earth sciences [5], [6] and systems biology [7], [8].

Recently, Wilkinson et al. [9] proposed a set of principles, which if implemented properly on a given research output will in turn make the resource "Findable, Accessible, Interoperable and Reusable" (FAIR). The principles are focused to ensure that research outputs are reusable, and will actually be reused, so that their added value will increase [10].

In order to provide reuse in the area of modeling of dynamical systems one needs to semantically annotate all the entities involved in the process of modeling (generate metadata), and store the annotations in a database-like structure. This will in turn allow for querying the asserted and inferred facts about the stored entities. The entities can include datasets, experimental settings, as well as generated models. In this paper, we focus on a framework for reusable process-based models (PBMs) of dynamical systems by illustrating a case study of annotating, storing and querying process-based models in the domain of aquatic ecosystems.

In the literature of modeling of dynamic systems, there are not many resources to be used for semantic annotation. Specific resources deal with representing systems and models in specific domains, such as systems biology [11], as well classical physics in connection with dynamics of biological systems [12]. Moreover, there are resources for representation of mathematical entities [13], as well as ontology formalisms for representing general experiments [14]. Finally, the state-of-the-art in storing setups and results of experiments is abundant with approaches and solutions in different domains, such as OpenML (biggest ML repository of datasets, tasks, flows, and runs) [15], BioModels (experiments and models from the domains of systems biology) [16], and ModelDB (repository for computational neuroscience models) [17].

This paper is organized as follows. In Sec. II, we present a overview of PBM of dynamical systems. Next, in Sec. III we present an ontological representation of PBMs and an annotation schema. Furthermore, in Sec. IV, we present the PBM of population dynamics in aquatic ecosystems and in Sec. V we discuss the annotation, storage and querying of models. Finally, in Sec. VI, we conclude the paper and discuss plans for future developments.

[1]The first two authors should be regarded as joint first authors.

II. Process-based modeling of dynamical systems

In this section, we introduce the PBM task and the core elements of the PBM approach to modeling dynamic systems. Note that the elements are only briefly introduced here; for further details on PBM, please refer to [3]. Furthermore, the use of the elements for modeling population dynamics in aquatic ecosystems will be illustrated on examples in Sec. IV. Finally, we give a brief description of two modes of running ProBMoT [4], the toolbox implementing the PBM approach, for (1) induction of new models from domain knowledge and data, and (2) for simulation of existing models on new data.

Process-based modeling of dynamic systems. Process-based modeling is a machine learning task of automated discovery of quantitative laws, expressed in the form of equations, in collections of measured data and domain-specific modeling knowledge. More specifically, the task of process-based modeling is: *Given* (1) domain-specific knowledge formalized as a library of template entities and template processes for modeling dynamical systems in a domain of interest, and (2) time-series observations of the behavior of the dynamical system to be modeled, *find* a process-based model (PBM, a set of specific entities and processes) with a simulated behavior that closely resembles the given observed behavior. In the continuation, we are going to introduce the formalism used to represent both process-based models and domain knowledge.

Entities and processes. The representation of PBMs and domain knowledge are based on two general concepts of *entities and processes*. Entities correspond to the static components of the modeled system, while processes relate to the dynamic interactions among entities. An example of an entity in aquatic ecosystems is an environment of the observed system. Note that despite the fact that it is considered to be static, the environment entity includes both time-invariant, constant properties, such as the volume or the altitude of the aquatic ecosystem, as well as time-varying, dynamic properties, such as temperature or sunlight. Thus, the PBM entity includes variables and constants that denote time-varying and time-invariant properties of the corresponding system component, respectively. The entity variables correspond to the input, output or state variables of the model of the observed system, while the entity constants denote constant model parameters.

A process corresponds to an interaction among multiple entities, hence the formal representation of a process has to specify the interacting entities, the equations modeling the interaction and the values of the constant parameters. For example, in population dynamics, we often observe the decay of the species (e.g., plankton) individuals into inorganic matter (e.g., nitrogen). The corresponding process would then specify (1) the two interacting entities of $plankton$ and $nitrogen$, (2) the equations modeling the temporal change of the entities' properties due to their interaction, e.g., the plankton decay $\mathrm{d}\,plankton.conc/\mathrm{d}t = -\delta \cdot plankton.conc$ and the related nitrogen accumulation $\mathrm{d}\,nitrogen.conc/\mathrm{d}t = \gamma \cdot \delta \cdot plankton.conc$[1], and (3) the values of the constant parameters decay rate $\delta = 0.3$ and conversion rate $\gamma = 0.05$.

Library of domain knowledge. Processes and entities above correspond to a specific ecosystem and its population dynamics. In order to specify more generic knowledge on population dynamics, we need to specify more generic building blocks for PBMs. These generic building blocks are entity and process templates that, in for a particular aquatic ecosystem, can be instantiated into specific components of its model. An example of a process template is a generic decay process, that specifies (1) interaction between two template entities of species S and inorganic nutrient N, (2) generic model of the decay, i.e., $\mathrm{d}\,S.conc/\mathrm{d}t = -\delta \cdot S.conc$ and $\mathrm{d}\,N.conc/\mathrm{d}t = \gamma \cdot \delta \cdot S.conc$, and (3) the ranges of possible values of the constant model parameters $\delta \in [0, 1]$ and $\gamma \in [0, 0.1]$.

In sum, PBM library of entity and process templates provides a recipe for building models in the domain of use. Following the encoded knowledge, models of arbitrary complexity can be established: They can include an arbitrary number of entities and process interactions among them, which allows the modeler to explore various scenarios and assumptions.

Inducing PBMs. For solving the task of inducing PBMs from knowledge and data, ProBMoT [18] toolbox takes three inputs. The first is a library of domain-specific knowledge. The second specifies the modeling task including the specific entities that appear in the observed system, the known configuration of the interactions among them and the modeling assumptions. The third is the dataset of measurements of the state and input/output variables of the observed system. Given these inputs, ProBMoT proceeds in three steps of (1) instantiating the templates from the library into specific model components that correspond to the task, (2) generating the candidate model structures corresponding to combinations of the model components, and (3) estimating the constant parameters and the fit of each model structure against data. Finally, the output of ProBMoT is a list of PBMs ranked according to their increasing simulation error, e.g., the discrepancy between the model simulation and the observed behavior.

Simulating PBMs. When simulating PBMs, ProBMoT also takes three inputs: a library of knowledge, a PBM, and a dataset specifying the values of input variables. Given these inputs, it uses the library to transform the given PBM into differential equations, simulates them and outputs the simulation trajectories, i.e., the dynamic behavior of the system variables.

III. Ontological representation of process-based models: An annotation schema

In this section, we present an ontological representation of process-based models. Furthermore, we use this representation as a basis for an annotation schema, which we use to enrich the process-based models with metadata, characterizing their structure and properties.

[1]The left-hand sides of the equations include the term $\mathrm{d}\,x/\mathrm{d}t$ used to denote the temporal change, i.e., the time derivative of the variable x. $e.conc$ denotes the value of the variable (property) concentration of the entity e.

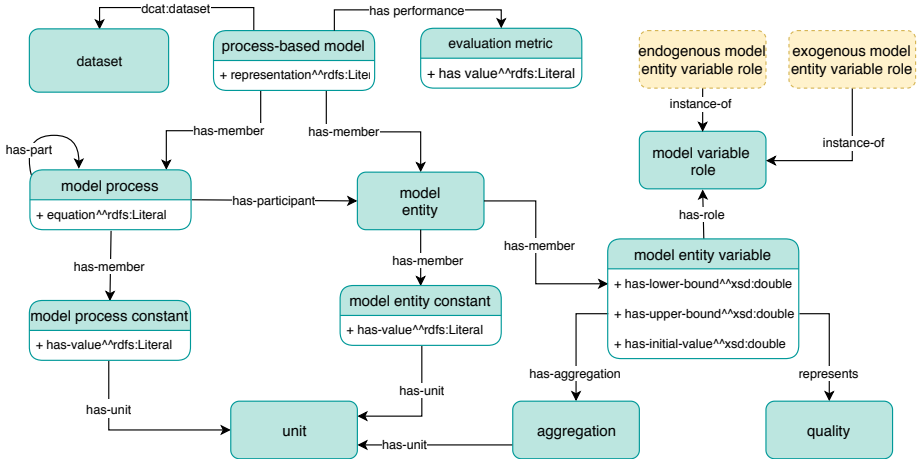

Fig. 1: Annotation schema of process-based models based on OntoPBM. Rounded rectangular boxes with solid lines represent ontology classes. Data and annotation properties are listed inside each class box. Dashed rectangular boxes represent instances.

OntoPBM ontology. PBMs are one of the main pilars of the Ontology for Process-Based Modeling of Dynamical Systems (OntoPBM). The ontology is available at https://w3id.org/ontopbm, as well as at BioPortal http://bioportal.bioontology.org/ontologies/ONTOPBM. In addition, OntoPBM offers a comprehensive description of the domain, covering the whole workflow of process-based modeling of dynamical systems. The ontology provides a description of the datasets, as well as a mapping schema for the domain-specific qualities represented by the features in the datasets with the constants and variables in the process-based models. Finally, it covers different experimental scenarios, executions of experiments with specific parameter settings, and results of the experiments.

Representation of PBMs. In this paper, we focus only on the knowledge about the process-based models encapsulated in OntoPBM as the basis for our annotation schema shown in Fig. 1. We use the class *OntoPBM: process-based model* from the OntoPBM ontology to represent process-based models. The class is connected with the class *OntoPBM:dataset* via the `dcat:dataset` relation, which can be used to specify the dataset that has been used to induce the model. Knowledge about the model's performance (error) can be asserted through the `has performance` relation. We distinguish between three types of performances, i.e., train, test, and validation. Details about the train performance are always available and used for annotation, whereas the presence of the other two depends on the chosen experimental scenario.

At the highest level, a process-based model is associated with model entities and model processes, the actors and actions in a dynamical system. To connect the entities and processes with the process-based model we use the `has-member` relation. Following the process-based modeling paradigm, in the ontology each *model entity* is further described with *model entity variables* and *model entity constants* as its members. Model entity variables can be either obtained from the measurements (dataset) or calculated within the model. The former have an exogenous role, while the latter hold an endogenous role. This is represented through the `has-role` relation.

A specific PBM entity variable can appear in multiple processes. To properly address such cases, we have to specify a function that aggregates the influences from the multiple processes on the specific variable. This is done by using the `has-aggregation` property. The aggregation functions include summation, product, minimum, maximum, and average.

For simulating models of dynamical systems, one needs the initial values of the model entity variables that correspond to endogenous variables. This value falls within a predefined range, which is defined by the domain knowledge. In OntoPBM this is represented with three data properties, i.e., `has-initial-value`, `has-upper-bound`, and `has-lower-bound`. The variables themselves are connected to the qualities they express via the `represents` relation. Finally, *model entity constant* has one optional data property, `has-value` with the unit of measurement.

PBM processes are organized in a hierarchy: a particular process can be composed of a number of sub-processes. OntoPBM models this hierarchy in a recursive way, connecting the model process with its sub-processes through the `has-part` relation. Multiple model entities can appear as participants in a particular process. In addition, model processes have model process constants. Finally, the mathematical equation of the process can be represented in a textual form by using an annotation property.

IV. Process-based modeling of population dynamics in aquatic ecosystems

In this section, we present the domain knowledge required to model population dynamics in aquatic ecosystems, formalized according to the process-based modeling paradigm introduced in Sec. II. Next, we illustrate the representation of the domain knowledge on an example process, chosen from the library of domain knowledge. Finally, for the purpose of annotation of the process-based models, we present an ontological formalization of the knowledge encoded in the domain library.

Domain knowledge for modeling aquatic ecosystems. The knowledge about modeling population dynamics in aquatic ecosystems is represented in a domain library introduced by Atanasova et al. [6]. It focuses on the the scenario of modeling nutrients cycling in lakes and includes template entities and template processes with equations modeling the dynamics of the interactions corresponding to the processes.

The template entities are organized in a taxonomy, starting with the `EcosystemEntity` and `Environment` entities at the top level. `EcosystemEntity` has two child entities of `Nutrient` and `Population`. The latter is a parent entity of the `PrimaryProducer` and `Zooplankton` entities.

While the template processes are also organized in a taxonomy (see Fig. 2), the domain library encodes (1) the knowledge about their alternative models, as well as (2) rules for combining the individual process models into the model of the whole ecosystem [4]. The combining rules follow from the `has-part` relation in the ontology, which encodes the fact that a process can include several sub-processes. On the other hand, the process modeling alternatives are encoded as mutually exclusive subclasses of a process template; we represent this in the ontology with the `is-a` relation.

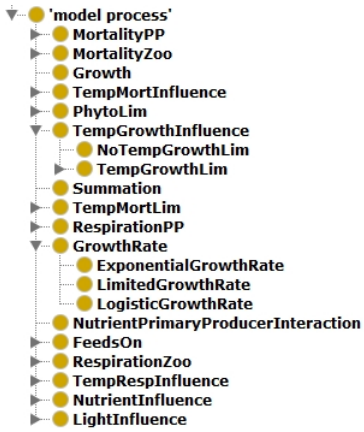

Fig. 2: Taxonomy of model processes in the aquatic ecosystems library. The *GrowthRate* and *TempGrowthInfluence* process alternatives are displayed as subclasses.

Example. To demonstrate how a template process is defined in the aquatic ecosystem library, here, we present the *Growth* process in more detail. Namely, it has three different participating entities: one instance of *PrimaryProducer*, and *Environment*, and up to 100 instances of *Nutrient*. Finally, it has two sub-processes, *GrowthRate*, and *TempGrowthInfluence*.

Equations (1) and (2) represent the mathematical model of the *GrowthRate* process template. It models the dependence of the change of the concentrations $conc$ of the primary producer pp and nutrient n in a lake from the primary producer's constant growth rate $pp.gR$ and its variable concentration $pp.conc$.

$$\frac{\mathrm{d}\, pp.conc}{\mathrm{d}t} = pp.gR \cdot pp.conc \tag{1}$$

$$\frac{\mathrm{d}\, n.conc}{\mathrm{d}t} = -n.alpha \cdot pp.gR \cdot pp.conc \tag{2}$$

The different behaviors of both sub-processes are modelled by their process alternatives. *GrowthRate* has three alternatives, i.e., *LogisticGrowthRate*, *LimitedGrowthRate*, and *ExponentialGrowthRate*, each of them modeling different rates of growth. *TempGrowthInfluence* has two alternatives, *NoTempGrowthLim*, indicating that the temperature has no influence on the growth process, while *TempGrowthLim* indicates that the temperature has influence on the growth process.

From this example, we can observe that each process alternative models different kind of behavior, expressed with different process constants and equations. Furthermore, this can lead to different results in the processes these alternatives participate in. Finally, this example shows the role of interactions of entities in the processes, the distinct system behaviors modeled by the process alternatives, as well as the interactions between the processes as a part of the whole ecosystem model.

Ontological formalization of library of domain knowledge. Having the domain knowledge encoded in a library of domain knowledge, we can further transform the representation in an ontology that will enable us to semantically annotate the process-based models of aquatic ecosystems.

For this purpose, we extended OntoPBM, by adding the taxonomy of model entities and processes defined in the aquatic ecosystems library (See Fig. 2 for the taxonomy of processes). This resource is available at http://w3id.org/ontopbm-aquatic. Furthermore, we encoded the relations between the model entities and processes, as well as their model constants and variables. Each of the model constants and variables can obtain values that are predefined in a certain range, and expressed in a specific unit. Finally, in Fig. 3 we depict an example of ontological representation of the interaction and constraints imposed between the *Growth* process and its sub-processes *TempGrowthInfluence* and *GrowthRate*, as well its connection with the participating entities.

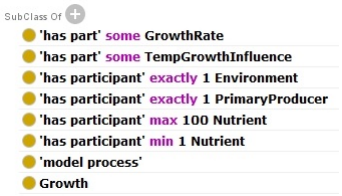

Fig. 3: Ontological representation of the *Growth* process.

V. Annotation, Storage and Querying of Process-Based Models of Aquatic Ecosystems

To facilitate the process of accessing and reusing process-based models of aquatic systems, we have developed a web-based search tool based on semantic technologies. In this section, we provide an introduction to the search tool and we describe the general architecture used for annotating, storing, and querying of process-based models of aquatic ecosystems.

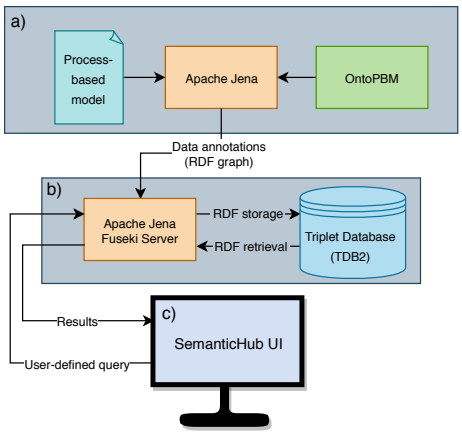

Fig. 4: A workflow for annotating, storing and querying PBMs.

Workflow. In Figure 4, we present a simple workflow for annotating, storing and querying PBMs. First, we annotate previously generated PBMs by using the terms defined in the OntoPBM ontology. Next, the annotations are stored in a database. Finally, we provide a web-based application that allows querying of stored annotations.

Annotation and storage of PBMs. We compiled a corpus of process-based models, previously generated using the ProBMoT tool [3], [4]. These models are stored in files with .pbm extension on a file server, and are in accordance with the structure of the aquatic ecosystems library used as library of domain knowledge. On the other hand, as previously mentioned, we represented the aquatic ecosystems library in ontological formalism in the OntoPBM ontology. This enabled us to automatically annotate the obtained process-based models using the proposed annotation schema. For example, for every entity and process defined in the domain library, there is an equivalent class (that can be used for annotation) in the developed ontology along with the relations that connect them.

We annotated the models using the Apache Jena library [19]. Next, we store the RDF graphs of the model annotations in a TDB2 triple store database [20]. This triple store enables us to store raw RDF files, which are consisted of triplets in the subject-predicate-object format. To fully exploit the benefits of having annotations based on ontology terms, alongside the model annotations, we stored the inferred OntoPBM and OntoPBM-Aquatic ontologies. The inference was done using the OWL Micro reasoner [21]. In order to make the triple store publicly available we host it on a Apache Jena Fuseki2 server [22], which allows remote data storage and querying.

Querying PBMs. After setting up the Fuseki2 server, we are able to pose SPARQL [23] queries over the stored annotations describing the models and the inferences made using the ontology and the reasoner. In order to provide the users with easy-to-use search tool where they do not have to write the actual SPARQL queries, we developed a user interface (UI) (see Figure 5). In the UI, the SPARQL queries are generated in the background and the user is formulating the query by using predefined drop down menus, containing ontology terms.

Our search tool is initially intended to be used by domain researchers in the field of process-based modeling of population dynamics in aquatic ecosystems, available at http://semantichub.ijs.si/models/. Nevertheless, the basic principles developed for this case study would hold for other domains.

User scenarios. When designing the UI, we had in mind the potential search parameters the end-users would find useful and designed several scenarios. The first is that the users can be interested in the connection between the models and the datasets used when conducting the experiments, i.e., finding all/best process-based models that were produced using specific dataset(s). The second scenario considers searching for models with a given structure. The structure is characterized by the specific entities and processes that appear in the model, therefore users can filter the annotated process-based models by choosing the exact entities and processes that they want to be present in the model. The two scenarios are by no means

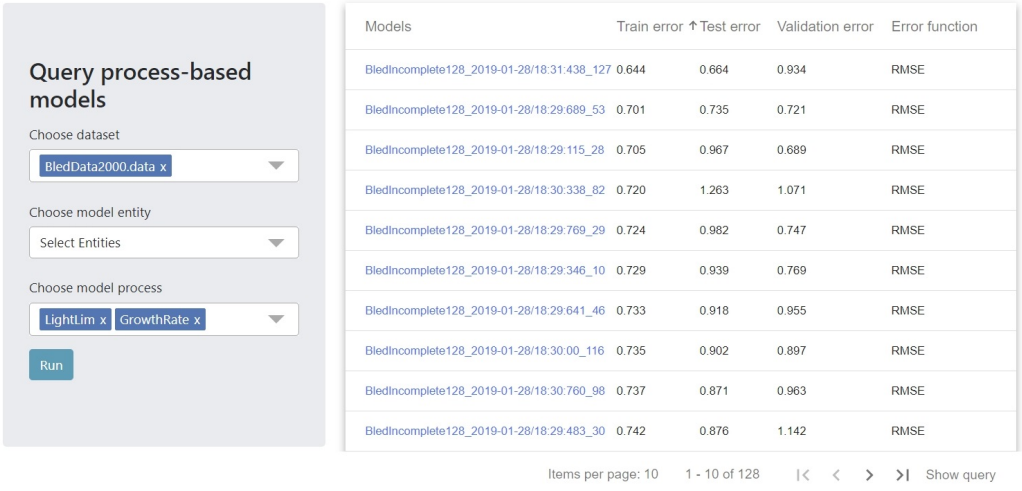

Fig. 5: A snapshot of the UI of the web-based application for visual querying of process-based models of aquatic ecosystems.

mutually exclusive, thus they can be combined when defining the search parameters.

Example query. To illustrate these scenarios, we focus on the following query "*Return the best model generated using Bled2000 dataset that has two processes, light influence and growth rate, in its structure*". The automatically generated SPARQL query is shown in Listing 1. The results of this query are rendered in a table (see Figure 5), where each row represents one model output, i.e., the process-based models. The retrieved models can be sorted by train, test, and validation error, and can be directly downloaded in .pbm format. Having the models in their original format gives way to improved management and better reuseability of the research.

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX RO: <http://purl.obolibrary.org/obo/>
PREFIX DCAT: <http://www.w3.org/ns/dcat#>
PREFIX OntoPBM: <http://w3id.org/ontopbm#>
SELECT ?label ?downloadURL ?trainErrValue
       ?testErrValue ?validationErrValue
WHERE {
  ?PBMInstance rdfs:label ?label.
  ?PBMInstance OntoPBM:OntoPBM_00800 ?downloadURL.
  ?PBMInstance OntoPBM:OntoPBM_00727 ?trainErr.
  ?trainErr OntoPBM:OntoPBM_00496 ?trainErrValue.
  ?PBMInstance OntoPBM:OntoPBM_00726 ?testErr.
  ?testErr OntoPBM:OntoPBM_00496 ?testErrValue.
  ?PBMInstance OntoPBM:OntoPBM_00728 ?validationErr.
  ?validationErr OntoPBM:OntoPBM_00496 ?validationErrValue.
  ?PBMInstance DCAT:dataset 'BledData2000.data'.
  {
  select (count(?userRequestedProcesses)
                              as ?foundProcessesNum)
  where {
    values ?userRequestedProcesses
                      {"GrowthRate" "LightInfluence"}
    {
      select distinct ?foundProcesses
      where {
        ?PBMInstance RO:RO_0002351 ?processInstance.
        ?processInstance rdf:type ?processClass.
        ?processClass rdfs:subClassOf OntoPBM:OntoPBM_00453.
        ?processClass rdfs:subClassOf ?processSuperClass.
        ?processSuperClass rdfs:label ?foundProcesses.
      }
    }
    FILTER (?userRequestedProcesses = ?foundProcesses)
  }
  }
FILTER(?foundProcessesNum = 2)
}
```

Listing 1: An example SPARQL query generated in the background for the user scenario defined in the UI.

VI. Conclusions & Further work

In this paper, we presented a workflow for annotation, storage and querying of PBMs and demonstrated its usability in the domain of aquatic ecosystems. The novelty of the presented work is that we are the first to propose an ontology-based framework for annotation, storage and querying of models of dynamic systems, expressed in the PBM formalism, with the use of state-of-the-art semantic technologies.

To semantically annotate PBMs and generate metadata, we used terms about the PBM paradigm from the OntoPBM ontology organized in an ontology-based annotation schema. Next, to capture the domain-specific characteristics, we extended OntoPBM with terms specific for aquatic ecosystems based on the library of domain knowledge. Furthermore, we stored the annotations of each PBM in an RDF triple store and this enabled us to execute SPARQL queries on both asserted and inferred knowledge. Finally, with the proposed workflow, we generate and store the minimal information about a PBM model, which is a step closer towards providing FAIR PBMs.

In future work, we plan to extend the annotation schema to cover datasets and PBM experimets, as well as different domain knowledge libraries. Finally, given the generality of our approach, we plan to use and adapt the proposed annotation schema on other representations of dynamic system models.

Acknowledgements

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A parallel heuristic for a k-medoids clustering problem with unfixed number of clusters

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***Abstract*—The k-medoids clustering model is a well-known NP-hard optimization problem which a number of widely-used clustering algorithms are based on. In the original k-medoids problem, the number of clusters k is an input parameter that must be defined before actual clustering. We address a modification of the k-medoids problem where the number of clusters is not pre-specified. Instead, it is a decision variable bounded by a monotonically increasing nonlinear function of k added to the k-medoids objective function. We propose an effective hybrid heuristic algorithm for the modified k-medoids problem and its shared memory parallel implementation. Our approach is rested upon the approximation of dissimilarity matrix via nearest neighbors, dual search, and a sophisticated variable fixing technique. The main advantage of our algorithm is that it provides a dual bound for the objective value, thus allowing one to ascertain the optimality of a solution found. We present computational results on large-scale problem instances with millions of decision variables.**

***Index Terms*—k-medoids clustering, parallel computing, k-median problem, Lagrangian relaxation, simulated annealing, exemplar-based clustering**

I. Introduction

Clustering is one of the most important and extensively studied task in unsupervised machine learning, which enjoys plenty of diverse applications. The most prominent clustering algorithms are based on grouping data items into clusters by optimizing some objective function (partition-based clustering), e.g. minimum-sum-of-squares (k-means) or k-center. One of the most best known clustering objective (after k-means) is k-medoids (or k-median) clustering. Given a set $I = \{1, \ldots, m\}$ of data items that we intend to partition into disjoint groups of similar objects. Let $d(i, j)$ be a measure of dissimilarity between data items i and j, e.g. a distance metric on I. The k-medoids objective is to find k data items (medoids) from I such that the total sum of dissimilarities between data items and their closest medoids is minimized. Note that medoids are often called exemplars or cluster representatives. The graph and geometric versions of the k-medoids problem are known to be NP-hard in the strong sense [1], [2].

Most common clustering algorithms based on k-medoids problem are PAM, CLARA, k-medoids, and CLARANS. They are extensively used in a wide range of applications varying from bioinformatics to computer vision. In particular, the k-medoids model is applied to clustering various types of datasets, e.g. psychological data [3] or human tumor cell lines [4]. It is known that near-optimal k-medoids solutions usually provide better clusterings than k-means and k-means++, especially for Gaussian mixture data [5]. An important advantage of k-medoids clustering algorithms over other metric distance-based clustering approaches, like k-means, is that they can be used with arbitrary dissimilarity measures. For example, dissimilarities may be defined by semimetrics. However, k-medoids clustering algorithms are notorious to have very high time and space complexity that prevents them from applying to large-scale datasets. Moreover, most of k-medoids algorithms are heuristics which, in general, find only local optimal solutions and do not guarantee that the found solution is close to global optimum.

The k-medoids problem has also been studied extensively in operations research, mathematical programming, and approximation algorithms communities. Comprehensive reviews on various solution approaches to the problem can be found in [6]–[9]. Nowadays, the k-medoids problem instances with several thousand data items can be solved exactly. There are also heuristics and approximation algorithms that can find provably near-optimal k-medoids clusterings of large-scale datasets. For example, the most effective exact methods are a branch-and-cut-and-price algorithm [10], [11] and a row-and-column generation method [12]. The best approximation algorithms include a local search heuristic admitting multiple swaps (with factor $3 + \varepsilon$) [13] and a dependent-rounding algorithm with approximation ratio of $2.675 + \varepsilon$ [14]. Among the most effective heuristics that can also ascertain the optimality of a found solution, one can mention a primal-dual variable neighborhood search [15] and a Lagrangian heuristic combined with a data aggregation approach [16]. They are able to find provable near-optimal k-medoids clusterings of datasets containing about $100,000$ data items. Note that there are also several parallel metaheuristics exploiting basic parallelization strategies, e.g. a parallel variable neighborhood search [17], [18] and a parallel scatter search [19]. The relaxation-based parallel algorithms include a Lagrangian heuristic for the closely related discrete ordered median problem, a distributed algorithm for finding dual bounds for the objective of large-scale k-medoids problem instances [20], and an effective parallel Lagrangian heuristic [21].

We consider the k-medoids problem on simple directed graph $G(I, A)$, where $A = \{(i, j) : i, j \in I;\ i \neq j\}$. We suppose that data items correspond to nodes from I. The measure of dissimilarity between data items i and j is defined as the weight d_{ij}, $(i, j) \in A$. We introduce the binary variables y_i which are 1 if data item $i \in I$ is a medoid, 0 otherwise;

and the variables x_{ij} which take 1 if data item j is assigned to medoid i, i.e. i is the most similar medoid to data item j. We also introduce two sets of nodes $\delta^-(j) = \{i \in I|\ (i,j) \in A\}$ and $\delta^+(i) = \{j \in I|\ (i,j) \in A\}$.

For the k-medoids clustering algorithms (as well as k-means and its variations), the number of clusters k is a pre-specified input parameter that has to be set appropriately before actual clustering. Affinity propagation is one of the most commonly used k-medoids clustering algorithms based on the idea of "passing messages" between data items. It does not require the number of clusters as an input parameter. Instead, the number of clusters is controlled by a set of equal weights assigned to each data item. The larger the weights are, the more clusters are produced. Usually, weights varies between the smallest and largest possible similarities between data items. Nevertheless, the algorithm is still heuristic that finds only local optimal solutions.

In this paper, we consider another approach to parametrize the number of clusters in the k-medoids clustering model. Suppose that, instead of being parameter, the number of clusters is a decision variable, whose value has to be determined. To bound it above, we introduce a penalty nondecreasing nonlinear function $\psi(k)$ added to the objective function of the k-medoids problem. Thus, we have the following integer program:

$$\min_{(x,y,k)} \sum_{(i,j)\in A} d_{ij}x_{ij} + \psi(k), \tag{1}$$

$$\sum_{i\in\delta^-(j)} x_{ij} + y_j = 1, \qquad j \in I, \tag{2}$$

$$x_{ij} \leqslant y_i, \qquad i \in I, j \in \delta^+(i), \tag{3}$$

$$\sum_{i\in I} y_i = k, \tag{4}$$

$$y_i,\ x_{ij} \in \{0,1\}, \qquad i \in I,\ (i,j) \in A, \tag{5}$$

$$k \in \{1,\dots,m\}. \tag{6}$$

The objective function (1) is to minimize the overall sum of dissimilarities between data items and their closest medoids. The constraints (2) ensure that either a data item j is a medoid or it is assigned to a medoid. The constraints (3) impose that each data item can only be assigned to medoids. The constraint (4) enforces that the number of medoids must be equal to k that varies from 1 to $m = |I|$.

Note that the presented problem is a network counterpart of the problem first proposed in [22] and motivated by modeling economies of scale applied to facility location costs. The authors developed a solution algorithm called DATALOC based on the decomposition of the problem into series of uncapacitated facility location problems. This approach was then improved for general penalty functions $\psi(k)$ (not necessary convex) in [23]. Finally, the discrete version of the general problem (1)–(6) was studied in [24], [25] and a fast relaxation-based heuristic was developed.

In this paper, for the modified k-medoids clustering problem, we develop a parallel shared-memory and improved version of the algorithm proposed in [25]. It is based on a Lagrangian relaxation and includes a fast subgradient algorithm to find high quality dual bounds for the objective value. Near-optimal solutions of the modified k-medoids problem are then determined by a core selection approach combined with a fast simulated annealing. High memory usage is the main bottleneck of most k-medoids clustering algorithms, including affinity propagation. A reason is that the algorithms must keep pairwise dissimilarities, whose number is the square of the number of data items. In our approach, we employ an approximation strategy for the dissimilarity matrix, using nearest neighbors. We test our algorithm on a number of large-scale problem instances and demonstrate that it is capable of finding provable near-optimal solutions (clusterings).

II. Sequential Lagrangian Heuristic

Here, we briefly describe the Lagrangian relaxation-based heuristic for finding near-optimal solutions of the modified k-medoids problem and our modifications to improve its efficiency and usability.

We consider one of the common Lagrangian relaxations of the original k-medoids problem obtained by relaxing constraints (2). They are added to the objective function together with Lagrange multipliers $\lambda \in \mathbb{R}^m$:

$$\mathcal{L}(\lambda) = \min_{(x,y,k)} \Bigg\{ \sum_{(i,j)\in A} d_{ij}x_{ij} - \sum_{j\in I} \lambda_j \Bigg(\sum_{i\in\delta^-(j)} x_{ij} + y_j - 1 \Bigg) + \psi(k) :\ \text{subject to (3)-(6)} \Bigg\},$$

The value of Lagrangian dual function $\mathcal{L}(\lambda)\ \forall\lambda \in \mathbb{R}^m$ is a lower (dual) bound for the objective value of (1)–(6). Rearranging terms, the last formula can be rewritten as

$$\mathcal{L}(\lambda) = \min_{(y,k)} \Big\{ \min_{x} \Big\{ \sum_{i\in I} \sum_{j\in\delta^+(i)} (d_{ij} - \lambda_j)x_{ij} :\ 0 \le x_{ij} \le y_i \Big\} - \sum_{i\in I} \lambda_i y_i + \psi(k) :\ \sum_{i\in I} y_i = p \Big\} + \sum_{j\in I} \lambda_j.$$

Let us introduce the reduced costs $\rho_i(\lambda)$ and $\mu_{ij}(\lambda)$ for variables y_i and x_{ij} as $\rho_i(\lambda) = \sum_{j\in\delta^+(i)} \min(0, d_{ij} - \lambda_j) - \lambda_i$ and $\mu_{ij}(\lambda) = d_{ij} - \lambda_j$, respectively. Moreover, suppose that there is permutation $(i_1 \dots, i_m)$ such that $\rho_{i_1}(\lambda) \le \dots \le \rho_{i_m}(\lambda)$. Thus, the value of $\mathcal{L}(\lambda)$ can be computed explicitly as

$$\mathcal{L}(\lambda) = \min_{k\in\{1,\dots,m\}} \Big\{ \sum_{l=1}^{k} \rho_{i_l}(\lambda) + \psi(k) \Big\} + \sum_{j\in I} \lambda_j. \tag{7}$$

At the same time, the values of variables $y_i(\lambda)$, $x_{ij}(\lambda)$, and $k(\lambda)$ for any fixed $\lambda \in \mathbb{R}^m$ can be calculated as

$$k(\lambda) \in \operatorname*{Argmin}_{q\in\{1,\dots,m\}} \Big\{ \sum_{l=1}^{q} \rho_{i_l}(\lambda) + \psi(q) \Big\},$$

$$y_i(\lambda) = \begin{cases} 1, & i \in \{i_1, \dots, i_{k(\lambda)}\}; \\ 0, & \text{otherwise.} \end{cases}$$

$$x_{ij}(\lambda) = \begin{cases} 1, & y_i(\lambda) = 1 \text{ and } \mu_{ij} < 0; \\ 0, & \text{otherwise.} \end{cases}$$

In order to find the best dual bound, we have to solve the Lagrangian dual problem $\max_{\lambda \in \mathbb{R}^m} \mathcal{L}(\lambda)$. It is a convex nonsmooth optimization problem that can be solved with any suitable nondifferentiable optimization algorithm. For our approach, we employ a fast subgradient algorithm with a heuristic step-size rule, popular in facility location applications [26]:

$$\lambda^{s+1} = \lambda^s + \alpha_s g(\lambda^s),$$

where $g(\lambda^s)$ is a subgradient of $\mathcal{L}(\cdot)$ at point λ^s:

$$g_j(\lambda^s) = 1 - \sum_{i \in \delta^-(j)} x_{ij}(\lambda^s) - y_j(\lambda^s),\ j \in I.$$

The step-size α_s is computed as:

$$\alpha_s = \frac{\beta_s(UB - \mathcal{L}(\lambda^s))}{\|g(\lambda^s)\|_2^2},$$

where β_s is a diminishing parameter, UB is an upper (primal) bound for the objective value of the modified k-medoids problem, and $\|\cdot\|_2$ is the Euclidean norm. An upper bound can be found by assigning each data item to one of $k(\lambda^s)$ closest medoids, i.e. to data items $i \in I$ such that the corresponding variable $y_i(\lambda) = 1$, $i \in \{i_1, \ldots, i_{k(\lambda)}\}$.

To speed up the subgradient algorithm, we leverage the delayed column generation technique from [25]. Its main idea is based on the observation that the values of the Lagrangian dual function, reduced costs, and subgradients can be computed much more efficiently if dissimilarities between each data item and the whole dataset are sorted in ascending order, i.e. if the dissimilarity matrix is column-wise sorted. In this case, at each iteration s, we need to traverse each column only until $d_{ij} - \lambda_j^s \geq 0$. It may considerably reduce the run time of the subgradient algorithm.

As was noted above, the main bottleneck of most commonly used k-medoids clustering algorithms is their high space complexity, since they have to store the whole dissimilarity matrix in RAM during clustering procedure. For example, pairwise dissimilarities between 100 thousand data items require 80 Gb of RAM. Here, we employ a strategy aimed at avoiding keeping the whole dissimilarity matrix. For each data item, we find the fixed number $t \ll m$ of nearest neighbors. Instead of the whole matrix, we then retain only dissimilarities between data items and their t nearest neighbors. Some common and basic approaches to finding nearest neighbors are max-heap and min-heap partial sorts that require $O(m \log t)$ and $O(m + t \log m)$ time.

When the subgradient algorithm terminates, it returns Lagrange multipliers $\bar{\lambda}$, the number of clusters $\bar{k} = k(\bar{\lambda})$, and the corresponding value of the Lagrangian dual function (a dual bound for the objective value). Note that $\bar{k}$ gives us a good "guess" of the optimal number of clusters. To produce a feasible primal solution, one usually applies some heuristics to improve the solution obtained by assigning data items to the closest medoids i: $y_i(\bar{\lambda}) = 1$. Instead, we adapt a so-called core selection technique first proposed for the k-medoids problem in [27] and successfully applied to several modifications of the problem (e.g. see [28]). The core selection is a variable fixing technique that reduces the original problem to the so-called core problem by fixing some decision variables to zero. The variables are fixed to zero with respect to their reduced costs computed for the returned Lagrange multipliers $\bar{\lambda} \in \mathbb{R}^m$. We set thresholds Δ and γ for reduced costs $\rho_i(\bar{\lambda})$ and $\mu_{ij}(\bar{\lambda})$, respectively. Thus, all the variables y_i and x_{ij} with reduced costs larger than the thresholds are fixed to zero, i.e.

$$i \in I(\bar{\lambda}, \Delta) \triangleq \{i \in I :\ \rho_i(\bar{\lambda}) > \Delta\},$$
$$(i,j) \in W(\bar{\lambda}, \gamma) \triangleq \{(i,j) :\ i \in I(\bar{\lambda}, \Delta), \mu_{ij}(\bar{\lambda}) > \gamma\}.$$

The remained variables are called core variables. Obviously, any solution feasible in the core problem is also feasible in the modified k-medoids problem, and the value of this solution is an upper (primal) bound of the objective value. The proper choice of threshold values can considerably decrease the size of the core problem. In order to solve the core problem, one usually applies commercial solvers or exact methods [16], [29]. However, since the number of clusters is not fixed and $\bar{k}$ may be big, the core problem may become too large and intractable, e.g. due to necessity to cover feasibility. This is especially the case for large-scale datasets. In contrast to [25], we use a fast simulated annealing heuristic to find good solutions of the core problem. Denote $S \subseteq I(\bar{\lambda}, \Delta)$, $|S| = \bar{k}$, a feasible solution of the core problem. In order to implement a simulated annealing, we can actually use two basic types of neighborhoods: the first one is the so-called FLIP neighborhood $Q(S) = \{T \subseteq I(\bar{\lambda}, \Delta) :\ T = S \cup \{j\}, j \notin S\} \cup \{T \subseteq I(\bar{\lambda}, \Delta) :\ T = S \setminus \{j\}, j \in S\}$, and the second one is the SWAP neighborhood $Q(S) = \{T \subseteq I(\bar{\lambda}, \nu) : T = S \cup \{i\} \setminus \{j\},\ i \notin S, j \in S\}$. The latter is often used in the case of the k-medoids problem. For our approach, we actually tried both variants and implemented a simulated annealing over the SWAP neighborhood.

III. Parallel Implementation

In this section, we describe how the described algorithm can be parallelized. We employ data parallelism paradigm and implement our algorithm using OpenMP.

The main idea is that each parallel thread deals with only m/p data items, where p is the total number of threads. First, we have to calculate dissimilarities between each data item and their t nearest neighbors. This can be easily parallelized such that each thread processes only m/p data items. The subgradient algorithm is parallelized so that each thread deals with a subset of Lagrange multipliers, subgradient components, and reduced costs. For example, the objective value is computed by distributing non-overlapping chunks of data items among threads which concurrently assign each data item to the closest medoid.

The main bottleneck of the parallel implementation is the necessity to compute the reduced costs $\rho_i(\lambda^s)$ needed to calculate a dual bound $\mathcal{L}(\lambda^s)$. Recall that we keep in RAM only the

dissimilarities for nearest neighbors (in ascending order) and employ a delayed column generation. Thus, to avoid a data race condition, threads must keep their own private vectors of reduced costs (of length m). The final vector of reduced costs is then obtained by summing all private vectors. This operation actually creates a computation overhead of $O(m)$ per one iteration and reduces parallel efficiency. Furthermore, to compute the value of $\mathcal{L}(\lambda^s)$, we need to find $k(\lambda^s)$ by assessing multiple partial sums of smallest reduced costs and $\psi(k)$. This operation requires $O(m)$ time in the worst case and cannot be parallelized. However, it is performed much faster in practice.

Subgradients and new values of Lagrange multipliers are concurrently computed in the same way as the objective value, i.e. each thread calculates only m/p of their components.

We employ a simple low-level parallelization strategy to implement our simulated annealing. The most time consuming part of the algorithm is to compute the objective value of the core problem. Thus, we parallelize only this part (the same way as for the modified k-medoids objective) and leave checking acceptance criteria and choosing neighbor solutions to be serial.

IV. Computational Experiments

In this section, we test the developed parallel algorithm on several well-known large-scale problem instances. We implemented our algorithm using C++ programming language. The experiments are performed on the HPC-cluster "Academician V. M. Matrosov" [30] (Segment I). It consists of 60 nodes of dual 16-core AMD Opteron 6276 Bulldozer/Interlagos 2.3 GHz and 64 Gb of DDR3-1600 memory. The computing nodes are connected via QDR Infiniband network. A computing node consists of two processors, hence we run our parallel algorithm using one processor with 16 cores. As test instances, we use the following large-scale clustering problems from the TSPLIB library (World TSP): $vm22775.tsp$, $sw24978.tsp$, and $bm33708.tsp$, which consist of coordinates of 22775, 24978, 33708 cities located in Vietnam, Sweden, and Burma, respectively.

We run the subgradient algorithm using the same values of parameters (step-size and β_s) as in [25]. For the core selection approach, we set the threshold values Δ and γ such that the numbers of variables y_i and x_{ij} included to the core problem are equal to $|I(\bar{\lambda}, \Delta)| = 3k$ and $|W(\bar{\lambda}, \gamma)| = 5m$, respectively. One can see that the obtained core problem is much smaller in comparison with the original modified k-medoids problem, e.g. it contains only $5m$ variables rather than m^2. For all the problem instances, we set the number of nearest neighbors t to be equal to 5000. For the simulated annealing, we set the initial temperature of 0.05 and the final one of 0.001. The number of local search iterations and the number of temperature reductions are set to 500 and 200, respectively. Though our algorithm does not require the dissimilarities to be defined by distance-metric, we use the Euclidean distance. We tested two types of convex penalty function $\psi(k)$ bounded the number of clusters, namely k^2 and $\frac{1}{500k}e^k$. Note that we add multiplier $1/500k$ to prevent fast growing of the exponential function.

The best results obtained over 10 independent runs are reported in Table I, where the column *Dual bound* contains the found dual bound for the objective value of the modified k-medoids problem, the column $Obj.$ demonstrates the value of a clustering solution found, GAP — the relative difference between dual and upper bounds in percent, and k — the number of clusters found.

TABLE I
Computational results on $vm22775.tsp$, $sw24978.tsp$, $bm33708.tsp$ problem instances

Prob.	Dual bound	Obj.	Gap(%)	k
p^2				
$vm22775$	1906067.29	1918369.32	0.641	643
$sw24978$	2750726.14	2764878.08	0.512	785
$bm33708$	3474710.76	3508426.11	0.961	864
$\frac{1}{500k}e^k$				
$vm22775$	1413384.85	1423902.98	0.739	709
$sw24978$	2263766.35	2278528.77	0.648	709
$bm33708$	3042895.68	3077315.67	1.119	709

One can observe that our approach managed to find near-optimal clustering solutions for all problem instances. Indeed, the values of the found clusterings are at most one percent greater than the corresponding dual bounds. We see that the value of Gap is correlated with the problem size, e.g. it is the largest one for the $bm33708$ problem. It seems that the relative difference of 1.119 obtained for $bm33708$ is mostly due to large integrality gap in this problem instance. We see that, when $\psi(k) = k^2$ is used, the number of found clusters increases together with the problem size. Interestingly that for $\frac{1}{500k}e^k$, our approach returned the same number of clusters which is equal to 709. Use of $\psi(k) = k^2$ in general results in clusterings having smaller Gap.

In Table II, we report the run time of our parallel algorithm, depending on the number of OpenMP threads, and the corresponding speedup ratio. The latter is computed as T_0/T_p, where T_0 and T_p are the run times of sequential and parallel algorithms using p threads. Note that our computer cluster is loaded, hence there may be some perturbations in computing time from run to run due to memory latency. One can observe that speedup ratio is heavily dependent on the problem size, thus our algorithm achieves a better speedup for larger datasets. This behavior is expected, since the amount of computation performed concurrently increases, while the memory latency is reduced. We see that nearly linear speedup is achieved when the number of threads is 2. Even when 4 threads are employed, the parallel algorithm achieves a good speedup, e.g. it is 3.62 for the $bm33708$ problem with $\psi(k) = k^2$. In general, the algorithm demonstrates better scalability for $\psi(k) = k^2$.

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TABLE II
COMPUTATIONAL RESULTS ON $vm22775.tsp$, $sw24978.tsp$, $bm33708.tsp$ PROBLEM INSTANCES

Prob.	Time(sec.)					Speedup ratio			
	1	2	4	8	16	2	4	8	16
				p^2					
$vm22775$	250.07	136.24	84.09	54.1	41.02	1.84	2.97	4.62	6.10
$sw24978$	336.75	182.58	109.48	68.05	48.43	1.84	3.08	4.95	6.95
$bm33708$	706.42	373.77	195.25	118.52	100.68	1.89	3.62	5.96	7.02
				$\frac{1}{500k}e^k$					
$vm22775$	246.69	140.92	84.01	66.85	49.99	1.75	2.94	3.69	4.93
$sw24978$	300.96	166.91	98.39	61.8	45.41	1.80	3.06	4.87	6.63
$bm33708$	676.16	369.95	214.77	135.27	96.75	1.83	3.15	5.00	6.99

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Computational Study of Time Constrained Influence Maximization Problem under Deterministic Linear Threshold Model for Networks with Nonuniform Thresholds

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***Abstract*—The Influence Maximization Problem (IMP) consists in choosing a set of vertices in a network that maximizes the spread of influence under a specific influence model. It is one of the relevant problems in network science. In the present paper we consider the time- constrained variant of this problem under the deterministic Linear Threshold (LT) model. Because of the deterministic nature of the influence model and additional time constraints the usually employed algorithms for solving IMP under nondeterministic LT model can not guarantee the quality of obtained solution. Thus we propose and study the algorithms for the problem in the considered formulation and compare their performance with the competition.**

I. Introduction

The rapid development of technology in recent decades transformed the world. The accessibility of Internet, and in particular of online social networking platforms is currently on a level when almost everyone can use them. The corresponding internet communications leave electronic traces that can be studied and analyzed, giving an insight at the processes behind them. In particular, it is very interesting how people form networks and how information moves through them. This is a very popular area of research in the so-called network science. The better understanding of the information dissemination processes makes it possible to construct better marketing campaigns, better emergency notification and communication protocols, etc.

One of the popular problems in network science is the so-called *Influence Maximization Problem* (IMP). It implies that there is a network of agents, each agent connected with some of its neighbors. In the context of IMP there must be defined a model which describes how the *influence* spreads from agent to agent. For example, it is easy to imagine such process as the process of how an infectious disease spreads over a population. A transmitter of a disease is an *active* agent, which inadvertently attempts to spread its *influence* (here – disease) to agents it communicates with. Each agent depending on a number of factors can either live through an interaction with an ill person without any consequences or become infected too. The ever-trending topic of vaccination and herd immunity perfectly fits into such models [1]. In its classical formulation [2] the goal of IMP is to find such a *seed set* – a set of agents which are made active at the initial time moment, that the influence spread is maximized (among other possible seed sets).

In literature, the two major information dissemination models studied in the context of IMP are the Linear Threshold model and the Information Cascade model [3]. Both models are stochastic in nature. The former (LT model) implies that each agent has a threshold, and the *active* agents from its neighborhood lower this threshold proportionately to the weight of corresponding edges between agents. Once the threshold is below 0 – an agents becomes active. However, the standard assumption is that it is impossible to accurately evaluate the individual thresholds, thus the Monte-Carlo simulation is used over a random sample of different thresholds for each agent. The IC model uses a stochastic experiment: once an agent becomes active it can activate its neighbors with certain probabilities.

In the present paper we study the variant of LT model called the *Deterministic Linear Threshold model*. It differs from the usual formulation in that it is not randomized: the thresholds are assumed to be fixed and known. While it might seem that it makes the IMP for this model easier to solve, it is not exactly so. In particular, in [4] it was shown that while for IMP under Linear Threshold model there exists a greedy algorithm with guaranteed approximation quality, there can be no such algorithms for the deterministic LT model unless $P = NP$. Moreover, we study the time-constrained variant of IMP: for a given network and given model to find a seed set that will transform the required portion of network agents after specified amount of discrete time moments. In our opinion, the time constrained variant makes more sense in a majority of practical situations, e.g. if we need to market a new product for which the quality decays over time, such as a flagship mobile phone or some exquisite foods, etc. In the paper we present a greedy algorithm designed for this problem and compare it with competition.

Let us present a brief outline of the paper. In the following section we present the formal definition of the Influence Maximization Problem, its time-constrained variant, Deterministic Linear Threshold model and other notions. We also provide

the necessary background and discuss related research. In the third section we propose a greedy algorithm for solving the considered problem and compare it with other greedy algorithms for solving IMP under deterministic LT model. In the last two sections we present and discuss the results of computational experiments, draw conclusions and outline the potential directions for future work.

II. Background and Notation

The roots of the Influence Maximization Problem (IMP) lie in the research of social contagion, in particular, the works by M. Granovetter and T. Schelling [5], [6] and other scientists. The simple variant of the Linear Threshold Model was first proposed in [5], together with the study of its dynamics. In its present formulation IMP was proposed and studied in papers [2], [7]. In particular, [2] considered both IC and LT model, proposed a greedy algorithm from the area of submodular optimization to solve IMP for these models and proved that the proposed algorithm gives $1 - \frac{1}{\epsilon}$ approximation guarantee, i.e. that the constructed solutions are at least $1 - \frac{1}{\epsilon}$ as good as the optimal ones. Note, that in the case of LT model this was possible due to the fact that it uses the Monte-Carlo simulation to deal with unknown agents' thresholds.

The interest to deterministic variant of Linear Threshold Model was fueled by its non-stochastic nature and its broad applicability to real-world phenomena, such as modeling the conforming behavior. Also there is a strong evidence pointing towards the fact that the thresholds can be determined via the data mining techniques [7]. In paper [4] it was shown that the NP-complete *set cover* problem can be effectively reduced to IMP under deterministic LT model. In practice it means that under currently standard assumptions there can be no polynomial algorithms for its solving. Thus in a number of papers there have been proposed several approaches to solving IMP and its variants, mainly using greedy heuristics of different kinds [8], [9], [10].

The consideration of time-critical or time-constrained variants of IMP is an evolutionary step in the study of the information dissemination phenomena. For networks with standard Linear Threshold model the corresponding problems were considered for example in [11], [12], [13]. To the best of our knowledge the first attempts to study it in the context of deterministic LT model were made in [14], [15], however, these papers considered the reduced variant of the model.

Now let us give a formal definition of the Deterministic Linear Threshold model and the Time-constrained variant of Influence Maximization problem that will be studied in the remainder of the paper.

A. Deterministic Linear Threshold Model

Assume that a network of agents is given by a directed graph $G = (V, E)$ without loops and multiple arcs. Here $V = \{v_1, \ldots, v_N\}$, $|V| = N$ is the set of vertices which interpret agents. The set E interprets the connections between agents: $(v_i, v_j) \in E$ meaning that there is an arc in G between v_i and v_j. By a *neighborhood* of a vertex v_i we mean the set of adjacent vertices from which the arcs go into v_i:

$$N(v_i) = \{v_j : (v_j, v_i) \in E\}$$

With each vertex v_i there is associated a value $\theta_i \in [0, 1]$, referred to as *threshold*. Similarly, with each network arc (v_j, v_k) there is associated its weight $w_{j,k}$. The weights must satisfy the condition that $\sum_{v_j \in N(v_i)} w_{j,i} \leq 1$, i.e. the sum of weight of arcs leading to a single vertex should not exceed 1.

The system evolves in discrete time moments $t = 0, \ldots$. At each time moment with each vertex v_i there is associated a binary weight $a_i(t) \in \{0, 1\}$ that can change with discrete time $t = 0, \ldots$. If $a_i(t) = 1$ then we say that v_i is active at time moment t, otherwise it is inactive. Once the vertex became active it can not become inactive again. The weight of vertices for the next time step is computed synchronously and simultaneously according to the following formula:

$$a_i(t+1) = \begin{cases} 1, & \sum_{v_j \in N(v_i)} a_j(t) \times w_{j,i} \geq \theta_i, \\ a_i(t), & \text{otherwise.} \end{cases} \quad (1)$$

The corresponding process defines the diffusion of information from the set of agents active at the initial time moment ($t = 0$) to other agents.

B. Time-constrained Influence Maximization Problem

Assuming that we denote the seed set as S, and the influence spread resulting from making agents from S active at $t = 0$ as $f(S)$, the classical formulation of the Influence Maximization Problem is:

For a given $k > 0$ to find a seed set S^*, $S^* \subseteq V$ of size $|S^*| = k$, such that it provides

$$S = \underset{S \subseteq V, |S| = k}{\arg\max} f(S).$$

Naturally, to compute $f(S)$ one has to evaluate the information dissemination process until (1) does not change the state of the network. And while it is easy to show that it might take at most $N - |S|$ time steps [14], in practical setting it is not always feasible to wait for too long. Realistically, e.g. in marketing campaign one often needs to provide as large a coverage of a new product as possible up to some time limit (such as the date when it becomes available for purchase). Thus, besides the time constraint we propose to consider an additional constraint on the amount of activated vertices.

Let us denote the influence spread of a seed set S at time moment $t = H$ as $f^H(S)$. Then the *Time-constrained Influence Maximization Problem* consists in the following:

Given the amount of time T and the desired resulting coverage $\alpha \in (0, 1]$ to find a seed set S^* of minimal size such that $f^T(S^*) \geq \alpha \times |V|$:

$$S^* = \underset{S \subseteq V : f^T(S) \geq \alpha \times |V|}{\arg\min} |S|. \quad (2)$$

The outlined problem can be viewed as a combinatorial optimization problem: for fixed $G = (V, E)$, weights $\{u_{i,j}\}, (v_i, v_j) \in E$, thresholds $\{\theta_i\}$, $v_i \in V$, time limit T

and coverage α we essentially need to traverse all sets that satisfy the constraint from (2) and find the one of minimal size. In the next section we consider possible algorithms for solving this problem and propose the new one.

III. The Greedy Algorithm for Solving Time-Constrained IMP

Obviously, as with the general variant of IMP, it is possible to choose vertices for inclusion into the seed set judging by the value of a corresponding graph characteristic, such as *degree centrality* or *betweenness centrality* [16]. However, this approach does not use all available problem-specific information. Also, one can apply to solving (2) any of the variety of methods that are typically employed in combinatorial optimization, such as local search methods, various evolutionary algorithms, including genetic algorithms, and also metaheuristics such as simulated annealing, etc. However, all these methods typically do not take into account the specificity of the problem at hand unlike specially-tailored greedy algorithms. What's more important, it is often possible to significantly improve the performance of a heuristic method by incorporating a specialized greedy algorithm into it.

In the existing literature the algorithms that fit the desired problem best are the ones described in [8], [15]. However, the algorithm from [8] does not take into account the time limit T as it is designed for solving IMP under the deterministic Linear Threshold model, and the algorithms from [15] deal with the slightly different diffusion model and also assume that all arcs weigh the same (e.g. $= 1$).

The algorithm proposed below shares the common feature with that described in [8], [15]: they all make use of what is referred to as *residual* in [8]. The idea is that it is possible to measure the potential gain achieved by adding a vertex v_i into a seed set by considering how it will influence the vertices to which it is connected with outgoing arcs. In particular, the *residual* measures how v_i becoming active reduces the threshold of adjacent vertices.

We propose the greedy algorithm that takes into account the importance of time limit by adding a decay. It uses the digital characteristics to which we refer as *gain* to measure the extent to which adding a specific vertex to the seed set will improve the influence spread. The pseudocode of the algorithm for computing gain is presented at Algorithm 1

Algorithm 1: Algorithm for computing potential gain.

for $t \leftarrow 1$ **to** T **do**
  for $i \leftarrow 1$ **to** N **do**
    if $a_i(t) = 0$ *and* $\theta_i > \sum_{(v_u,v_i)\in E} a_u(t) \times w_{u,i}$ **then**
      for $h : (v_h, v_i) \in E$*:*
        $\theta_h > \sum_{(v_g,v_h)\in E} a_g(t) \times w_{g,h}$ **do**
          $gain_h = gain_h + \frac{T-t+1}{\theta_i - \sum_{(v_u,v_i)\in E} a_u(t)\times w_{u,i}} \times (\theta_h - \sum_{(v_g,v_h)\in E} a_g(t) \times w_{g,h}) \times w_{h,i}$

It is easy to see that Algorithm 1 uses progressive decay: the gain of the vertex is discounted more as the time frame when the gain is measured moves towards T (by means of the $T-t+1$ factor. The denominator $\theta_i - \sum_{(v_u,v_i)\in E} a_u(t) \times w_{u,i}$ shows how much more weight should the active agents bring to v_i to make it active. The larger this value - the less is the potential gain. The factor $\theta_h - \sum_{(v_g,v_h)\in E} a_g(t) \times w_{g,h}$ shows how close v_h is to becoming active and finally the factor $w_{h,i}$ represents how much v_h becoming active will influence v_i. Starting from an empty seed set, the gains are computed and the node with the highest gain is put into the seed set. It continues until the influence spread satisfies the predisposed conditions, e.g. until at least 80 % of vertices are active as the result of influence spreading. The algorithm needs to reevaluate *gain* every time a new node is added to the seed set. However, in order to increase its performance by somewhat sacrificing the seed set size, one can add to a seed set not one vertex but top k vertices with the highest value of *gain.*

We additionally augmented the algorithm with a simple *pruning* heuristic. It employs the basic concept of steepest decline hill climbing local search algorithm. Informally, it attempts to throw away each member of seed set and tests if the influence spread falls below the needed coverage. Assuming that the function computing influence spread of a set S after T time moments is denoted by $f^T(S)$, the pseudocode of the pruning procedure is shown as Algorithm 2.

Algorithm 2: Pruning algorithm.

Data: S,T,α,N
$keep_going = True$
while $keep_going$ **do**
  $state_changed = False$
  for $v_t \in S$ **do**
    $S' = S \backslash \{v_t\}$
    if $f^T(S') \geq \alpha \times N$ **then**
      $S = S'$
      $state_changed = True$
  if $state_changed == False$ **then**
    $keep_going = False$

IV. Computational Experiments

The algorithm proposed in the previous section was implemented in C++. To compare its performance we also implemented the TDG algorithm from [8]. As a computing platform we used one core of Intel 6770 Processor with 16 Gb RAM available.

The experimental evaluation was implemented as follows: as test networks we used three fragments of online social networks from the network repository [17]. In particular, the instances employed below are: `soc-hamsterster` [18], `socfb-Haverford76`, `socfb-Swarthmore42` [19]. The data on the considered networks can be found in Table I

We generated vertices thresholds as uniformly chosen from $[0.1, 1]$. As for the weights of arcs we tested two variants. In the first one the weights of arcs were randomly chosen in accordance with the uniform distribution. In the second, we

Network	N	$\|E\|$	$0.8 \times N$
socfb-Haverford76	1446	59589	1156
socfb-Swarthmore42	1659	61050	1327
soc-hamsterster	2426	16630	1940

TABLE I
DATA ON STUDIED NETWORKS

assumed that all arcs going into a specific vertex v_i have equal weights $= \frac{1}{|N(v_i)|}$, i.e. that all agents influence others equally.

The problem to be solved was to find the seed set for the Time-Constrained IMP with parameter T ranging from 10 to 150 with increments of 20, while parameter α was fixed to 0.8. The results of experiments are shown in Tables II and III. The GRD and GRD′ stand for the proposed greedy algorithm and its variant with pruning, while labels TDG and TDG′ identify the algorithm from [8] and its version with pruning.

T	10	30	50	70	90	110	130	150
socfb-Haverford76								
GRD	260	242	230	233	225	223	221	213
GRD′	244	234	222	223	217	218	215	206
TDG	382	272	260	258	262	252	251	250
TDG′	249	222	219	219	220	214	208	211
socfb-Swarthmore42								
GRD	315	282	250	256	243	252	242	247
GRD′	266	252	235	238	229	233	229	236
TDG	409	316	278	273	268	265	271	266
TDG′	262	243	234	226	221	223	227	220
soc-hamsterster								
GRD	774	656	628	612	605	599	600	590
GRD′	625	592	579	574	571	564	562	557
TDG	822	661	640	635	634	629	628	624
TDG′	602	574	557	559	555	566	560	562

TABLE II
RESULTS OF COMPUTATIONAL EXPERIMENTS FOR DIFFERENT WEIGHTS

T	10	30	50	70	90	110	130	150
socfb-Haverford76								
GRD	72	49	45	44	44	40	43	41
GRD′	71	41	36	37	34	35	34	35
TDG	86	64	64	66	59	57	67	64
TDG′	82	40	40	35	36	37	41	37
socfb-Swarthmore42								
GRD	68	28	25	24	21	21	21	20
GRD′	65	27	24	19	17	17	17	17
TDG	70	35	38	31	33	29	31	27
TDG′	67	29	24	21	20	19	19	18
soc-hamsterster								
GRD	465	313	251	230	213	199	188	176
GRD′	186	131	106	105	105	105	105	106
TDG	222	170	169	160	160	160	160	161
TDG′	173	130	130	129	132	130	131	132

TABLE III
RESULTS OF COMPUTATIONAL EXPERIMENTS FOR EQUIVALENT WEIGHTS

Discussion. From the first glance at the results in Tables II and III what catches the eye is that the case when the weights of all edges going into a single vertex are equivalent is significantly simpler than the case with randomly generated weights. In particular, the difference in seed set size can be an order of magnitude.

Another interesting observation is that the pruning procedure makes a huge impact on the effectiveness of algorithms. In most cases it yields the reduction of the seed set size from 5 to 20%. From our point of view it hints at the good synergy between IMP for deterministic LT model and local search and metaheuristic-based methods (with possible greedy initialization and mutation-like operators).

The performance of the proposed greedy algorithm compared to the TDG algorithm from [8] has two sides. By default, our algorithm finds smaller seed sets than its counterpart. However, the pruning procedure eliminates a larger part of the solutions found by TDG, resulting in (usually) smaller seed sets. On the one hand, the lesser effect from pruning means that the solution is already quite good. On the other, the end result is that TDG often evaluates the innate quality of vertices for inclusion into seed set better (if we carefully polish it by removing irrelevant ones).

It also strikes as counter-intuitive that for the case when the weights of edges are randomly generated, both algorithms do not seem to significantly decrease the amount of vertices in the seed set with the increase of the amount of available time moments. This feature requires additional study, but the current hypothesis is that it can be attributed to the typical structure of social network: they usually have a very dense core and a lot of vertices with small degree. Thus, once the core vertices are activated — the stragglers are pretty hard to involve. The results for the case with equivalent weights show the similar trend but on a different scale since the problem is much less complex in this setting.

The interesting question is: how close to the optimal solutions are the ones found by the proposed greedy algorithm? For IMP under non-deterministic LT model, the greedy algorithm maximizing the marginal gain yields a solution with a specific approximation ratio. For IMP under the deterministic LT model it is unlikely that such a result can be obtained.

From a practical point of view, the effectiveness of the pruning procedure shows that the solutions obtained by greedy algorithms are surely far from optimal. On the other, in [15] it was shown that for the case with equivalent weights of edges, for small networks (with about 80 vertices) the solutions found by similar greedy algorithms were very close to optimal. It was done by reducing the considered variant of IMP to the Boolean satisfiability problem and using the specific algorithms for solving the constructed instances [20], [21]. For the case with randomly generated weights, IMP can be reduced to Integer Programming problem and solved via state-of-the-art specific tools, however, the corresponding reduction is quite nontrivial and is out of the scope of the present paper. Nevertheless, even for the relatively small networks considered above, finding the exact solution is a very laborious task.

V. CONCLUSIONS AND FUTURE WORK

In the present paper we have proposed the greedy algorithm for solving Time-Constrained Influence Maximization Problem under the Deterministic Linear Threshold Model. The algorithm heuristically estimates the potential gain of

an inclusion of each vertex into a seed set. The preliminary experiments show that the algorithm performs quite well, on the level with competition or better.

The combination of studied greedy algorithms with simple local search-based pruning strategy have shown surprisingly good results. Thus in the future we plan to incorporate the developed greedy algorithm into evolutionary and metaheuristic approaches in order to improve its performance and results. Also it is planned to develop a parallel implementation of the algorithm to be able to work with more relevant networks with tens and hundreds of thousands vertices. Another interesting direction of research consists in reducing the time-constrained IMP under the deterministic LT model to integer programming problem and using the tools such as CPLEX [22] or Guroby [23]. They typically solve optimization problems with thousands of variables and it will be interesting to assess their performance on this class of tests.

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Thermal Imaging Dataset for Person Detection

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Abstract – In this paper will be presented an original thermal dataset designed for training machine learning models for person detection. The dataset contains 7412 thermal images of humans captured in various scenarios while walking, running or sneaking. The recordings are captured in the LWIR segment of the electromagnetic (EM) in various weather condition- clear, fog and rain at different distances from the camera, different body positions (upright, hunched) and movement speeds (regular walking, running). In addition to the standard lens of the camera, we used a telephoto lens for video recording, and we compared the image quality at different weather conditions and at different distances in both cases and set parameters that provided the level of detail in the image that can be used to detect the person.

Keywords: Person detection, thermal imaging, surveillance, access control, dataset, biometric

I. Introduction

The security surveillance system is expected to alarm any unauthorized movement (sneaking, running, etc.) in the area of the protected facilities and the state border by day and night and in all weather conditions. The aim of our project is to define a machine learning model for the detection and recognition of people on the thermal images that could be implemented in the surveillance system to assist the protection of people, facilities and areas.

To learn a model, necessary is to choose an adequate learning dataset. A learning dataset to be of high quality and reliability must contain a large number of images where objects are displayed in different ways, on different lighting conditions, recording angles, different distances from the camera, etc. When a dataset satisfies these conditions, it is more likely that a learned model will generalize better for various situations that may occur in real life, or in our case in the surveillance area.

A data set can be created by using and combining images from existing data sets, capturing new images according to the defined scenarios that best fit the needs and research goals, and combining images from existing data sets and own recordings.

In our case, we have created a dataset by recording own images, which is perhaps the hardest and most demanding approach. On the other hand, in such a way, we had the opportunity to create a dataset that best suits the needs of our research and goal of detecting people in harsh weather conditions. We recorded people in clear, rainy and foggy weather at different distances form the camera and in different body positions, as well as different motion speeds, maximizing the simulated conditions for detecting people in the surveillance and monitored areas.

The choice of equipment to be used for recording also depends on the purpose of the research. Due to night conditions and recording in harsh weather conditions, an infrared thermo-vision camera will be used.

In recent years, thermal cameras have been increasingly present in surveillance systems. Concerning the spread of the areas of application of thermal-vision systems, such as the use of autonomous vehicles, automatic screening at airports, video surveillance usage, recognition of face expression for high-end security applications, monitoring body temperature for medical diagnostics, etc. [1], their price was drastically reduced, their characteristics improved, and availability increased. We choose the long-wave segment of the electromagnetic spectrum of thermal cameras (LWIR segment, wavelength 7 - 14 μm) because of its physical properties such as the ability to record objects under night conditions, in bad weather conditions, with high shooting ranges, etc. [2].

Part of the images are recorded by a telephoto lens so that smaller parts of the body such as arms and legs are clearly visible, as well as a step cycle and other soft biometric traits that can be useful for gait recognition task.

The rest of the paper is structured as follows. In Section II. the basics of infrared thermo-vision with emphasis on the LWIR part of the infrared spectrum is described. A list of widely used thermal imaging datasets that contain the LWIR segment is given in Section III. The process of creating a dataset, from defining scenarios, capturing images, processing videos up to the annotation of the image is described in Section IV. The paper ends with conclusion and plan for future research.

II. Infrared Thermal Imaging Basics

Infrared (IR) thermal sensors have the capability of imaging scenes and objects based either upon the IR light reflectance or upon the IR radiation emittance. The IR radiation is an EM radiation emitted in proportion to the heat generated or reflected by an object and, therefore IR imaging is referred to as thermal imaging. The wavelengths of IR are longer than those of visible light (Fig. 1), so IR is not visible to humans [2].

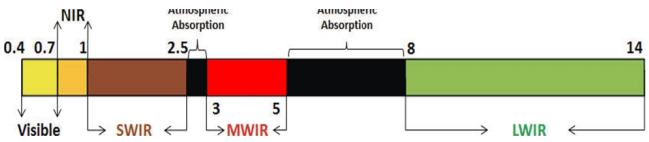


Fig. 1 Electromagnetic spectrum with illustrated IR segments wavelengths in μm [2]

Given the wavelength, the IR spectrum is divided into the following bands [2]: Near-Infrared - NIR, ranges from

0,7 to 1 μm; Short-Wave infrared - SWIR, ranges from 1 to 3 μm; Mid-Wave infrared - MWIR, ranges of 3 to 5 μm; Long-Wave infrared - LWIR, ranges from 8 to 14 μm; Very Long-Wave infrared - VLWIR, in a range greater than 14 μm.

The NIR and SWIR bands are sometimes referred to as "the reflected IR radiation" and MWIR and LWIR bands as "thermal IR radiation". The latter does not require an additional source of light or heat since the thermal radiation sensors can form an image of the environment or object solely by detecting the emission of thermal energy of observed objects. Since IR sensors depend on the amount of emission of the thermal energy of a recorded object, they are, unlike the visible light cameras, invariant to illuminating conditions, robust to a wide range of light variations [3, 4] and weather conditions, and so can operate in a total darkness.

III. THERMAL IMAGING DATASETS

To set up an image dataset, necessary is to define a scenario, select an appropriate environment that meets the required conditions for selected research task, taking into account lighting and weather conditions, and include volunteers who will perform the defined activities. In the case of thermal imaging, the task is even more complicated because it involves shooting in night time or darkness. In our case, this task is further complicated by the need for shooting in fog and rain.

Researchers commonly create the dataset according to their goals and tasks they intend to solve [1, 5, 6]. Table 1 summarizes the thermal datasets, with a brief description of the images they contain, the IR bands that include and with the reference to the research in which have been used.

When using existing databases such as OTCBVS Benchmark Database [7], KAIST Multispectral Pedestrian Dataset [8], CASIA Night Gait Dataset [9] and CASIA Infrared Night Gait Dataset [10], the research goal needs to be adjusted to the available data, which is not the case when the dataset is created from the scratch. In our case, we wanted to create a dataset that will simulate the real-life situation of unauthorized movement in the monitored area, sneaking around protected objects and crossing the state border in the night time at favorable and unfavorable weather conditions. Such recordings none of the existing datasets include.

Table 1. Thermal imaging datasets for human detection

IR band	*Dataset*	*Ref.*
LWIR	OTCBVS Benchmark Database; OSU Color-Thermal Database; image resolution 240x320	[7]
LWIR	CASIA Night Gait Dataset	[9]
LWIR	CASIA Infrared Night Gait Dataset; human silhouette image is normalized to the resolution of 129×130 NLPR Database - daytime	[10]
SWIR	Controp Fox 720 thermal camera, video sequence resolution 640 x 480 pixels at distance 3000 m	[11]
LWIR	520 images captured with FLIR ThermoVision A320 InfraRed camera; resolution 320x240	[12]
LWIR	OTCBVS datasets	[13]
MWIR LWIR	OTCBVS; 360 × 240 pixels; 768 images captured with ICI 7320 thermal camera; resolution 320x240	[14]
LWIR	Video sequence 25 FPS at resolution 640x512	[15]
LWIR	OTCBVS dataset 01; OSU Thermal Pedestrian Database\00001\00001; OSU Thermal Pedestrian Database\00002\00002; Terravic Motion Infrared Database	[16]
LWIR	Tetravision image database	[17]
LWIR	ANTID dataset; Resolutions range from 320×240 to 920×480 both 8 and16 bit pixel; PNG file type. Images are recorded with various FLIR cameras and images representing different type of objects: humans, animals, cars, static objects…	[18]
LWIR	IR Tau2 640x512, 13mm f/1.0 (HFOV 45°, VFOV 37°) FLIR BlackFly (BFS-U3-51S5C-C) 1280x1024, Computar 4-8mm f/1.4-16 megapixel lens (FOV set to match Tau2). Conditions: Day (60%) and night (40%) driving, streets and highways, clear to overcast weather. Frame Annotation Label Totals: 10,228 total frames and 9,214 frames with bounding boxes: Person (28,151), Car (46,692), Bicycle (4,457), Dog (240), Other Vehicle (2,228); Video Annotation Label Totals: 4,224 total frames and 4,183 frames with bounding boxes.: Person (21,965), 2. Car (14,013), Bicycle (1,205), Other Vehicle (540).	[19]
LWIR	FLIR ThermoVision A-20M; 10.000 thermal images at resolution 320x240 pixels from height 1,5 m	[20]
LWIR	NEC-C200 infrared thermal camera with 320x240 pixel image resolution up-sampled to 640x480 using cubic kernel; 17.000 images in testing dataset	[21]
LWIR	MoviRobotics S.L. indoor autonomous mobile platform mSecuritTM with FLIR thermal camera	[22]
LWIR	MTIS - thermal imaging system launched on a mobile phone, resolution 64 × 62; distance: 2 - 9 m, max 29 m	[23]
SWIR	WVU Outdoor SWIR Gait (WOSG) Dataset	[24]
LWIR	1,440 walking samples collected from 8 subjects in different walking conditions at distance 2,6 m	[25]

IV. DATASET DESCRIPTION

The main goal was to create a dataset for learning a deep learning model for person detection in realistic conditions that can happened during surveillance and monitoring protected area. All scenarios are recorded with thermal cameras in night conditions and during the winter period. Recordings were done in clear weather, fog and in heavy rain.

Recorded people had to mimic people who intentionally but unauthorized enter the monitored area, therefore should move at the different distance from the camera, with different movement speeds and body positions, from crawling on all fours, hiding, hunched walking to running.

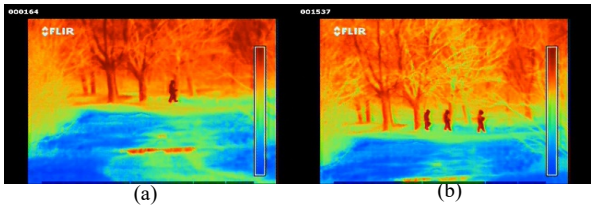
A. Dataset design criteria

The basic scenarios that should be met:

- **Clear weather:**

1. It is used to estimate the maximum (reference) distance of the camera on which the person on the record can be detected with a naked eye. The reference distance of 110 m is selected and the recording with the standard lens is carried out at a distance of 165 m, Fig 2.
2. Primarily use for training the person detection model

3. Record people while walking, running, sneaking (hunched walking).



(a) (b)

Fig. 2 Comparison of images taken at the clear weather and the distance of 165 m: (a) standard thermal camera lens, (b) using telephoto lens

- **Dense fog weather:**
  1. Evaluation of the camera's ability to record in fog and conditions with low visibility - reference distances of 30 and 50 m
  2. It is used to prepare a test set to examine the robustness of a model for person detection: the objective is to learn a model for person detection at clear weather footage and observe its ability to be used in conditions that simulate realistic conditions in protected areas such as fog or rain.
  3. Record people while walking, running, sneaking (hunched walking).
- **Heavy rain weather:**
  1. Estimate the camera's ability to record in rainy weather and weather with high humidity - distances from 30 to 215 m
  4. It is used during the test phase to test the robustness of the model for person detection trained on clear weather images and to examine the ability to be used under real-world surveillance conditions.
  2. Record people while walking, running, sneaking (hunched walking).

B. Data collection

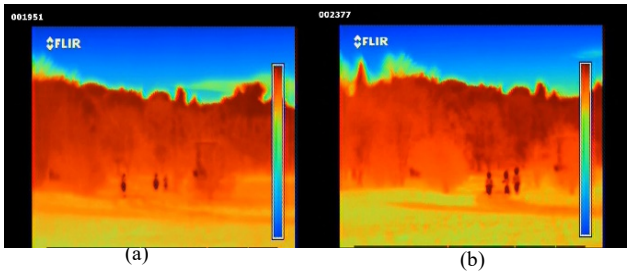
We used the FLIR ThermaCam P10 [26] LWIR thermal imaging camera for recording with a standard lens and FLIR 7 degrees Telephoto Lens (P/B series) [27] mounted on a tripod at a height of about 140 cm. The camera captures a thermal images of resolution of 320 x 240 pixels, and we used an external video recorder to enhance the quality of the recordings, which upscale images at a resolution of 1280 x 960 pixels. For the measurement of distance, we used the ViewRanger application [28] installed on the CAT S60 [29] smartphone. The CAT S60 smartphone was also equipped with a thermal camera, but we do not include images taken using this smartphone in this dataset.

1) Clear weather

The recording was carried out on a meadow with a small forest, so it was possible to simulate the conditions of hiding people to determine the camera's potential in terms of "whether and how much it can see through trees or bushes". The shooting location was approximately 180 m in length and the air temperature was about 2 ° C under night conditions, with good visibility and without affecting atmospheric conditions.

Using a standard lens, the person is 110 m away, recorded at a normal pace individually and in a group (three people).

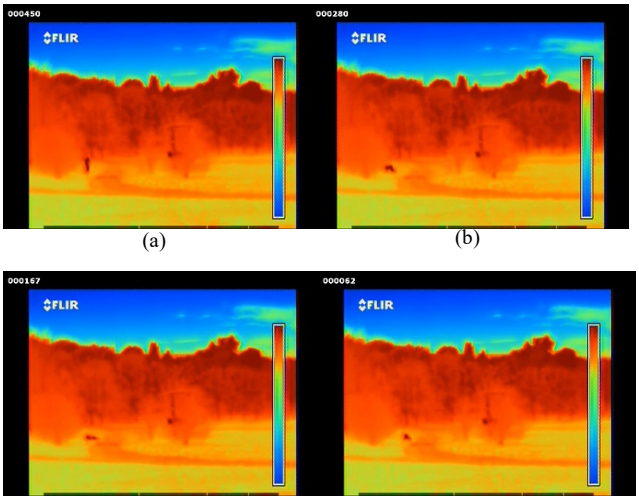
We recorded one and three persons, so that they walked away from the camera (50 to 110 m) and then walked over the camera's field of view (at a distance of 110 and 165 m). In this scenario, people have changed body positions, so they were recorded during upright walking at the distances of 50 to 165 meters while the reference distance was 110 m. The recording was done using the standard lens of FLIR Thermal Cam P10 and using the telephoto lens. Using a standard lens, the person was recorded 110 meters away, walking at normal pace, individually and in a group (three people). At the same distance, people were recorded using the standard lenses during running, as well using a telephoto lens. For example, Fig. 3 shows three normal walking persons and gives a comparison of image quality taken using standard and telephoto lens at a distance of 110 m.



(a) (b)

Fig. 3 Comparison of images taken at the clear weather and the distance of 110 m: (a) standard camera lens, (b) telephoto lens

Also, we recorded a person in clear weather at a distance of 110 meters with changed body positions - from normal to walk on all four, crawling and lying on the ground (Fig. 4).



(a) (b)

(c) (d)

Fig. 4 Comparison of images taken at the clear weather and the distance of 165 m using standard lenses – one person – changing positions: (a) normal walking, (b) fourleg walking; (c) lying on the ground - left side of the person; (d) lying on the ground - head in the direction of the camera

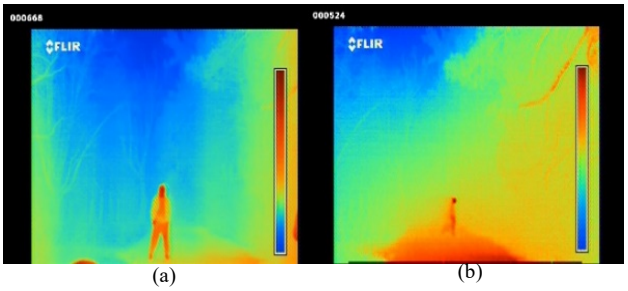
Then the shooting was continued with a standard lens so that people walk away from the distance of 110 m to the distance of 165 m.

At this distance (165 m), people were recorded while walking over the camera's view field at upright normal speed walking and upright running and at the hunched normal speed walk and hunched running, Fig. 4. At this distance we used only telephoto lens since the images recorded using a standard lens were low quality and it was almost impossible to detect and recognize a person with naked eye.

2) Foggy weather

Due to the high density of water particles in the air in fog conditions, LWIR radiation is highly dispersed, so the visibility for the thermo-visual camera is significantly reduced compared to other atmospheric conditions. This was the most demanding scenario as it is stated in the reviewed literature [29, 30].

Although it was primarily intended to repeat shooting scenarios as well as at clear weather, the same was not possible. With regard to available equipment and extremely dense fog, people at distances of over 50 meters were not visible at all. After the initial visual inspection of the recorded images, we selected distance of 0 to 30 m and at 50 m, using only the telephoto lens, Fig. 5.



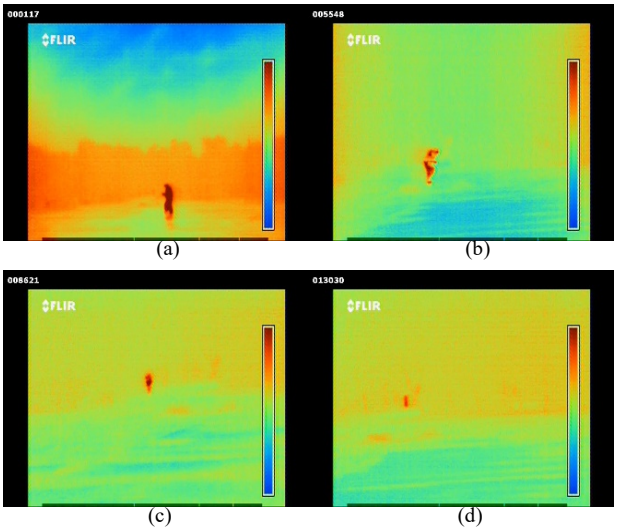
(a) (b)

Fig. 5 Comparison of images taken at the foggy weather and the distance of: (a) telephoto lens at 30 m, (b) telephoto lens at 50 m

We recorded up to three persons that changed the way of movement and position of the body. Recording was done in the part of the woods on the asphalt road, and the people moved away from the camera and crossed the camera view field with normal upright walk, hunched and running. The air temperature was about 2 ° C and the visibility was significantly reduced due to dense fog (less than five meters of visibility).

3) Rainy weather

For shooting over the rainy weather, we choose the location that provided the ability to shoot at distances of over 165 meters. We have made recording using standard and telephoto lenses at distances of 30, 70, 110, 140, 170, 180 and 215 m. Two persons were recorded at all distances - individually and together at normal walking and running in upright and hunched positions, Fig. 6. Shooting at a distance of 215 m was possible using the telephoto lens only.



(a) (b)

(c) (d)

Fig. 6 Comparison of images taken in heavy rain weather and the distance of: (a) telephoto lens at 30 m, (b) telephoto lens at 70 m (hunched); (c) telephoto at 140 m; (d) telephoto at 215 m

C. Data preprocessing

After recording and video pre-processing, we got about 20 minutes of videos recorded on the clear weather, about 13 minutes on fog and about 15 minutes on rainy weather. The resulting video material needed additional processing to be prepared for training, so we cut all the videos into smaller parts that best fit the pre-defined scenarios. At this stage, we used VSDC Video Editor's free software tool to cut video materials [31].

After cutting the videos into smaller parts, it was necessary to extract frames from all the videos we've got. We performed the image extraction using MATLAB and corresponding scripts for extracting video frames. The result was a total of 11,900 frames in 1280x960 resolution (for a clear weather at all distances, all body positions and motion speeds). For fog, we obtained a total of 4,905 images for both recording distances and all body positions. For rainy weather, there are 7,030 frames for all distances and all body positions.

For supervised learning of a model for person detection in thermal images, there should be available annotated frames with tagged persons in the learning set as well as in the test set that will serve as ground truth. That is why the next phase was the process of frame annotation and tagging of all persons present on each image. As the manual annotation and objects tagging is long lasting and tedious work, we tried to choose representative images that will be manually annotated. Considering that human walking or running is a repetitive activity, we have selected the frames at different distances and angles from the camera, that would maximally show the differences in body positions. Therefore, several scenarios for choosing the candidate images have been applied. The first step was the visual inspection of all the frames, and then the corresponding frames were selected according to the defined criterion (maximum difference in the motion and position of the body, as well as visibility of the recorded persons). After this phase, the initial set selected for manual annotation and persons tagging was reduced to a total of 7,412 frames. In

a formed set, 3,174 frames were obtained for a clear weather, 1,460 images for fog, and 2,778 images for rain.

D. Dataset annotations

Annotation and tagging of objects in images is one of the most time-consuming procedures in the preparation of the dataset. There are several free tools available for the image annotation, such as the VGG Annotator [32], which runs from the Internet browser and has several useful features, then Labelbox [33], LabelMe [34], Annotorious [35].

The choice of image annotation tool depends on the method to be used for model learning, so in our case, we have chosen the tool available on the GitHub repository called Boobs - Yolo BBox Annotation Tool [36]. Fig. 7 shows user interface of tool that we used for annotation, and Fig. 8 shows the same tool when images is loaded and objects (persons) annotated with bounding boxes.

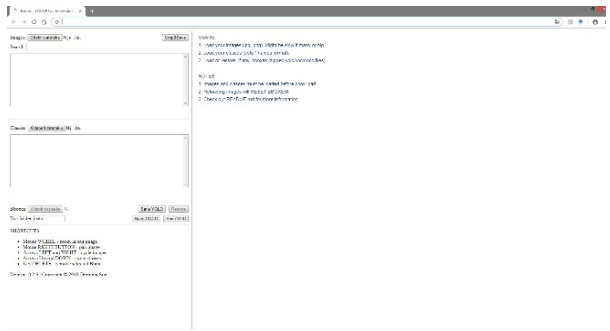


Fig. 7 Boobs – YOLO BBox Annotation Tool user interface

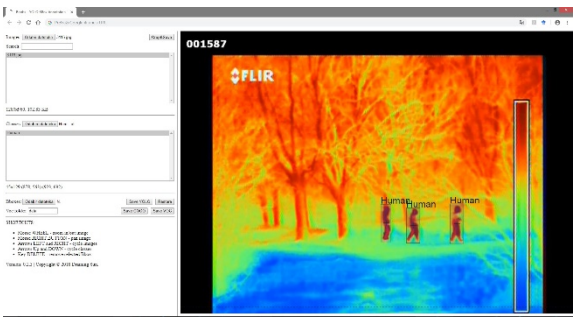


Fig. 8 Boobs – YOLO BBox Annotation Tool user interface with annotated image

This tool runs within the web browser, and supports all popular browsers (Firefox, Chrome, Safari, Opera). The key reason for using this tool is its option to simultaneously store annotations into the three most popular formats for machine learning - YOLO [37], VOC [38] and MSCOCO [39]. This saves time for later phases of model learning because no subsequent conversion is required for specific format.

In our case, we saved the image annotations in all three formats for the later research, but for now we used only YOLO format because we have already used YOLO detector [40] for person detection on video materials and we got state-of-the-art detection results [41, 42]. In the YOLO format image annotation is saved as .txt file for each image so at the end of annotation the number of txt files is the same as the number of annotated images. Annotation in YOLO format comprises of five labels in a line for each annotated object in the image, Fig. 9. The first value is a categorical number representing an object class, so if there are several object classes in the image, they are sequentially numbered starting from 0. The second value in the line represents the center of the selected object on X axis [*object center in X*]. The third value represents the center of the object on Y axis [*object center in Y*]. The fourth value represents the width of the object on X [*object width in X*], and the fifth value represents the width of the object at Y [*object width in Y*] [43].

```
0 0.703515625 0.6541666666666667 0.03203125 0.13125
0 0.5921875 0.6578125 0.034375 0.11770833333333333
0 0.523828125 0.6520833333333333 0.02578125 0.122916666666666
```

Fig. 9 YOLO format annotations of three annotated objects shown in the Fig. 8.

If there are multiple tagged objects in the image, each is described in a new line within the same txt file corresponding to the image on which the objects are located. For example, Fig. 9 is an example of the three annotated objects shown in Fig. 8. Since all object represent people and belong to the same class, each annotated object is numbered with 0 and the txt file has three lines that begin with zero.

After the annotation of objects or persons in the image is finished, the next step is to train the machine learning model for person detection. For the training and testing purposes we used the YOLO detector [40] within the Darknet framework [44], available in the GitHub repository [45]. The preliminary results have show that the prepared set is worthwhile to continue researching and learning a model for person detection on thermographic images [46, 47].

V. CONCLUSION

This paper presents a new dataset of thermal images designed for learning a model of human detection. A particular concern was paid to simulate realistic conditions in the protected area at different weather conditions. Shooting of people made under difficult weather conditions - by dense fog and heavy rain, is an additional feature of this set of data.

Recorded persons moved in the way that is common for people who intentionally but illegally enter the supervised area: at different distance from the camera and different positions, different speeds of movement and in different movement types, from creeping, sneaking to walking and running.

Motion captured by a telephoto lens provide enough details to be used for recognizing individual activities (running, walking, hunched walking, hunched running, etc.) and for the gait recognition and identifying people by way of walking.

The formed dataset will be used to learn a person detection model on thermal images using deep neural network such as YOLO detector. The later plan is to use formed dataset for gait recognition and recognition of movement types in adverse weather conditions.

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Software Development for Rule-Based Spreadsheet Data Extraction and Transformation

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Abstract—The paper proposes a knowledge-based software platform to generate applications for spreadsheet data extraction and transformation. The platform includes a flexible table object model and a domain-specific language for expressing user-defined rules of table analysis and interpretation. They serve to represent knowledge of table layout and content features, as well as their interpretation, depended on transformation goals. The platform enables translating such user-defined rules to Java programs. The generated source code is serialized as a project prepared for building an executable application by using the Maven tool. The execution of the generated application transforms spreadsheet data from arbitrary form defined by the rules to the canonical one. The empirical results demonstrate the applicability of the software platform to develop applications for converting data from arbitrary spreadsheet tables originated from various domains to relational flat file databases.

Index Terms—spreadsheet data transformation, table analysis, table interpretation, rule-based programming

I. Introduction

A big volume of arbitrary tables (e. g. cross-tabulations, invoices, roadmaps, and data collection forms) circulates in spreadsheet-like formats. Spreadsheets can be considered as a general form for representing tabular data with an explicitly presented layout (cellular structure) and style (graphical formatting). The arbitrary spreadsheet tables can be a valuable data source in business intelligence and data-driven research. However, difficulties that inevitably arise with extraction and integration of the tabular data often hinder the intensive use of them in the mentioned areas.

Typically, arbitrary spreadsheet tables contain unstructured and non-standardized ("messy") data. Unlike relational tables, they are not organized in a predefined manner. They lack explicit semantics required for high-level computer interpretation such as SQL queries. To be accessible for data analysis and visualization, their data need to be extracted, transformed, and loaded (ETL) into databases. Since arbitrary tables can have various complex cell layouts (structures), often the familiar industrial ETL-tools are not sufficient to populate automatically a database with their data.

Usually, researchers and developers faced with the tasks of spreadsheet data integration use general-purpose tools. They often offer their own implementations of the same tasks. In such cases, domain-specific tools can reduce the complexity of software development in the domain of the spreadsheet data integration. This is especially important when a custom software for data extraction and transformation from heterogeneous arbitrary spreadsheet tables is implemented for a short time and with a lack of resources.

A. Related Work

There are several recent studies devoted to the issues of spreadsheet data converting. The tools [1]–[6] are devoted to issues of converting data presented in spreadsheets or web tables to the linked data formats (RDF/OWL). The solutions for spreadsheet data extraction and transformation [7]–[10] are based on programming by examples. Some of them include own domain-specific languages, e.g. XLWrap [1], M^2 [2], TableProg [7], and Flare [9].

Hung et al. [11] propose TranSheet, a spreadsheet-like formula language for specifying mappings between source spreadsheet data and a target schema. DeExcelerator framework [12] aims at the development of a framework for information extraction from partially structured documents such as spreadsheets and HTML tables. The framework exploits a set of heuristics based on features of tables published as Open Data. MDSheet framework [13] also implements a technique that automatically infers relational schemes from spreadsheets. The framework [14] constructs trained spreadsheet property (e. g. aggregation rows or hierarchical header) detectors based on rule-

assisted active learning. Embley et al. [15] propose an algorithmic end-to-end solution for transforming "header-indexed" tables in CSV format to a relational form ("category tables") based on header indexing. Senbazuru, a spreadsheet database management system proposed by [16], provides extracting relational data from spreadsheets ("data frames").

The recent papers [17], [18] develop domain-specific solutions. The work [17] proposes algorithms and accompanying software for automatic annotation of natural science spreadsheet tables. The other tool [18] extracts RDF data from French government statistical spreadsheets and populates instances of their conceptual model. The system CACheck [19] automatically detects "smelly" cell arrays by recovering their intended computational semantics. TaCLe [20] automatically identifies constraints (formulas and relations) in spreadsheets. The papers [21] consider the issues of tabular document processing.

B. Contribution

Our work shows new possibilities in spreadsheet data transformation from arbitrary to relational tables, using rule-based programming for the following stages of table understanding: (1) role analysis (extracting functional data items, entries (values) and labels (keys), from cell content); (2) structural analysis (recovering internal relationships of extracted items); (3) interpretation (associating extracted items with concepts of external vocabularies).

We develop TabbyXL, a platform for developing software for spreadsheet data extraction and transformation from an arbitrary (Fig. 1, a) to the relational (canonical) form (Fig. 1, b). Compared to the mentioned solutions it draws up this process as consecutive steps: role analysis, structural analysis, and interpretation.

The platform implements a two-layered table object model combines the physical (syntactic) and logical (semantic) table structure. Unlike others models, it is not based on using functional cell regions but determines that functional items can be placed anywhere in a table.

We also design and implement a novel domain-specific rule object model for representing rules expressed in CRL (Cells Rule Language). Such rules map the physical structure to the logical one of an arbitrary table. Our rule model enables translating CRL rules to Java programs for the spreadsheet data transformation. In contrast to the existing mapping languages, our rule language and model express the spreadsheet data conversion in terms of table understanding.

This paper extends our approach to table understanding based on executing rules for table analysis and interpretation [22], [23] by adding the rule object model for representing and translating CRL rules to the source code, as well as an implementation of CRL-to-Java translator based on this model.

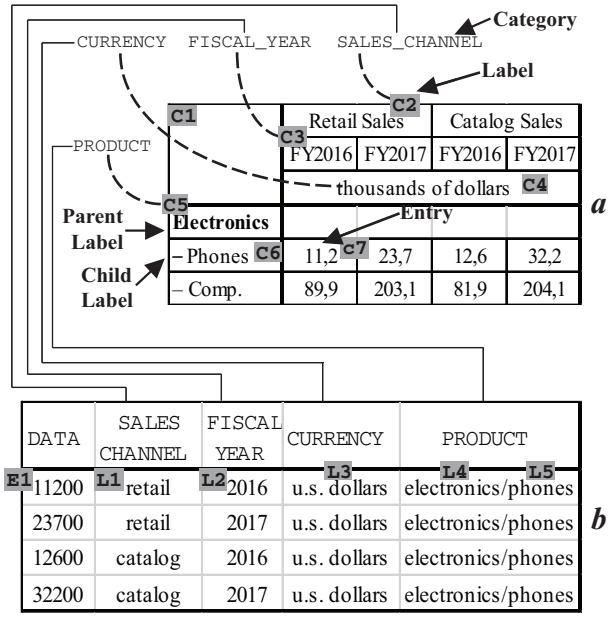

Fig. 1. A fragment of a arbitrary spreadsheet table (a) and its canonical form (b).

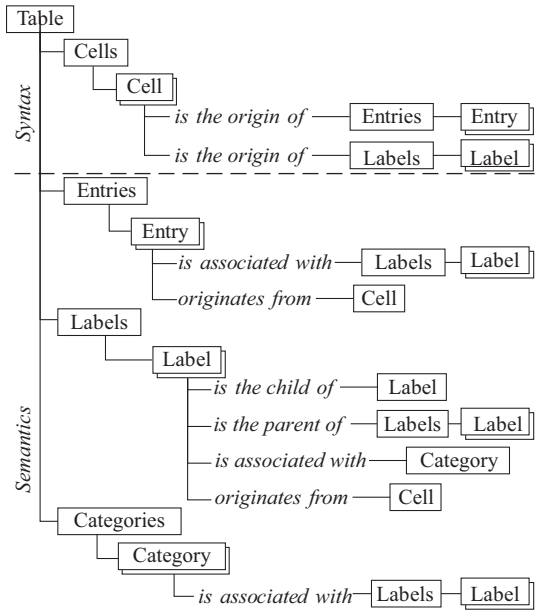

Fig. 2. Two-layered table object model [23].

II. Table Object Model

The table object model is designed for representing both a physical structure and logical data items of an arbitrary table in the process of its analysis and interpretation (Fig. 2). Our model adopts the terminology of Wang's table model [24]. It includes two interrelated layers: physical represented by the collection of cells and logical that consists of three collections of entries (values), labels (keys), and categories (concepts). This model is presented more detail in our previous paper [23].

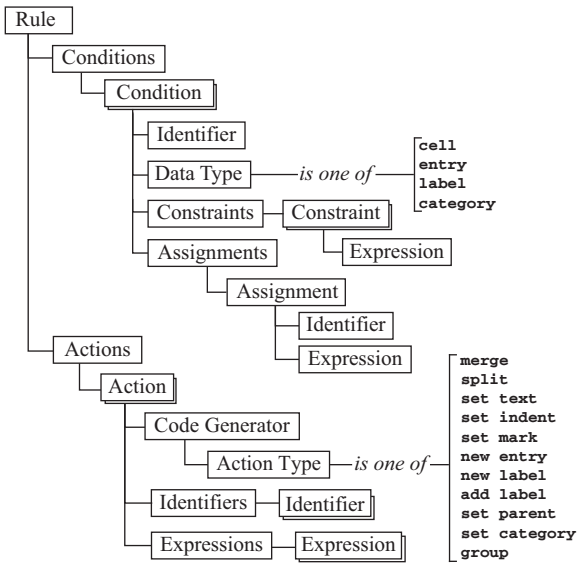

Fig. 3. CRL rule object model.

The physical layer consists of a set of cells. "Cell" object represents common features of a cell that can be presented in a spreadsheet format, including: positions in rows and columns; style (font, alignment, etc.); text content, data types; annotation (user-defined tags to annotate the cell). These features are extracted from an arbitrary table (Fig. 1, a).

The logical layer includes sets of the following data items. "Entry" object serves to represent a data value of a table. An entry can be associated with only one label in each category. "Label" object represents a label (key) that addresses one or more entries (data values). A label can be associated with other label as child-parent, "Category" object represents a category of labels. Each label is associated with only one category. Labels combined into a category can be organized as one or more trees. The recovered data items of the logical layer can be presented as a relational table in the canonical form (Fig. 1, b).

III. Table Analysis and Interpretation Rules

Table analysis and interpretation rules are intended to map explicit features (layout, style, and text of cells) of an arbitrary table into its implicit semantics (entries, labels, and categories) Such rules can be expressed in a general-purpose rule-based language and executed with a rule engine [22]. To determine a functionality needed for developing them, we design CRL[1], a domain-specific rule language, which specializes in expressing such rules. Our language hides details which are inessential for us and allows to focus on the logic of table analysis and interpretation. The syntax of CRL rules is presented more detail in our previous paper [23].

[1]https://github.com/tabbydoc/tabbyxl/wiki/crl-language

In this paper, we propose the rule object model for representing CRL rules (Fig. 3). This model enables to translate CRL rules to the source code of application software for converting spreadsheet data from an arbitrary to the relational form.

The rule object model includes a set of conditions and a set of actions as shown in Fig. 3. The set of conditions is built according to the left hand side ("when") of a rule. They enable to query available facts of a table such as cells, entries, labels, and categories.

The set of actions describes the right hand side ("then") of the rule. They are executed when all conditions of the set being true. The actions modify the existed facts or generate new ones.

A. Conditions

A condition consists of the following items: (1) Data Type denoting the fact type ("cell", "entry", "label", or "category"); (2) Identifier names "variable" of the specified fact type; (3) Constraints define (Java Boolean expression) for restricting the requested facts; (4) Assignments are used for binding additional variables with some values.

A rule can use two kinds of conditions. The first requires that there exists at least one fact of a specified data type, which satisfies a set of constraints:

```
cell | entry | label | category
variable: constraints, assignments
```

The second kind of conditions determines that there exist no facts satisfied to specified constraints:

```
no cells | entries | labels | categories:
constraints
```

Such conditions have no identifiers and assignments.

B. Actions for Cell Cleansing

In practice, hand-coded tables often have messy layout (e. g. improperly split or merged cells) and content (e. g. typos, homoglyphs, or errors in indents). We address several actions to the issues of cell cleansing that can be used as the preprocessing stage.

- "merge", the action combines two adjacent cells when they share one border.
- "split", the action divides a merged cell that spans n-tiles into n-cells. Each of the n-cells completely copies content and style from the merged cell and coordinates from the corresponding tile.
- "set text", the action provides modifying textual content of a cell. Some string processing (e. g. regular expressions and string matching algorithms) implemented as Java-methods can be involved in the action.
- "set indent", the action modifies an indentation of a cell.

C. Actions for Role Analysis

This stage aims to recover entries and labels as functional data items presented in tables. We also enable associating cells with user-defined tags (marks) that can assist in both role and structural analysis.

- "set mark", the action annotates a cell with a word or phrase. The assigned tag can substitute the corresponding constraints in subsequent rules. The typical practice is to set a tag to all cells, which play the same role or are located in the same table functional region. Thereafter, we can use these tags in subsequent rules instead of repeating constraints on cell location in the regions.
- "new entry", the action generates an entry, using a specified cell as its origin. Usually, a value of the created entry is an expression obtained as a result of string processing for its textual content of the cell.
- "new label", the action generates a label in a similar way.

D. Actions for Structural Analysis

The next stage recovers pairs of two kinds: entry-label and label-label.

- "add label", the action binds an entry with an added label. A label can be specified as a value of a category indicated by its name.
- "set parent", the action connects two labels as a parent and its child.

E. Actions for Interpretation

The stage includes actions for recovering label-category pairs.

- "set category", the action associates a label with a category.
- "group", the action places two labels in one group. Arbitrary tables often place all labels of one category in the same row or column. Consequently, we can suppose that the labels belong to a category without defining its name. In the cases, grouping two or more labels means that they all belong to an undefined category. All labels of a group can be associated with one category only.

IV. Development of Spreadsheet Data Transformation Programs

TabbyXL[2] implements both the presented table object model and the approach to rule-based spreadsheet data extraction and transformation. It enables automatically generating Java source code from CRL rules. A generated program can be compiled to executable Java bytecode. We use ANTLR[3], the parser generator, to implement the CRL-to-Java translator. This allows to parse CRL rules and to build their object model which is then translated to Java source code. The generated source code can be serialized as a project prepared for building an executable application by using the Maven tool. Fig. 4 shows the workflow for generating Maven-projects for such programs (a), including Java source code generating from CRL rules (b).

As an alternative, the rules can be executed by Drools rule engine. In this case, they should be expressed in a dialect of CRL that is implemented as DSL in corresponding of Drools requirements. Unlike the pure CRL, this dialect supports DRL attributes in rule declarations. CRL rules are automatically translated into DRL, a native format of Drools, through the DSL-specification that defines CRL-to-DRL mappings. The rule engine matches asserted facts (cells from an instance of the table object model) against the rules. The instance is augmented by recovered facts (entries, labels, and categories). At the end of the transformation process, the instance is exported as a flat file database.

V. Application Example

The application we considered aimed at developing an interactive statistical atlas of the Irkutsk region (StatAtlas). It required extracting data from government statistical reports distributed by IrkutskStat (Irkutsk Regional Committee of the Russian Federal State Statistics Service). Source data were presented as arbitrary tables in Word documents. All tables were extracted and converted to Excel format, using VBA macro. We also accompanied each table by two tags $START and $END for specifying its boundaries on the worksheet. We developed a ruleset in CRL format for recovering functional roles and relationships inside each table. All tables were transformed into relational ones by running the ruleset. Note that our software platform was used only in this phase of the workflow. As a result, all transformed tables were aggregated and converted to CSV format with geocoded names of territories and loaded into the database of StatAtlas.

Fig. 5 depicts an arbitrary table (a) as an example of a layout form being used in IrkutskStat reports, as well as a corresponding relational table in the canonical form that is generated as a result of the table transformation (b). The ruleset we used contains only 7 rules expressed in CRL format as follows: (1) generating "column" labels from cells located in the head part of a table; (2) associating child column labels with parent ones; (3) generating "row" labels from cells located in the stub part; (4) associating child "row" labels with parent ones; (5) generating entries from cells located in the body part; (6) associating entries with column labels (7) and with row labels. The data and steps to reproduce this example are available at GitHub[4].

[2]https://github.com/tabbydoc/tabbyxl/releases/tag/v1.0.4

[3]https://www.antlr.org

[4]https://github.com/tabbydoc/tabbyxl/wiki/example-3

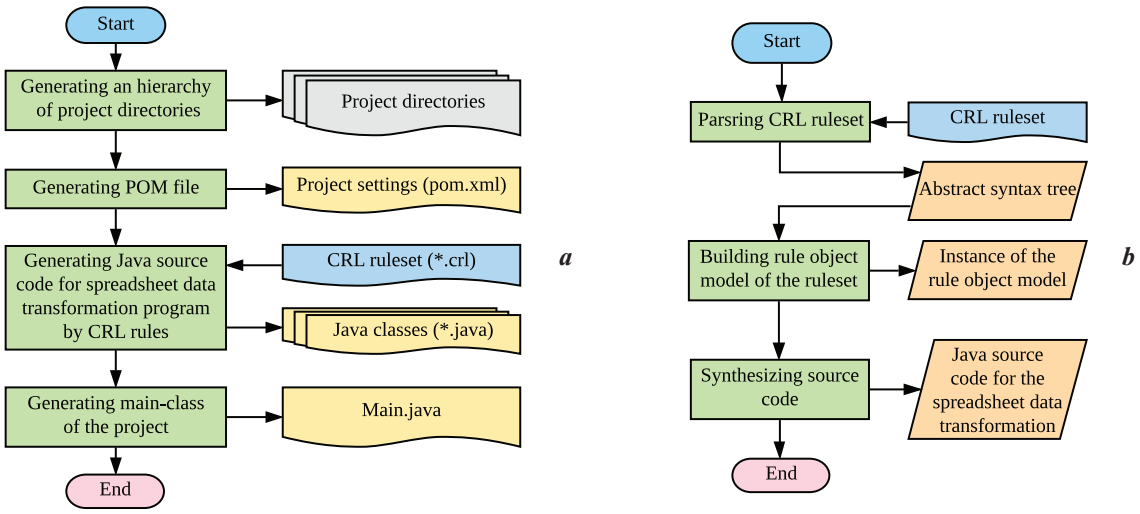

Fig. 4. Workflow for generating Maven-projects for spreadsheet data transformation programs (a), including translating CRL rules to Java source code (b).

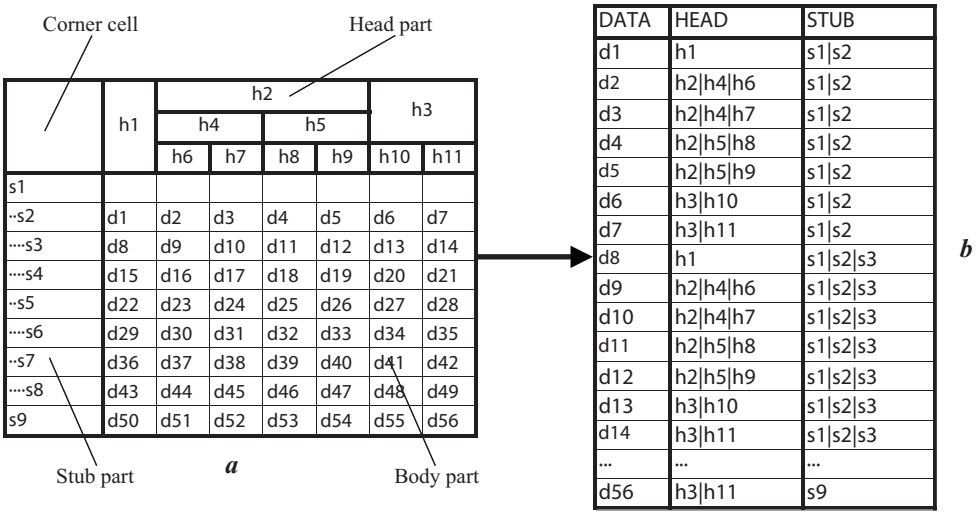

Fig. 5. Source table (a) and its target representation in the canonical form (b).

VI. Experimental Results

The purpose of the experiment is to show a possibility of using our platform for converting tables, which originate from various sources produced by different authors but pertain to the same document domain. The experiment includes two parts: (i) designing and implementing an experimental rule-set for tables of the same genre, and (ii) evaluating the performance of the rule-set on a set of these tables. All data and rules for reproducing the experiment results are available as the published dataset [25].

We used Troy200 [26], the existing dataset of tables, for the performance evaluation. It contains 200 arbitrary tables as CSV files collected from 10 different sources of the same genre, government statistical websites predominantly presented in English language.

We designed and implemented a rule-set that transforms the tables of the dataset into the relational form according to the presented target requirements. We also prepared ground-truth data, including reference entries, labels, entry-label, and label-label pairs extracted from Troy200 tables. Their form is designed for human readability. Moreover, they are independent of the presence of critical cells in tables. The performance evaluation is based on comparing the ground-truth data with the tables generated by executing the presented rule-set for the experiment

TABLE I
The performance evaluation results of the tested ruleset for recovering data items and their relationships.

	data items		relationships	
metrics	entries	labels	entry-label	label-label
recall	0.9813	0.9965	0.9773	0.9389
precision	0.9996	0.9364	0.9965	0.9784
F-score	0.9904	0.9655	0.9868	0.9582

dataset.

We used the standard metrics: recall, precision, and F-score, to evaluate our rule-set for both role and structural analysis. The experiment results are shown in Table I. Among 200 tables of the dataset, only 25 are processed with errors (1249 false negatives in 25 tables, and 488 false positives in 14 ones). total 1256 false negatives in 25 tables, and 498 173 false positives in 14 ones Only one table is not processed. This results in 948 false negative and 316 false positive errors, which amount to about 73% of all errors. In this case, entries are not recovered because they are not numeric as it is assumed in the used rule-set.

This experiment exemplifies the use of our language for developing a task-specific rule-set. The performance evaluation confirms the applicability of the implemented rule-set in accomplishing the stated objectives of this application.

VII. Conclusions and Further Work

The presented approach can be applied to develop software for extraction and transformation data of arbitrary spreadsheet tables. We expect TabbyXL to be useful in cases when data from a large number of tables appertaining to a few table types are required for populating a database. Our application experience and the experiment results demonstrate that the platform can be used for developing programs for the transformation of spreadsheet data into the relational form. One rule-set can process a wide range of tables of the same genre, e. g. government statistical websites. Our platform can be used for populating databases from arbitrary tables, which share common features.

The work focuses rather on table analysis than on issues of interpretation. We only recover categories as sets of labels, without binding them with an external taxonomy of concepts (e.g. linked open data). The further work on table content conceptualisation can overcome this limitation. Moreover, we observe that arbitrary tables can contain messy and useless data. It seems to be interesting to incorporate additional techniques of data cleansing in the platform.

Acknowledgment

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Event Trees Transformation for Rule Bases Engineering

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***Abstract* - The paper describes an approach for rule bases engineering by transforming event tree diagrams which are applied in the field of failure and risk analysis of technical systems. The approach is based on the identification and extraction of structural cause-effect elements of event trees and their transformation into the elements of a target knowledge representation language, in particular, CLIPS. Description of an extended event tree formalism, an event tree metamodel and transformation technique are presented. An illustrative example describes the development of a rule-based knowledge base for diagnosing and forecasting the states of complex technical systems based on the approach proposed.**

Keywords – knowledge acquisition; knowledge base; rules; event trees; model transformation, code generation; CLIPS

I. INTRODUCTION

Rule-based knowledge representation languages are still the most widespread and popular for industrial diagnostic expert systems engineering [1] despite the increasing popularity of semantic technologies, in particular, ontologies. One way to increase the efficiency of knowledge bases engineering with the aid of them is the use of principles of visual programming and automatic code generation. That in turn results to minimize the risks of programming errors, to use the previously developed information in the form of visual models, and to increase the participation degree and responsibility of non-programming users in the development process.

There are many universal languages (standards) for domain knowledge visualization (e.g., DFD, IDEF0, IDEF5, UML, etc.) and specialized notations focused on certain knowledge representation formalisms (e.g., Rule Visual Modeling Language (RVML) [2], UML-Based Rule Modeling Language (URML) [3]), but domain experts prefer to use domain-specific notations that have a system-wide focus and oriented on knowledge systematization or decision-making support (e.g., concept maps, mind maps, fishbone diagram, Venn diagram, feature models, semantic models, fuzzy conceptual models, etc.). These models include tree-like semantic structures, such as fault trees and event trees used in the field of failure and risk analysis of technical systems [4-6]. These notations provide effective description, clear and convenient representation of domain experts' knowledge.

In this paper we propose to use conceptual models in the form of event trees as a data source for rule-based knowledge bases engineering.

There is special software to modeling event trees: RELEX Windchill FTA (Relax Software Corporation) [7], Risk Spectrum (Relcon AB) [8], SAPHIRE [9], RAM Commander ETA (A.L.D. Group) [10], Reliability Workbench incorporating FaultTree+ (ISOGRAPH) [11] and others. These systems support visualization and building event trees but don't provide a way to synthesize (generate) any source codes including for knowledge representation languages. Moreover, analyzed software implies the use of knowledge contained in the created trees for solving mathematical problems (such as search of minimal cut set, events with maximum or minimum probability, and etc.) but not for engineering intelligent decision support systems or knowledge bases.

Also it should be noted that today there are no unified standards (or specifications) for representation and serialization of event trees, and each software uses its own format. However, most of them are XML-based, because XML is the most common method for integration of software that provides the exchange of information between applications.

Thus, this paper is devoted to an approach for automated development of rule-based knowledge bases by transforming event trees serialized in a XML-based format. The C Language Integrated Production System (CLIPS) [12] is selected as the target knowledge representation language for compatibility with our early developments [2, 13].

II. THE PROBLEM STATEMENT

The problem of knowledge base engineering on the basis of event trees analysis can be represented as a models transformation problem [14]. In this case, the transformation is the process of an automatic generation of a target knowledge base from a source model according to a set of transformation rules. Transformation rules describe how one or more constructs of the source language can be transformed into one or more constructs in a target knowledge representation language.

Let's formalize the problem statement as follows:

$$T : CM^{ET} \rightarrow KB, \quad (1)$$

where CM^{ET} is a source conceptual model in the form of an event tree; KB is a target knowledge base in the form of CLIPS code, $KB = \langle Code^{CLIPS} \rangle$.

Thus, it is necessary to define a set of transformation rules (T) in the context of engineering rule-based knowledge bases and implement them in the form of a special tool (a transformation module).

The previously developed technology [15] that was implemented in the form of a web-based program system – Knowledge Base Development System (KBDS) [13] was used. This technology supports the creation of software components (transformation modules) designed for converting the source conceptual models, represented in XML-like formats, into the knowledge base codes of the target knowledge representation language, in particular, CLIPS.

III. Event Trees

A. A standard formalism

Event tree formalism [16] is a graphical technique that uses boolean operators to evaluate the consequences of a risk by drawing (mapping) all probable outcomes from an initiating event in their logical sequence.

Event trees are used to determine and analyze the variants of emergency including complex interactions between technical systems. Event tree building procedure is based on a direct logic. In general, this method can be used to analyze failures, accidents and emergency, where the initial state is considered as the main event, i.e. a state of a technical object at the operation start time.

B. Domain-specific extention

Analysis of some domain problems, in particular, the problem of industrial safety expertise [17], showed the need for domain-specific extension of the standard event tree formalism in order to obtain more complete information about the investigated events, their causes and consequences.

In particular, based on the [18-20], it is defined the followings:

- in most cases any investigated process is a sequence of states that unite groups of events on certain grounds. In the field of technical diagnostics, as a rule, there are two main states of the technical object and its structural elements: an operation state and failure state, which in turn can include a set of intermediate states, depending on the classification basis;

- each of the states has a certain initial event that is determined not only by the previous states (events), but also by additional factors, such as external effecting factors and properties of the object under investigation.

In this connection, it is proposed to extend the standard event tree formalism (and its visual representation), in particular:

- to define the levels of the event tree corresponding to the stages of the process under investigation. In particular, when solving problems of predicting the states of technical systems, these levels may have the following names: defect, damage, destruction, emergency;

- to define a specialized event (represented in the form of a triangle) describing the initial event of a certain stage (or level, state, sub-state). This event corresponds to the concept of mechanism [17] and can be considered as a combination of the object properties and effecting factors that determine the development of the processes under investigation on a certain stage;

- to determine the possibility for describing a mechanism by a composition of different factors in the form of the followings logical rules:

IF (property_1 **AND** … **AND** property_n) **AND**

($\text{effecting factor}_1$ **AND** … **AND** $\text{effecting factor}_n$)

THEN the mechanism of j-stage **AND** ($\text{event}_1 \circ \ldots \circ \text{event}_n$), when $\circ$ is a some logical operation, $\circ \in \{\wedge, \vee, \oplus\}$.

C. An event tree template and metamodel

A generalized event tree template (Figure 1) is obtained on the basis of extensions proposed. This template describes stages, sequence of events and the mechanisms of their occurrence and can be used as an event tree draft for experts. In the absence of tree elements that extend the standard formalism, we get a standard event tree.

A metamodel of an extended event tree (abstract syntax), which defines in abstract form the main concepts of the extended event tree formalism, is shown in Figure 2. This metamodel is built using the Ecore meta-modeling language [21] and further is used as a source metamodel when developing transformation rules describing the correspondences between the elements of this metamodel

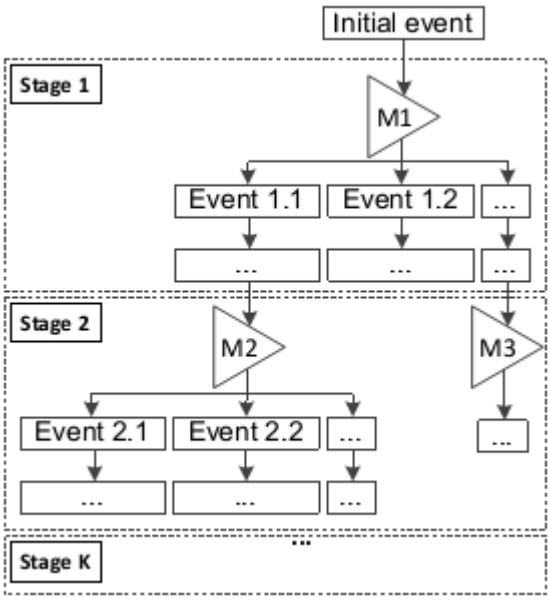

Figure 1. A template of an extended event tree

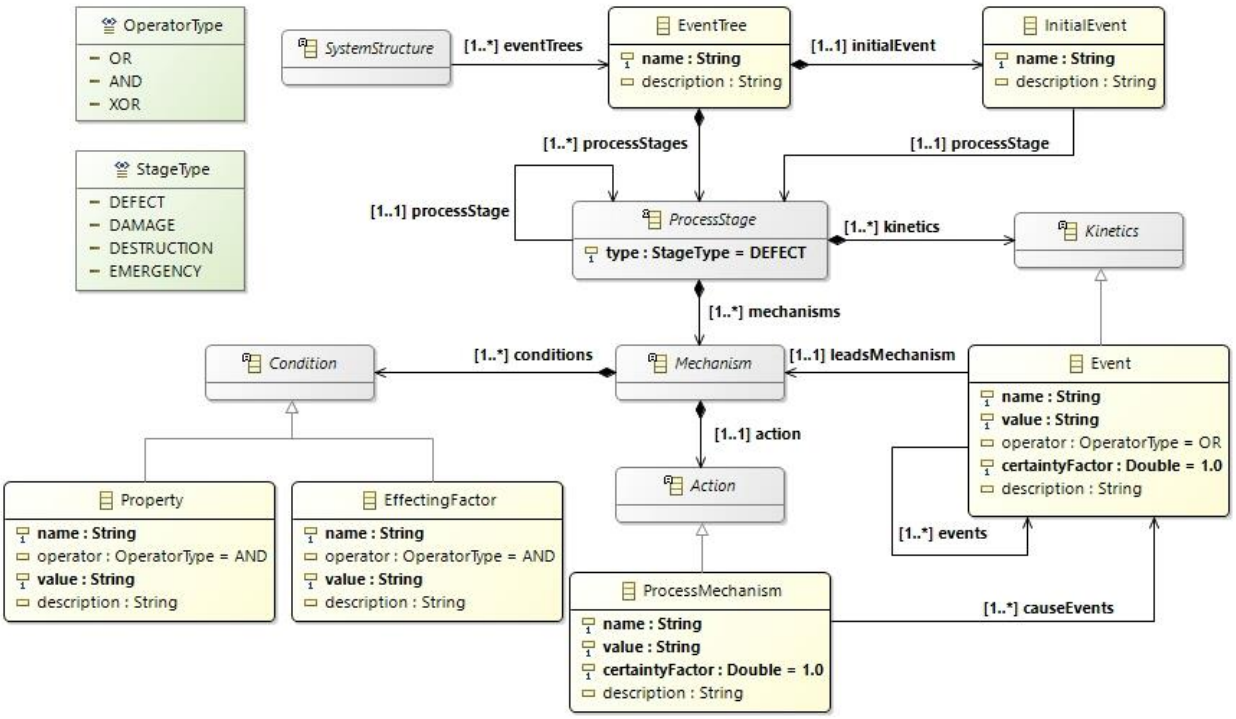

Figure 2. A metamodel of the extended event tree formalism

and a target metamodel of rule-based knowledge base.

D. Event tree seralization format

Currently, there is no unified standard format (a standard textual notation) for the event tree representation, and designed for computer-aided processing. So, it is proposed a XML serialization format for extended event trees formalism. Table 1 contains XML format description (a concrete syntax).

TABLE I. XML-LIKE FORMAT FOR REPRESENTATION OF EXTENDED EVENT TREES

Main XML nodes	Description
System	Information about the object under investigation (e.g., plant, line, branch, mechanical system, etc.)
Component	Information about a structural hierarchy of the object under investigation
Element	Information about a structural element of a mechanical system
EventTree	General information about the event tree
ProcessStage	General information about the stage
InitialEvent	Information about the mian initial event
Mechanism	General information about the mechanism
Property	Information about a property of of the object under investigation (a system element)
EffectingFactor	Information about an effecting factor
ProcessMechanism	General information about the mechanism (an initial event of a certain stage)
Event	Information about a concrete event and its parameters
Operator	Boolean operator: AND, OR, XOR

IV. EVENT TREES TRANSFORMATION TECHNIQUE

Event trees transformation technique is based on the generalized algorithm for transformation of conceptual models into knowledge base source codes that described in [13]. The main task of the proposed algorithm is to transform elements of an extended event tree (presented in XML format) into constructions of a knowledge representation language (CLIPS). So, the following main steps can be defined:

Step 1: Building the event tree describing the sequence of some emergency events, and their serialization in XML format. It should be noted that various tools for event trees modeling can be used at this step.

Step 2: Analyzing a XML structure of a serialized event tree. In this case, the main tree elements are extracted and matched with the elements of a rule-based model. This model is an universal means of intermediate representation of extracted knowledge in the form of logical rules which are independent form the knowledge representation language used (e.g., CLIPS, Jess, Drools, RuleML, SWRL, etc.).

Step 3: Visualizing and modifying the obtained rule-based model in RVML notation [2].

Step 4: Generating a knowledge base source code in CLIPS format based on the rule-based model.

Thus, let's define the transformation operator from (1):

$$T = \langle T_{CM-RM}, T_{RM-KB} \rangle, \quad (2)$$

$T_{CM-RM} : M_{XML}^{ET} \rightarrow M^{PR}$, $T_{RM-KB} : M^{PR} \rightarrow Code^{CLIPS}$

when T_{CM-RM} is a set of rules for transformation of a source extended event tree to a target rule-based model; T_{RM-KB} is a set of transformation rules of the rule-based model into CLIPS code; M_{XML}^{ET} is a representation of an extended event tree model in XML format; M^{PR} is a representation of acquired knowledge in the form of a rule-based model; $Code^{CLIPS}$ is a target CLIPS code.

Transformation rules for T_{CM-RM} and T_{RM-KB} are described in terms of the domain-specific declarative language – Transformation Model Representation Language (TMRL) [22]. TMRL constructs make it possible to describe the elements of the transformation scenario in a declarative form, in particular, the rules for the correspondence between elements of a source metamodel and a target metamodel.

Examples of the correspondence between the main elements of an extended event tree diagram, a rule-based model and CLIPS are presented in Table 2.

Complex rules containing several conditions are formed on the basis of the mechanism. Complex rules containing several actions are formed on the basis of the process mechanism description, which leads to some set of subsequent events. Also, each event can cause one or more subsequent events. Therefore, such a chain of events may also correspond to rules.

It should be noted that each event in the tree, as well as the process mechanism can be assigned a certainty factor. The certainty factor value reflects the subjective degree of expert confidence in the occurrence of a specified event or mechanism.

V. Implementation

Implementation of the proposed technique was carried out using a specialized technology for automatic development of software components (converters) of intelligent systems [15] and the corresponding software – KBDS [13]. These converters provide the knowledge base code generation by transforming conceptual models.

In particular, an experimental software component (converter) was developed to generate a rule-based model

TABLE II. The Elements Correspondences

Extended event tree	Rule-based model	CLIPS
EventTree	Model	-
InitialEvent / Event	FactTemplate / Fact	Deftemplate
InitialEvent (name) / Event (name)	Slot	(slot "<name>")
Mechanism	RuleTemplate / Rule	defrule
Property / EffectingFactor	FactTemplate / Condition	deftemplate / defrule (consequent)
Property (name) / EffectingFactor (name)	Slot	(slot "<name>")
ProcessMechanism	FactTemplate / Action	deftemplate / defrule (antecedent)

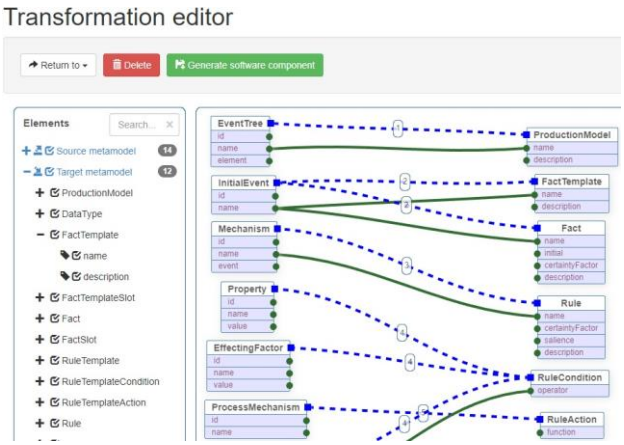

Figure 3. A transformation model in a special editor

by transforming extended event trees. The process of component development is described in [15]. Therefore, let's briefly summarize the main stages of this process:

- Creating a new project for a certain component in KBDS.
- Constructing (or generating) a source metamodel for an extended event tree using reverse engineering (extraction an abstract concepts and their relationships based on the analysis of a source XML document) or conversion of XML schema of a source event tree. The built metamodel for an extended event tree is sown in Figure 2.
- Creating a transformation model (scenario) that describes correspondences (transformation rules) between the elements of the source metamodel of an extended event tree and the target metamodel of the knowledge representation formalism (a rule-based model), and linking it to the software component being created. The special graphic editor included in KBDS (see Figure 3) is used for formation of transformation rules.
- Generating the transformation model code on TMRL.
- Correcting the TMRL code for the transformation model (in particular: adding complex rules reflecting, for example, the homonymy relationship between the elements of the source and target metamodels).

The final synthesis of a software component is carried out on the basis of the generated transformation model.

VI. Illustrative Example

Let's consider an illustrative example of the proposed approach and software application for rule base engineering by transforming the event tree diagrams. Created knowledge base describes a cause and effect complex of changes in technical conditions of petrochemical equipment elements (tanks and apparatus), and it is used for industrial safety expertise tasks, in particular, for definition of some degradation processes (corrosion, corrosion fatigue) and their events.

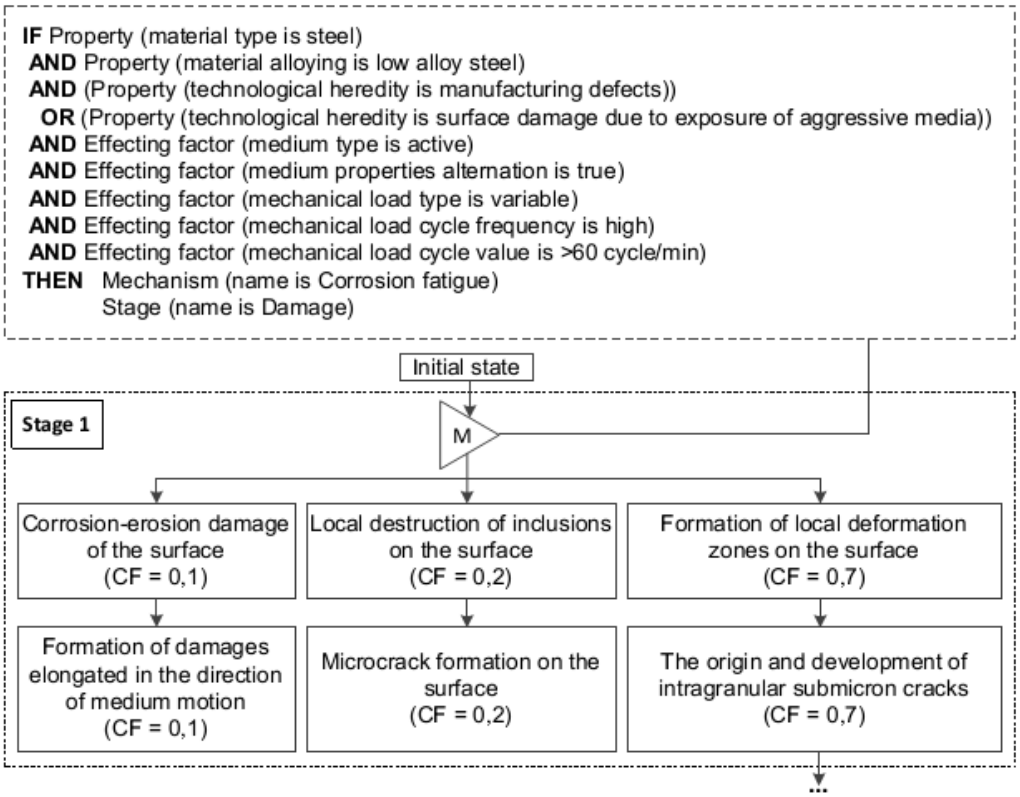

Figure 4. A fragment of an event tree diagram for corrosion fatigue

The main steps of knowledge base engineering with accordance of the proposed technique are the followings:

Step 1: Domain experts build extended event tree diagrams for degradation processes with using the template (see Figure 1) at different stages. In particular, the fragment on Figure 4 describes the "*damage*" stage for the "*corrosion fatigue*" degradation process. The technical object is a flange connection with angular diameter 6 in a strapping pipeline of a compressor. Built diagrams serialized as XML documents, a file fragment represented below:

```
<EventTree id="ET-1" name="Event tree" element="ELM-1">
 <InitialEvent id="IE-1" name="Failure of flange connection AD 6"/>
 <ProcessStage id="PS-1" name="Damage">
  <ProcessMechanism id="MEC-1" name="Corrosion fatigue" pnode="IE-1">
   <Property id="P-MEC-1-1" name="material type" value="steel"/>
   <Property id="P-MEC-1-2" name="material alloying" value="low alloy steel"/>
   <Operator id="OPR-1" name="OR">
    <Property id="P-MEC-1-3" name="technological heredity" value="manufacturing defects"/>
    <Property id="P-MEC-1-4" name="technological heredity" value="surface damage due to exposure of aggressive media"/>
   </Operator>
   <EffectingFactor id="EF-MEC-1-1" name="medium type" value="active"/>
   <EffectingFactor id="EF-MEC-1-2" name="medium properties alternation" value="true"/>
   <EffectingFactor id="EF-MEC-1-3" name="mechanical load type" value="variable"/>
   <EffectingFactor id="EF-MEC-1-4" name="mechanical load cycle frequency" value="high"/>
   <EffectingFactor id="EF-MEC-1-5" name="mechanical load cycle value" value=">60 cycle/min"/>
  </ProcessMechanism>
  <Event id="EV-1" name="Corrosion-erosion damage of the surface" certainty-factor="0,1" pnode="MEC-1"/>
  <Event id="EV-2" name="Formation of damages elongated in the direction of medium motion" certainty-factor="0,1" pnode="EV-1"/>
  <Event id="EV-3" name="Local destruction of inclusions on the surface" certainty-factor="0,2" pnode="MEC-1"/>
  <Event id="EV-4" name="Microcrack formation on the surface" certainty-factor="0,2" pnode="EV-3"/>
  …
 </ProcessStage>
 …
</EventTree>
```

Step 2: The constructed diagrams are transformed into the rule-based model with the aid of a specialized converter. This converter uses information about XML tags (constructions) and their correspondences (see Tables 1 and 2).

Step 3: Obtained rule-based model can be visualized and modified with the use of RVML notation [2] (in particular, users specify certainty factors).

Step 4: CLIPS code generation based on Table 2 correspondence patterns.

The following CLIPS code corresponds to the formed rule-based model:

```
(deftemplate InitialEvent
(slot id)
(slot name))
…
(deftemplate EffectingFactor
(slot id)
(slot name)
(slot value))
…
(defrule ProcessMechanism-MEC-1
```

```
    (declare (salience 4))
    (Property (name "material type") (value "steel"))
    (Property (name "material alloying")(value "low
alloy steel"))
   (EffectingFactor (name "medium type")(value
"active"))
   (EffectingFactor (name "medium properties
alternation")(value "true"))
   (EffectingFactor (name "mechanical load type")(value
"variable"))
   (EffectingFactor (name "mechanical load cycle
frequency")(value "high"))
   …
   =>
     (assert
      (ProcessMechanism (name "Corrosion fatigue"))
      (ProcessStage (name "Damage"))
     ))
```

VII. Conlusion

The paper describes the approach for rule bases engineering by analyzing and transforming extended event tree diagrams, which are applied in the field of failure and risk analysis of technical systems. The extension includes definition of levels describing different stages of the process under investigation, and specialized events corresponding to the mechanism concept.

The target knowledge representation language is CLIPS.

The proposed approach reduces the risk of programming errors at the stages of knowledge formalization and codification due to automatic source knowledge base codes generation, and also provides the ability for the domain experts to use domain-specific notations and domain models when engineering intelligent systems.

KBDS [13] and a previously developed technique [15] are utilized as a software and algorithmic platform for the proposed approach implementation. One of the results of this implementation is a software component (converter) with open REST API that can be used for other software projects. The component tested for development of rule-based knowledge base drafts for industrial safety expertise tasks.

Acknowledgment

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National Access Point for Provision of EU-wide Multimodal Travel Information Services

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Abstract - **Multimodal travel information includes static or dynamic travel and traffic data covering at least two modes of transport and allowing the possibility to compare transport modes. According to EU directives, EU-wide multimodal travel information services should be accurate and available across borders to various users. They should be accessible through appropriate National Access Points, one of whose main tasks is mutual interaction for the exchange of travel and traffic information, which EU member states should provide according to the EU Intelligent Transport Systems Directive (EU ITS Directive) and some delegated regulations. This paper provides a proposal for deployment of the National Access Point for multimodal travel information services in the Republic of Croatia. Along with the proposal, a brief analysis of regulations that define requirements, key stakeholders and the required data categories are presented in the paper. Also, the system architecture and functional requirements are presented on a conceptual level.**

Keywords – National Access Point, multimodal travel information services, Intelligent Transport Systems (ITS)

I. INTRODUCTION

The term Intelligent Transport Systems (ITS) refers to a holistic, control as well as information and communication technologies (ICT) upgrade of classic traffic and transport systems, which significantly improves system performance, traffic safety, efficiency in transportation of goods and passengers, increases passenger protection and comfort, reduces pollution, etc. [1] Typical examples of such applications are driver and passenger information systems, traffic management, incident management systems, urban public transport management, and so on. [2] This new concept based on intelligent communications solutions can make a significant contribution to a sustainable, secure and efficient transport system, and therefore the European Commission has adopted the Directive 2010/40/EU [3] on the framework for deploying Intelligent Transport Systems in the field of road transport and for interfacing with other modes of transport, also known as the "ITS Directive". The ITS Directive envisages the application of functional, technical and organizational specifications for ensuring compatibility, interoperability and continuity of implementation and operational use of multimodal services at the EU level. The Directive 2010/40/EU is a general document for coordination of ITS development in the European Union. Like other directives, it is not directly applicable in each member state. However, it is the obligation of member states to adapt their national legislation to achieve goals set by this EU directive. The basic objective of the ITS Directive is setting up of framework for future activities, which will consequently lead to the harmonization of ITS development in Europe. Seamless door-to-door travel across Europe is one of the European Commission's goals set out in the 2011 Transport White Paper, aiming to establish the framework for a European multimodal transport information, management and payment system. Multimodal travel information for people wishing to travel across Europe (cross EU borders) is one of the pre-requisites of seamless travel, ideally using a single point of access to information about relevant services via any mode of communication and in any European country. [4]

Multimodal traffic information allows travelers to plan their trip from A to B by comparing different travel options using different transport modes. Multimodal traffic information can include a combination of two and more modes of transportation that the user/traveler uses: air, rail, waterway, bus, public transport, bicycle riding and walking. Such services allow the user to obtain personalized routing results according to specific criteria or travel needs. [5], [6].

Multimodal travel information services are currently available at regional and national levels in many parts of the EU. However, the continuity of services and interoperability of systems are required in order to provide EU-wide multimodal travel information for the citizens of Europe. [4]

The prime users of multimodal travel information are citizens (passengers). Users can look for information to help them identify the most cost efficient, the fastest and the most convenient way to travel during a particular trip. Moreover, users can search for information about any changes they wish or have to make on their journey, whether they are limited to the state of traffic, possible stoppages, in case they are redirected to different routes and the like. Users may require information on both short-distance local travel and long-distance travel. Traffic system stakeholders are authorized to provide information not only to citizens, but also to companies involved in transport or public service management, considering the ability to use real-time information on incidents, traffic jams and traffic restrictions that can increase the efficiency of the traffic network management and reduce operating costs. Moreover, logistics companies and companies dealing with transport objects use information in real-time for their daily activities when deciding on the optimal routes.

The following chapters will define the National Access Point and groups of key stakeholders. We will explain which

data are expected to be part of National Access Point for Multimodal Information (NAPMM), as well as data, formats and protocols that have to ensure system interoperability. Basic functional requirements will be presented at the functional level, and the basic framework for implementation in the Republic of Croatia will be described.

II. NATIONAL ACCESS POINT AND STAKEHOLDERS

National Access Point for Multimodal Information (NAPMM) is defined as a digital interface where at least the static travel and historic traffic data, together with the corresponding metadata, are made accessible for reuse, or where the sources and metadata of these data are made accessible for reuse [3]. Efficient exchange and reuse of data for the provision of comprehensive travel information services are key motivators for setting up this kind of system, and therefore all stakeholders should make data, corresponding metadata and information on the quality of the data accessible to users through the Access Point. From the technical perspective, NAPMM point may take various forms, such as a database, data warehouse, data marketplace, repository and register, web portal or similar, depending on the type of data. NAPMM requires contribution from various groups of stakeholders, as illustrated in Figure 1. Transport authorities (*any public authority responsible for traffic management or planning, control or management of a given transport network or modes of transport, or both, falling within its territorial competence*), transport operators (*any public or private entity that is responsible for maintenance and management of a transport service*), transport on demand service providers (*any public or private provider of transport on demand service to users and end-users, including travel and traffic information thereof*) and infrastructure managers (*any public or private body or undertaking that is responsible in particular for establishing and maintaining transport infrastructure, or part thereof*) contribute with data that is being collected and available in a machine readable format.

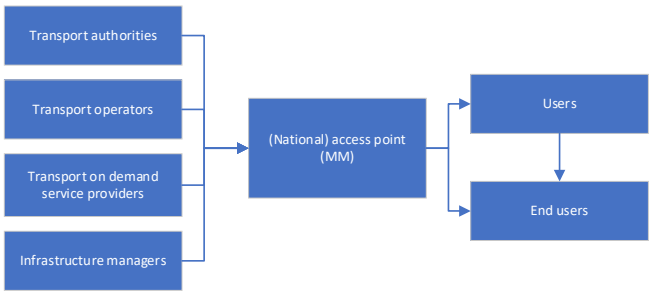

Figure 1. NAPMM and involved stakeholders

Users (*public or private entity which uses the National Access Point, such as transport authorities, transport operators, travel information service providers, digital map producers, transport on demand service providers and infrastructure managers*) and end users (*any natural or legal person who has access to travel information*) can get access to static or dynamic travel and traffic data. Users can use this data as an enabler for various transportation related services (digital maps, provision of multimodal travel information) as well as for optimization of their own business processes. End users will use this data to make well informed travel decisions, enjoying considerable time savings as they will be able to use travel information services as an ITS service, including digital maps that enable them access to travel and traffic information of at least one transport mode.

Multimodal travel information services, according to the Delegated Regulation 2017/1926 supplementing the Directive 2010/40/EU of the European Parliament and of the Council with regard to the provision of EU-wide multimodal travel information services [7], applies to all transport modes, such as schedule based transport (air, rail including high speed rail, conventional rail and light rail, long-distance coach, maritime transport including ferry, metro, tram, bus, trolley-bus, cableways), transport on demand (shuttle bus, shuttle ferry, taxi, ride-share, car-share, car-pool, car-hire, bike-share, bike-hire, dial-a-ride) and personal based (car, motorcycle, bicycle, walking). Due to the specifics of the transport system in Croatia, some transport modes, like high speed rail, metro and inland waterway passenger transport, do not exist and will not be considered. On the other hand, some other modes of transport, like cable car transport, which is not originally stated in the Delegated Regulation 2017/1926, will be introduced.

III. DATA

According to the definition in the Delegated Regulation 2017/1926 [7], multimodal travel information services are based on both static and dynamic travel and traffic data, where 'dynamic travel and traffic data' stands for data related to different transport modes that often change on a regular basis, and 'static travel and traffic data' stands for data related to different transport modes that do not change at all or change seldom and on a regular basis.

Both static and dynamic data are divided in three levels of service, based on the expected time of inclusion in NAPMM, as presented in Figure 2.

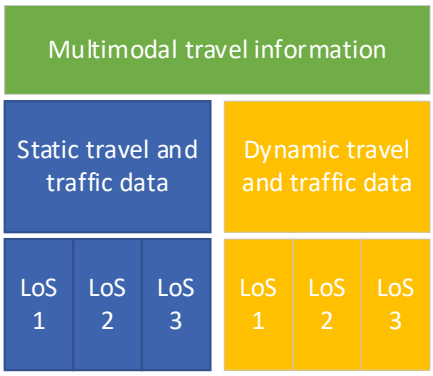

Figure 2. NAPMM data organization

The static travel data Level of Service 1 for example, include location search data of origins and destinations and access nodes, trip plans, access nodes and trip plan computations for both scheduled modes of transport and for road transport (for personal modes). The proposed deadline for the integration of this data to NAPMM is December 1, 2019, at the latest. The static travel data Level of Service 2 include data on location search for demand-responsive modes, information service, trip plans, auxiliary information and availability check, and deadline is December 1, 2020, at the latest. The static travel data Level of Service 3 include data on a detailed common standard and special fare query for all scheduled modes, information service for all modes, trip plans and trip plans computation, while deadline is December 1, 2021, at the latest. These deadlines are defined for a comprehensive TEN-T network, and for all levels of service the implementation on other parts of the Union Transport Network should be completed by December 1, 2023, at the latest.

Dynamic travel and traffic data are also divided on three service levels. Level of service 1 includes passing times, trip plans and auxiliary information. Level of service 2 includes passing times, trip plans and auxiliary information for all modes, information service regarding publicly accessible charging stations for electric vehicles and refueling points and availability check. Level of service 3 includes future predicted road link travel times.

Multimodal travel information services include a number of relevant pre-existing standards and technical specifications that exist, covering road (DATEX II), rail (TAP-TSI technical documents B1, B2, B3, B4, B8, B9), air (IATA SSIM) and underlying spatial data (INSPIRE). The application of these protocols is crucial for ensuring interoperability of services.

Datex II is a data exchange standard for exchanging traffic information between traffic management centers, traffic service providers, traffic operators and media partners. For example, it contains traffic incidents, current road works and other special traffic-related events. [8] The document 'Telematics Applications for Passenger Services Technical Specifications for Interoperability' (TAP TSI) defines European-wide procedures and interfaces between all types of railway industry stakeholders (passengers, railway undertakings, infrastructure managers, station managers, public transport authorities, ticket vendors and tour operators). [9] The IATA SSIM is the official set of standards, guiding the industry with recommended practices, messaging formats and data processing procedures that are to be used by all IATA member airlines and their business partners for the exchange of airline schedules, communication of airport information, coordination and minimum connect time data. INSPIRE is an EU initiative to establish an infrastructure for spatial information in Europe that is geared to help to make spatial or geographical information more accessible and interoperable for a wide range of purposes supporting sustainable development. [1], [4]

IV. FUNCTIONAL REQUIREMENTS

To be in line with EU recommendations NAPMM shall be independent of architecture and the type of technology used for its implementation, so it is defined by functional requirements. Planning, implementing, and managing the National Access Point can be deployed in a variety of ways and can involve different stakeholders, while meeting the conditions of interoperability, which will enable all stakeholders to connect to the system as well as communicate with other access points.

In technical terms, NAPMM is based on information-communication system (ICT solution). The information-communication system that functions as a national access point is primarily intended as a data transfer agent that has the task of linking information sources and information users in a secure and controlled manner. It is characterized by the functionality of ensuring low latency connectivity between devices, business applications, information sources, and intermediaries and users and end users.

NAPMM is characterized by a three-layer architecture in functional terms, as shown in Figure 3. The National Access Point connects stakeholders, data sources and metadata and applications, i.e. users and end users. As recommended in the European Commission guidelines, to optimize system performance and reduce total costs, it is proposed to establish a single access point for all priority areas.

In order to provide full functionality of the NAPMM, we need to integrate it with internal and external systems. Internal systems are in function of the system itself, while external systems are in function of other stakeholders. When sharing multimodal information, it is necessary to provide integration points and appropriate support, including eventual adaptation in accordance with NAPMM requirements, so that the system has access to relevant data.

The communication architecture of the system includes protocols for communication with stakeholders, application programming interfaces, as well as protocols for communication with users and end users. NAPMM should have support for all protocols defined in chapter III, since this requirement is key for ensuring interoperability.

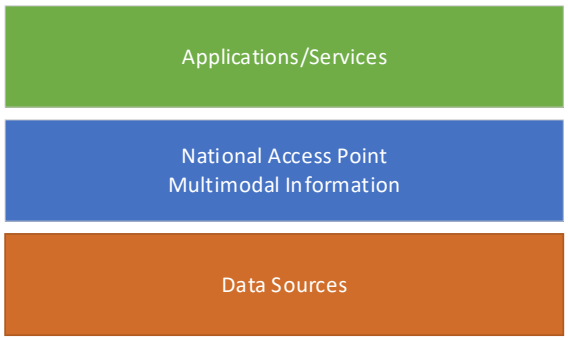

Figure 3. NAPMM three-layer architecture

Based on the functional variations, it is possible to define three levels of NAPMM, respectively, levels 1, 2 and 3. Depending on the model chosen, or the level of the NAPMM, the requirements on technical characteristics, as well as on the quality and level of data may vary. For example, the NAPMM Level 1 is only a data window, while the NAPMM Level 3 also contains data itself, and therefore the quality requirements are different. It is also necessary to emphasize that differences in the technical capabilities and quality of the national access point are different from the quality of the data.

NAPMM Level 1 allows for forwarding data from available sources in real time without data analytics. Basic data processing (transformation) is supported. It supports the management of data sources and users, assigning different roles according to user profiles. Communication with data sources and users takes place via the appropriate application programming interface (API).

NAPMM Level 2 enables forwarding of data from available sources in real-time. Basic data analytics is supported. "Raw" data from the source is not stored, but only data that are the result of the analysis. Basic data processing (transformation) is supported. Managing data sources and users is supported, assigning different authority according to user profiles. Users can customize the profile configuration (data stream customization). No billing is supported. Communication with data sources and users takes place via the appropriate Application Programming Interface (API).

NAPMM Level 3 enables data collection in standardized format, processing and storage of data, distributing data to third parties through appropriate communication and application interfaces, creating multiple user profiles for different stakeholders, users and end users, assigning rights and authority to system users. It has the capability of analytics of data collected, data backup capabilities, data source and data management functionality, third-party connectivity support, system monitoring and overall monitoring support, appropriate user interface, appropriate control panel, business and operational management capability, and if necessary, billing of data usage.

V. STEPS FOR IMPLEMENTATION OF NAPMM IN CROATIA

Currently, multimodal information services across Europe are generally not interoperable and are fragmented in terms of what they offer, including modal and geographical coverage, real-time information, and quality levels. Unfortunately, this is also true in the case of the Republic of Croatia. Therefore, it is necessary to bring to life a strategy on multimodal traffic services in Croatia as a prerequisite for the continuity and harmonized dissemination of this 21st century asset.

The strategy needs to define all the phases necessary for the implementation of the ITS Directive. Its first part, the description of the current situation should cover all potential stakeholders in the road, rail, sea and air traffic domains, service providers, users and end users, which are primarily related to the TEN T corridors, but also to the rest of the transport network. A detailed analysis of all involved and proposed stakeholders needs to be carried out, including the identification of the existing data that stakeholders collect, identification of the technical possibilities of the existing information and communication systems for storing and sharing traffic data (if any), the existing processes related to data collection and sharing, as well as quality control processes. In the analysis of the stakeholders, it is necessary to consider their individual potential for adjustment to a new strategy and the potential of the whole system for adjustment to the objectives of the ITS Directive. It would also be necessary for individual stakeholders to define if and which upgrade equipment or systems they need and to estimate the costs.

The strategy, furthermore, needs to define in detail the functional system requirements, the processes and the data exchange scenarios for all stakeholders involved in the system. If the creation of a new NAPMM for data defined by the ITS Directive is proposed, it is necessary to define the functional architecture of the system, the logical architecture of the system, the system communication architecture and the organizational structure of the system. The analysis should also include all operational and business processes necessary for the operation of the NAPMM defined by the ITS Directive. If the strategy defines a solution in the form of expansion of the existing National Access Point, this solution needs to be elaborated from a functional, logical, communicative and organizational aspect. The implementation plan should include key implementation scenarios, which should comprise the priority lists of stakeholders that will be involved in the process, and the phases and procedures for their integration. It is necessary to define which stakeholders with which data type and with what modifications to the existing systems participate in the exchange of information. Several scenarios need to be devised which follow the implementation system of the ITS Directive, depending on the defined functional capabilities, i.e. the available project budget. And finally, a proposal for tools, measures and procedures for quality control and assurance needs to be written.

VI. CONCLUSION

The Republic of Croatia, in accordance with the ITS Directive, aims to define the strategy for establishing a National Access Point for the provision of information on multimodal travel and exchange of information on the TEN-T network and urban hubs. The aim of this initiative is to provide access to static information and information available to public and private stakeholders (service providers) as well as access to dynamic information, if any. The motivation for implementing the measure is to enable the exchange of relevant information by laying down all defined technical prerequisites, creating value added services for travelers within the Republic of Croatia and the EU,

enhancing cooperation of all relevant stakeholders and establishing stakeholders' partnership.

This paper gives an overview of the features of national access points for sharing multimodal information on travel and traffic. The motivation for introducing this type of service is analyzed, basic analysis of key documentation is provided, key stakeholders (groups) are identified, and data exchanged between them. An overview of the basic functional features of NAPMM is given, as well as an overview of the steps to be implemented for the deployment of such a system in the Republic of Croatia. Future papers will deal with a detailed analysis of stakeholders, data collected and exchanged, and a detailed description of functional features of the NAPMM system.

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PAPERS

Privacy-Preserving Encryption-Domain Video Retrieval over the Cloud via Block Transformations of Key Frames

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Abstract—**Thanks to the popularity of mobile devices and convenience of cloud computing environment, more and more people are getting use to store their captured video in the cloud; however, there's no guarantee that the stored information is not accessible to the cloud computing server, thus leading to the concern of privacy. A naïve approach to encrypt all videos before uploading them to the cloud does protect the privacy, but at the expense of seriously affecting the retrieval performance as every encrypted video should be downloaded, decrypted, and compared with the query request. We proposed to perform the video retrieval directly in the encrypted domain, i.e., in the cloud while only the desired ones will be retrieved and decrypted.**

Keywords-video encryption; video retrieval;cloud computing; encryption-domain processing;block-transformations

I. INTRODUCTION

Many said it has been a cloud-computing era as the industry no longer needs to invest money on buying high-end hardware/software but just relies on the commonly provided cloud services. This is particularly true when wirelessly connected mobile devices are extremely common and are all equipped with the capability of capturing photos, videos and sounds. Due to huge amount of available storage and ubiquitous accessibility, most of the captured multimedia data are chosen to be kept on the cloud. However, when data privacy is a concern, many people may choose to encrypt the data before uploading them to the cloud, so that the servers on the cloud could not temper with the data. Such an approach does help on protecting the privacy, but is at the expense of sacrificing the retrieval efficiency. More specifically, to find a piece of information encrypted and stored on the cloud server, all the encrypted data should be downloaded to the local client to get decrypted and compared with the query data.

In this paper, we focus on dealing with video data only, and propose a system that can support encryption-domain video retrieval; that is, we encrypt every video before uploading it to the cloud and the video retrieval can be done directly in the encryption domain without the need to go through the download/decrypt/compare operations and only the ones that are similar enough to the query will be downloaded and decrypted. Note that to support encryption-domain video retrieval, the traditional encryption algorithms such as RSA, DES and AES cannot be used as the corresponding encryption-domain video retrieval is, to the best of our knowledge, not supported or not computationally efficient, and therefore we have developed a novel encryption-domain video retrieval scheme based on block transformations. Also notice that to support video retrieval, only key frames of a video are encrypted through block transformations while the whole video data itself can be encrypted using the traditional RSA, DES or AES encryption algorithm separately as it is only needed when the corresponding encrypted key frames are found to be similar to the query. This helps reduce the extra storage overhead for supporting encryption-domain video retrieval.

The rest of the paper is organized as follows. Section 2 reviews papers that are closely related to our work. Section 3 describes our whole system in great detail. Section 4 evaluates our work to demonstrate its effectiveness. Section 5 concludes this work and hints for some potential further research directions.

II. RELATED WORK

There are three types of researches that are related to our work: video encryption, video retrieval, and encryption-domain video retrieval.

The first type of research is on video encryption. It is with no doubt that for encryption, algorithms like DES, RSA, IDEA and AES are commonly used; however, they are mainly used for text and binary data, and in general are not suitable for directly encrypting huge amount of multimedia information such as videos. A naïve algorithm [1] is to treat the bit-stream in a MPEG file as text data and ignore its special structure by encrypting every byte with DES or AES. Though the security can be guaranteed, the processing time is not acceptable. Li et al. [2] therefore proposed a method to permute the pixels to perturb the multimedia data to achieve the security, while still being able to roughly maintain the data size. In spite of its simplicity and efficiency, such a method is thought to be vulnerable to known-plaintext attack [3]. Li et al. [2] shows that when secrete permutations can be dynamically updated and combined with other techniques,

known-plaintext attacks could be avoided. To reduce the encryption processing time, Socek et al. [4] proposed *selective encryption* algorithm to only encrypt a proportion of the original data; however, the involved encryption algorithms are DES or AES, while the selected part is not in regard of the whole data.

The second type of research is on video retrieval. While early works mainly rely on keyword-based approaches that require videos to be annotated before hand, modern studies tend to use content-based approaches generally following the ensuing steps, where at the preprocessing time, (1) decompose a video into scenes, shots and key frames; (2) extract the features from key frames, objects, or the corresponding motions; (3) based on the semantic information and features, cluster or annotate the video data to construct the indices to be stored in the database for later use.; and at the run time, retrieve the most similar results to the query video and/or allow users to feedback to the system to further refine the search results. In general, context-based video retrieval approaches adopt low-level features such as colors, shapes and textures for comparison where *color histogram* is one of the simplest methods as it can represent the color distribution among all the video frames while not being affected by the geometrical transformations such as translations, rotations, scaling or distortions often observed in a video. Yu et al. [5] proposed a video retrieval method based on color histogram and *non-uniform quantization*, and speed up the search by applying a multi-resolution structure.

The third type of research is on encryption-domain video retrieval. As far as we know, there seems to be no study in this regard. By concentrating on text information, Swaminathan et al. [6] developed a system that ranks the search results according to the similarity to the query by performing the comparisons directly in the encryption domain; however, such work may not be directly applicable to search features in videos. In addition to being able to perform fast and accurate video search, Lu et al. [7] tried to reduce the transmission overhead by making use of secrete keys to encrypt video and build indices and then upload the encrypted data and indices to the cloud. They extract/process/encrypt the information derived from color histogram, and perform XOR with secrete keys, followed by permutations to achieve the encryption. At run time, secure inverted index and secure min-hash are used to speed up the search.

III. PROPOSED SYSTEM

A. System Architecture

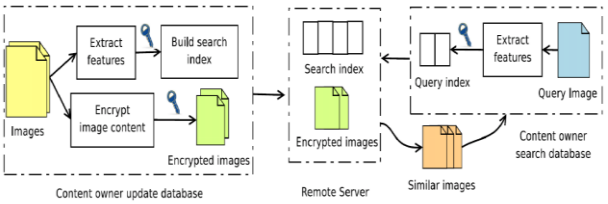


Figure 1. The system architecture of Lu et al. [7]

Lu et al. [7] though proposed an encryption-domain video retrieval system, the underlying method is still a text-based approach, while our work intends to modify it to build a system that completely makes use of video features, in particular, color histograms in key frames, to support encryption-domain video retrieval. Figure 1 shows the architecture from [7], where on the left is the information provided by a user containing three parts: a secrete key, the video encrypted using the key, and the index built from extracted video features and encrypted using the key. Note that the index is meant to speed up the search so that we don't need to compare the whole video. For video retrieval, the encrypted index build from the query's features is uploaded to the cloud and compared to find the most similar video, which will be downloaded and decrypted on the client side.

B. Encryption Methods

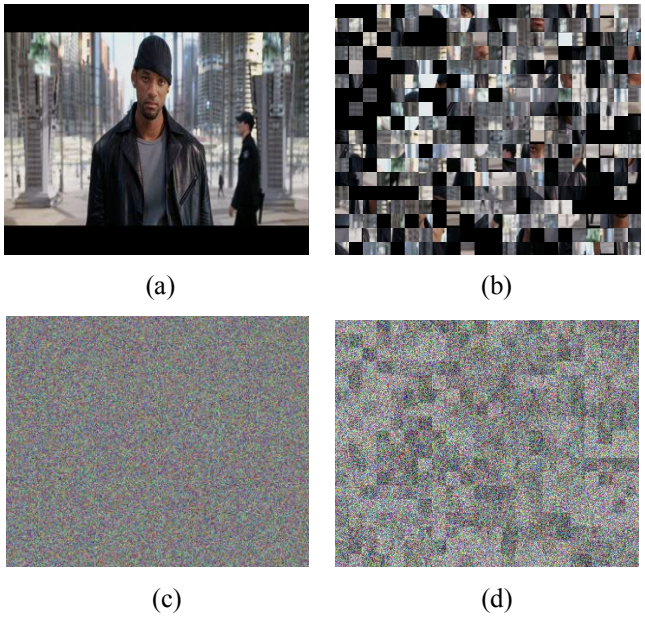


Figure 2. Video encryption

As mentioned before, AES or RSA like algorithms are not suitable for encrypting video features, we opt to manipulate the visual content so that the original video is kept as secrete while it's still possible to perform video retrieval. The idea is to perform secrete permutation, but instead of pixels, we permute blocks, to change from Figure 2(a) to Figure 2(b), to increase efficiency. However, as part of the content is still visible, we further combine it with a random noise, as shown in Figure 2(c), to derive the result shown in Figure 2(d). This kind of permutation can be applied to every frame of a video, but we choose to do it on a per-shot base as it can strike a better balance between security and efficiency.

C. Encrption-Domain Video Retrieval

To be able to perform encryption-domain video retrieval, we combined the video retrieval framework proposed by Hu

et al. [8] with aforementioned Lu et al. work in [7] to become a client-server architecture, where on the client, features from a video are extracted and clustered into shots, and a representative frame, termed as key frame is selected from each shot. Each such key frame is encrypted as just mentioned and uploaded to the cloud server for future comparison and retrieval to find the most similar video at the run time. For comparison, different features/indices can be used, including *color histogram*, *block color histogram* (dividing a key frame into blocks and calculating the color histogram of each block), and *color moments*. To measure the similarity, after numerous experiments, we adopt the L_1 norm.

IV. EXPERIMENTAL RESULTS



Figure 3. The 15 key frames for dividing the first video into 15 shots

TABLE I.
COMPARISONS ON THE NUMBER OF HISTOGRAM BINS

Bins / Accuracy	256^3	100^3	50^3	10^3
15 shots	0.784	0.768	0.766	0.764
20 shots	0.816	0.8	0. 79	0.766
25 shots	0.816	0.802	0.766	0.796

We have conducted experiments using two videos. The first one is an advertising video, from which we extract the first 500 video frames and divided into 15, 20, and 25 shots, respectively, as shown in Figure 3, to seek for better video retrieval accuracy, as will be shown later. As for the video features for retrieval, we compare with the work from Shih et al. [9] to divide a frame into blocks and calculate the corresponding color moments. We simulate this approach but change it to color histogram, called block color histogram, and in addition, we also calculate the color histogram for the whole frame. Table I shows the accuracy results for different number of shots for different video features. It can be seen that the color histogram for the whole frame offers best retrieval accuracy.



Figure 4. The 15 key frames for dividing the second video into 15 shots

The second testing video is from the movie I. Robot, where we extract 18555 frames and 2423 key frames, as shown in Figure 4. To compare with Yu et al. [5], we also use RGB color space with the bins to be 256^3, and the query frames are 1000 randomly chosen frames from the aforementioned 18555 frames. Here Top(K) is referring to the K topmost frames that are similar to the query frame. As can be seen in Table III, our work offers comparable accuracy.

TABLE II. COMPARISONS WITH YU ET AL.[5]

Top(k) / Accuracy	3	4	5
Yu's	0.78	0.81	0.85
Our's	0.807	0.815	0.817

To understand how our system impacts the overall storage when encryption is performed, on one hand, we have tried to extract a shot from the second video containing 22 frames, convert it into an uncompressed AVI file, and compress it into a MPG file; on the other hand, we have encrypted those frames in the same shot using aforementioned algorithm, converted it to an uncompressed AVI file, and then a compressed MPG file. Table IV shows the corresponding file sizes and demonstrates that the encrypted version is not necessarily larger than the original one. Furthermore, Figure 5 shows that there's no quality loss after the decryption, which means we can successfully recover the video frames after retrieval.

TABLE III. STATISTICS ABOUT STORAGE

	.avi	.mpg
Original video	6.537 Mbytes	216 Kbytes
Encrypted video	10.212 Mbytes	215 Kbytes
Decrypted video	6.537Mbytes	216 Kbytes

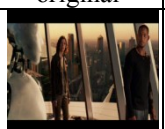
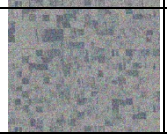
Frame #	original	Encrypted	decrypted
18858			
18868			
18878			

Figure 5. Some frames of encryption/decryption from the second video

V. CONCLUSION AND FUTURE WORKS

We have proposed a system that can perform encryption-domain video retrieval. Each input video is decomposed into shots to determine the key frames, and these key frames are encrypted through a block-based permutation combined with noise, before uploading to the cloud server. At run time, the query video follows similar procedures to extract its key frames, and encrypted to be sent to the cloud server to look for similar videos stored in the cloud environment directly in the encryption domain. Only the ones that are similar enough will be downloaded to the client and decrypted as the retrieval results. Evaluation results show that our proposed work provides not only the desired privacy, but also satisfactory accuracy when compared with traditional content-based video retrieval systems which do not address the issue of privacy.

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Flow-based Anomaly Detection Using Multilayer Perceptron in Software Defined Networks

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***Abstract*—For high-speed networks, this paper developed a flow-based anomaly detection system for reducing the overhead in Software Defined Networks (SDN). The controller in SDN uses a deep learning technique, Multilayer Perceptron (MLP), to automatically generate the weights for detecting the anomaly. We investigate the activation functions and the number of hidden layers used in MLP to compare flow-based MLP (FBM) and packet-based MLP (PBM). The results show that FBM is a better solution than PBM because it has lower false positive rate when true positive rate is high. Also FBM can provide lower overhead because PBM spends 123% time over FBM on establishing the MLP model.**

Keywords—deep learning, flow-based, multilayer perceptron, anomaly detection system, software defined networks

I. INTRODUCTION

In a high-speed network of 10Gbps~100Gbps, it is a big challenge to monitor packets' contents for Network-based Intrusion Detection System (NIDS). Therefore, instead of packet-based monitoring methods, flow-based monitoring methods attract more attention in high-speed networks. The flow is defined as "the collected IP packets through an observation point over a period of time, where these packets having the same attributes belong to a flow" [1]. The advantages of a flow-based method include: (1) It can be integrated into packet forwarding devices, such as routers and switches, so additional devices are not needed; (2) As the packet information is aggregated into flow information, the amount of data to be analyzed is greatly reduced; (3) the flow information is generated only based on the packet headers, so its privacy is much better.

Some flow-based monitoring methods were proposed, but they need to be individually installed or set up in the routers and switches. Thus, setting up a large network is time-consuming and laborious. In 2008, Stanford University proposed a new network architecture called Software Defined Networks (SDN) [2], which can separate the control plane from the data plane in a network. The switch in the data plane is a forwarding engine which transmits packets according to the rules defined by the controller in the control plane. That is, the control-plane functions are handled by the controller. Under the SDN architecture, network management and setting become very easy because new network services can be quickly deployed to the controller through software, significantly reducing operating costs and the error occurring probability.

As the SDN controller has the flow information of the overall network, the SDN network is more suitable for flow-based monitoring methods than the traditional network. Some papers investigated flow-based methods to detect traffic anomaly in SDN [3-6]. In this field, how to correctly and effectively detect anomaly flows is the key issue. The previous research determines it mainly depending on the researchers' observations and experiences. Recently, the deep learning, an important role of artificial intelligence, uses deep neuron-like methods to mimic human learning, and can automatically find the correlation of data. Thus, applying deep learning to automatically generate detecting anomaly rules is a good direction because we don't need to accumulate many experiences about traffic anomaly.

In the paper, we propose a flow-based Multilayer Perceptron model (MLP), short for FBM, to detect traffic anomaly. The paper has main contributions: (1) developing a flow-based anomaly detection system in a SDN environment; (2) constructing a flow-based MLP model; and (3) performing various experiments to evaluate the effects of various parameters in the FBM model on performance.

The organization of this paper is as follows. Section 2 describes the background, including related literatures and the MLP model. Section 3 explains how to apply MLP to detect anomaly flows. The experiment including environment setting and used parameters is shown in Section 4 while the experimental results are exhibited in Section 5. Finally, Section 6 concludes this paper.

II. BACKGROUND

This section describes the related research, including the flow-based anomaly detection and some intrusion detection models using machine learning. Since this paper uses MLP to construct an anomaly detection model, the relevant knowledge about MLP is also introduced.

A. Flow-based Anomaly Detection

In order to achieve rapid anomaly detection, the flow-based technique becomes more important. The paper [7] used the flow-based method to detect anomaly with flow characteristics in a traditional network. [3-6] studied the anomaly detection in a SDN environment. The entropy is used to detect Worms, DDoS, and Port Scan attacks in [4] while DNS amplification attacks are focused in [6]. However, both used simulated attacking packets to train the model. In a SDN environment, [3] used the controller as an analyzer including the actuators, the comparators, and the scorers to count the

degree of risk under attacking. On the other hand, [5] applied blockchain technology to verify the security of flows in a SDN environment. The comparison of these papers is summarized in Table I.

TABLE I. COMPARISON OF RESEARCH ON FLOW-BASED ANOMALY DETECTION

Paper	SDN	Method	Attack
[7]	N	Sampling	TCP SYN Flood
[4]	Y	Entropy	Worms Port Scan TCP SYN Flood
[6]	Y	Entropy	Zombies DNS Amplification
[3]	Y	The degree of risk	TCP SYN Flood SQL Slammer Worm DNS Amplification NTP Attack
[5]	Y	Blockchain	Zombies Internal attack in SDN

B. Anomaly Detection with Machine Learning

Recently, many machine learning methods were adopted to improve the anomaly detection. [8] applied flow-based features into Replicator Neural Network (RNN) to learn the characteristics of intrusions for anomaly detection. [9] used back-propagation neural network (BPNN) to identify the behavior of intrusions. [10] applied regression and K-means methods to train the data set and figure out whether the traffic is an anomaly. Four machine learning algorithms: NaiveBayes, SupportVector Machine, J48, and Deep Neural Network (DNN), as classifiers were compared for training different types of anomaly [11] This paper found that deep learning is the best classifier among four algorithms. The comparison of these papers is shown in Table II.

TABLE II. COMPARISON OF RESEARCH ON INTRUSION DETECTION WITH MACHINE LEARNING

Paper	Method	Data set	Attack
[8]	RNN	Reality	Zombies
[9]	BPNN	Reality	DoS Attack, R2L Attack U2R Attack
[10]	K-means	Simulation	DoS Attack, R2L Attack U2R Attack
[11]	NaiveBayes, SVM, J48, DNN	Reality	DoS Attack, R2L Attack U2R Attack

R2L: Remote to Local, U2R: User-to-Root

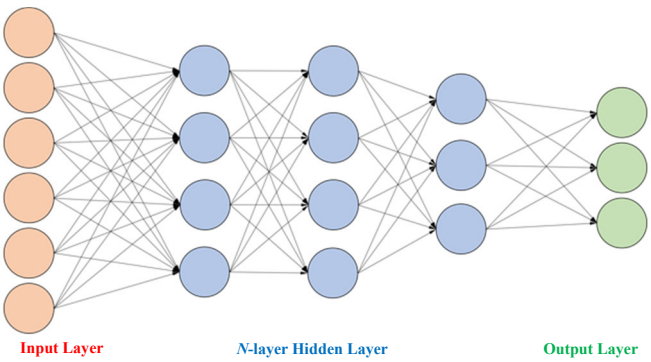

Figure 1. Multilayer perceptron model

C. Multilayer Perceptron (MLP)

MLP is a feedforward neural network, which has the gradient descent feature. MLP is different from a typical single-layer neural network which has limited hidden layers and uses a linear function. MLP is composed of multiple neurons and uses back-propagation supervised learning. As shown in Fig. 1, MLP can be regarded as a directed graph which consists of an input layer, multiple hidden layers, and an output layer, where neurons of the previous layer are connected to neurons of the next layer. Except the input neurons (neurons in the input layer), every neuron has a activation function, which continuously reduces the gradient to achieve the convergence.

There is a corresponding weight between each neuron in the previous layer and each neuron in the next layer. The weights are used to calculate the output value of each neuron. Suppose that MLP has an input layer, a N-layer hidden layer, and an output layer. Let $y_{k,i}$ represent the output of the ith neuron of the kth layer where k=0 represents the input layer and k=N+1 represents the output layer. $w_{k,i,j}$ represents the weight between the ith neuron of the kth layer and the jth neuron of the k+1th layer. The outputs of the input-layer neurons can be calculated by Equation (1) while the outputs of neurons in other layers (including the output layer) can be calculated by Equation (2), as

$$y_{0,j} = x_j, \tag{1}$$

$$z_{k,j} = \sum_i w_{k-1,i,j}\, y_{k-1,i} + b_{k,j}; \quad (k=1\ldots N+1),$$

$$y_{k,j} = f_{k,j}(z_{k,j}), \tag{2}$$

where x_j represents the jth input, $b_{k,j}$ represents the offset, $f_{k,j}$ represents the activation function, and $z_{k,j}$ represents the value, which sums up the weights, but has not been activated yet, of the jth neuron in the kth layer.

In Equation (1), when k=0, the output of a neuron in the input layer is directly set as its input. As seen in Equation (2), for the ith neuron of the kth layer, by using the outputs of neutrons in the previous layer, calculating $z_{k,j}$ by weight calculation, and performing the activation function on $z_{k,j}$, the output $y_{k,i}$ can be obtained.

The activation function is usually a kind of differentiable function because thus MLP can use the back-propagation method to get the input from the output. The commonly used functions are Sigmoid function, ReLu function, and Maxout function. Sigmoid function is often used in the area of population change and regression in social sciences. Its characteristics is that it can limit the output to a certain range, which is helpful for the convergence. Among the category of Sigmoid function, the Tangent function has the smallest gradient and the fastest convergence speed. ReLu function is a nonlinear function that conforms to the biological learning situation. The output is zero when the input is less than zero while the output remains unchanged when the input is more than zero, so the convergence of ReLu function can be efficiently achieved. Maxout function will select the maximum among all sum-up values in the virtual neutrons by adding a virtual hidden layer as the output.

III. FLOW-BASED MULTILAYER PERCEPTION MODEL (FBM)

In this section, we explain how to establish FBM, i.e., adopting appropriate flow features and choosing the proper activation functions in MLP.

A. Flow features

According to the OpenFlow standards in SDN [12], the controller will collect 14 kinds of information. Among them, we select six features, namely, duration, protocol_type, src_bytes, dst_bytes, count, and srv_count, as the input of the neutron in the input layer. Thus, in FBM, there are six neutrons corresponding to six features in the input layer. These six features are described in Table III.

TABLE III. FEATURES USED IN FBM

Features	Explanation and unit
duration	Living time of the flow (seconds)
protocol_type	The protocol of the flow (tcp、udp、icmp)
src_bytes	The amount of data transmitted by the flow from source to destination (bytes)
dst_bytes	The amount of data transmitted by the flow from destination to source (bytes)
count	Number of connections to the same destination host as the current connection in the past two seconds. (times)
srv_count	Number of connections to the same service (port number) as the current connection in the past two seconds (times)

B. Activation function

For consistency, we let all neurons have the same activation function, i.e., all $f_{k,j} = f$. We use three common and effective functions, described in subsection II.C, Sigmoid function, ReLu function, and Maxout function as the activation function of FBM.

Sigmoid function can limit the output to a certain range, so it can speed up the convergence. There are several functions belonging to the category of Sigmoid, and we adopt Tangent function as

$$f(z_{k,j}) = \frac{\sin z_{k,j}}{\cos z_{k,j}}. \quad (3)$$

For ReLu function, if $f(z_{k,j})$ is less than zero, it is regarded as zero; otherwise, it remains unchanged, as

$$f(z_{k,j}) = \begin{cases} 0 & \text{for } z_{k,j} < 0, \\ z_{k,j} & \text{for } z_{k,j} \geq 0. \end{cases} \quad (4)$$

Finally, on using Maxout function, the weight value $w_{k-1,i,j}$ between the ith neuron of the (k-1)th layer and the jth neuron of the kth layer is changed to a set of weight values $w_{k-1,i,j,l}$. Thus, the value of summing up the weights in the jth neuron of the kth layer, $z_{k,j}$, becomes a set of values, $z_{k,j,l}$, as

$$z_{k,j,l} = \sum_i w_{k-1,i,j,l}\, y_{k-1,i} + b_{k,j,l}. \quad (5)$$

Maxout function will select the maximum among all $z_{k,j,l}$ as the output, as

$$f(z_{k,j}) = \max_l z_{k,j,l}. \quad (6)$$

IV. EXPERIMENT SETUP

In this section, we introduce the details about the setting of conducted experiments.

A. Experiment tool

We used H2O.ai [13] to implement FBM and packet-based MLP (PBM). H2O.ai is an open source deep learning analysis tool, written in Java, R language, and Python. It is usually used to explore cloud platforms or distributed architectures. In H2O.ai, there are various embedded machine learning algorithms such as Random Forest, Naïve Bayes, and K-Means. Currently, H2O.ai supports many operating systems. We set up H2O.ai on the computer which installs Ubuntu operating system, used Java as the programming language, and chose MLP as deep learning model.

B. Data set

The NSL-KDD dataset [14] proposed in 2009 is to solve the bias problem caused by the KDD Cup 1999 Dataset. 80% of this dataset is NSL-KDD_Train, which is for the training and has 125,973 network traffic samples. The remaining 20% is NSL-KDD_Test, which is for the testing and has 22,554 samples. Each traffic sample has 40 features where 14 features are flow-based features. Each flow is labeled as normal or anomaly. In PBM, we use all 40 features as inputs of the input layer, i.e., the input layer has 40 neutrons. In FBM, six flow features, namely, duration, protocol_type, src_bytes, dst_bytes, count, and srv_count, are extracted as inputs of the input layer.

C. Performance metrics

To exhibit the performance of FBM, we use the receiver operating characteristic (ROC) curve. The ROC curve is presented with the true positive rate (TPR) and false positive rate (FPR). The area under the ROC curve (AUC) is used as performance metric. A higher AUC means the better performance.

Another important performance metric is consumed time, including modelling time and detection time. Modelling time refers the time required for training MLP while detection time is the time required to detect anomaly using the MLP model. Detection time is an important factor for real-time detecting traffic anomaly in a high-speed network.

V. EXPERIMENT RESULTS

The experiment uses AUC value, modelling time, and detection time as performance metrics to investigate the differences between FBM and PBM models. The effects of activation function and the number of hidden layers on performance are studied.

A. Effect of activation function

The results of PBM and FBM using different activation functions are shown in Fig. 2 where the number of hidden layers is 50. Observing this figure, PBM with Sigmoid function can achieve the best AUC of 0.91. In FBM, Maxout function can provide the best AUC of 0.89, which is higher by 0.013 using Sigmoid function and 0.005 using ReLu function. We can infer that because PBM has many features, Sigmoid function can still use other features to detect traffic anomaly even when the back-propagation gradient is zero. However, in this case, FBM will generate some errors because it only has few features. On the other hand, Maxout is very suited to FBM, which has few features because Maxout extends one weight to

a set of weights. Therefore, it has good results when the number of features is rather few.

FBM need less modelling time than PBM for any activation function. The average difference of modelling time between FBM and PBM is 50 seconds in our experiment, i.e., PBM spends 123% time over FBM, as shown in Fig. 2(b). It is worth noting that ReLu function is better than other functions on modelling time, that is, it can reduce the modelling time by about 40%.

For detection time, as shown in Fig. 2(c), PBM using Maxout function spends 2.224 seconds, i.e., 0.863 seconds longer than FBM using the same function, while FBM using Sigmoid function spends the time similar to PBM using the same function.

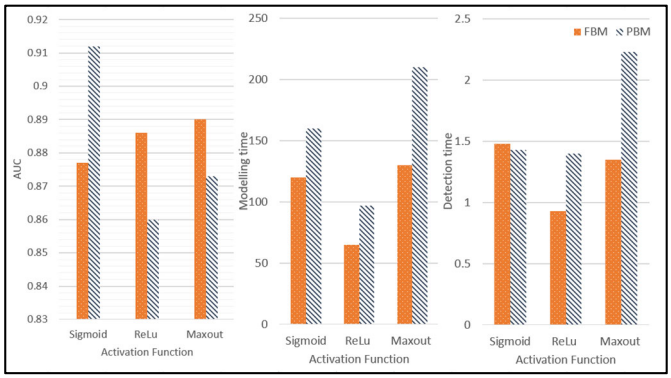

Figure 2. Different activation functions: (a) AUC, (b) modelling time, (c) detection time

B. *Impact of the number of hidden layers*

As shown in Fig. 3(a), the number of hidden layers has no strong correlation with the AUC. Although 50-layer hidden layer of FBM is best when using Maxout function, the performance of 40 layers is not as good as that of 30 layers. For PBM, the best performance is using Sigmoid function, but the performance of 50 layers is worse than that of 40 layers. Therefore, we can infer that more hidden layers do not guarantee the better detection accuracy.

It is reasonable that the modelling time increases when the number of hidden layers increases, as shown in Fig. 3(b). In particular, Maxout function itself adds an additional virtual layer of neurons to enhance the training, resulting in the sharp increase of modelling time when the number of hidden layers increases. On the other hand, the detection time is not proportional to the number of hidden layers because of its tiny value , as shown in Fig. 3(c). Therefore, the number of hidden layers should be carefully determined because more hidden layers do not generate better performance, but causes longer modelling time.

C. *Comparison between FBM and PBM*

Deeply observing the established models of PBM and FBM, we find out that they have some significant differences. In FBM, six kinds of features are used for detecting the anomaly. Among them, protocol_type is the most important factor, i.e., its weight is 0.475 on determining anomaly. The duration and src_bytes occupy 0.14 and 0.11, respectively. Among 40 features used in PBM, the service_type, which indicates the protocol in the application layer, occupies the highest weight, i.e., 0.45. The flag which indicates whether the connection is successful or failed account for 0.09.

Finally, figure 4 directly exhibits the ROC curves of FBM and PBM. After TPR exceeds 0.92, FPR of FBM is smaller than that of PBM, and the largest gap is 0.2. It means that when a high TPR is achieved, FBM can generate less false positive than PBM. In general, the NIDS should operate in the case with high TPR. Thus, FBM is a better solution than PBM even its AUC is 0.89, which is lower than 0.91 achieved by PBM.

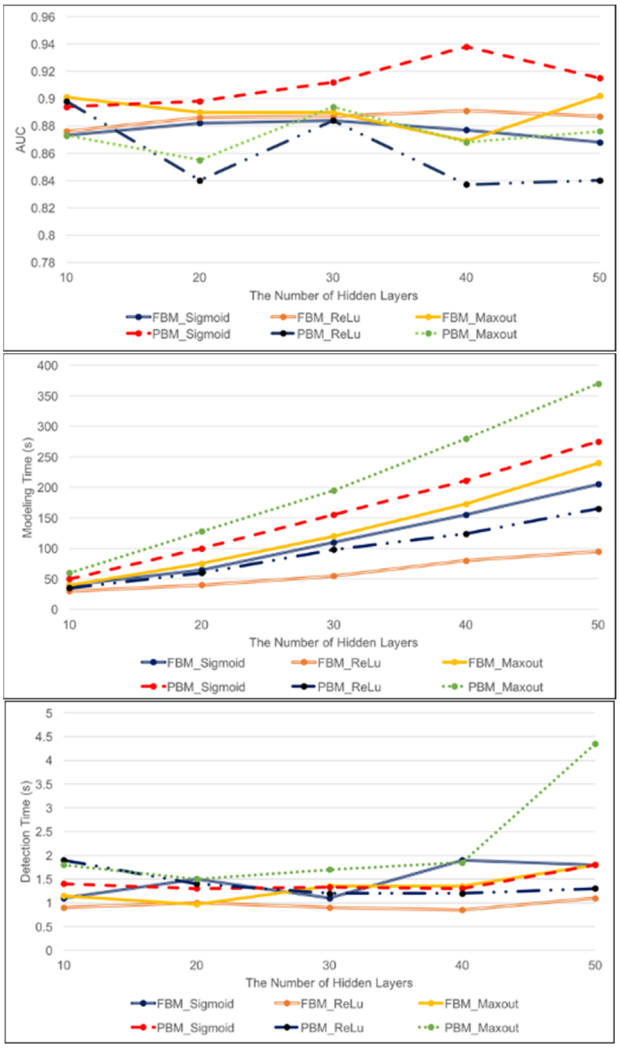

Figure 3. Different number of hidden layers: (a) AUC, (b) modelling time, (c) detection time

VI. Conclusions

This paper demonstrates the applicability of FBM for traffic anomaly detection in a SDN environment. We measure the AUC value, modelling time and detection time for different activation functions and different number of hidden layers in FBM. Maxout function is more suitable to FBM while Sigmoid function is more suitable to PBM. For modelling time, ReLu function spends the least time to establish a model. The increase on the number of hidden layers will raise the modelling time, but it does not strongly correlate to AUC value. Finally, FBM is a better solution than PBM because it has lower FPR when TPR is high. Thus, FBM is very suitable to a high-speed network because it can provide satisfactory performance and low overhead, compared to PBM.

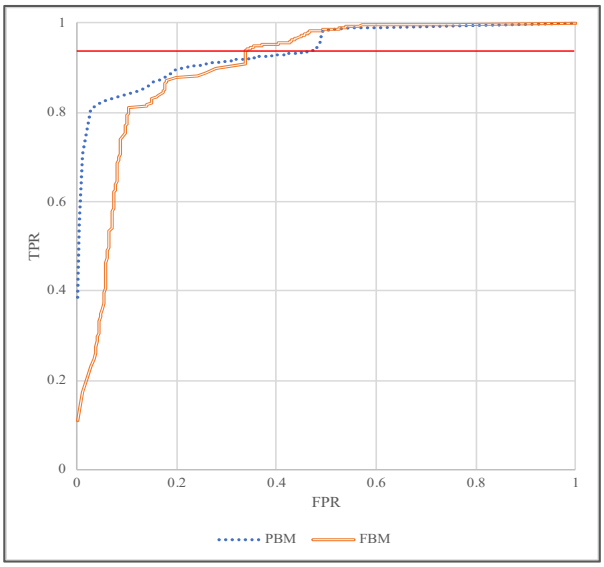

Figure 4. ROC curves of FBM and PBM

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An Overview of Automotive Security Standards

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***Abstract*—Traditional vehicle standards, such as ISO 26262-1:2011, were focused mainly on reliability and functional safety aspects. Due to the demand for increased connectivity and the emergence of autonomous driving systems, security of vehicles is becoming ever more relevant and important. Modern vehicles are a part of the cyber physical world and can be attacked from the Internet. These security needs can be addressed at many levels such as secure design and development of the software running on the Electronic Control Units, secure bus networks as well as secure connectivity to the outside world, e.g., the Internet. Unfortunately, until now there are no global standards dedicated to vehicular security. The good news is that recently some standardization activities have started to support the security aspects of the vehicles. This includes addressing the security on many levels, such as secure programming guidelines (e.g., MISRA), threat analysis and risk assessment (e.g., SAE J3061), cyber security engineering of road vehicles, (e.g., ISO/SAE 21434) and connectivity to the backend (e.g., ISO 20078). In this paper an overview of these security standards is given.**

Keywords—Automotive Security; Standards; Risk Analysis; Secure Software Development

I. INTRODUCTION

Today's automotive systems consist of a large number of Electronic Control Units (ECUs) connected together using various different networking protocols and standards. A modern vehicle consists of more than 100 ECUs and this number is ever increasing with the addition of new functionalities such as driver assistance systems and automated driving. These functionalities are pushing towards the usage of more software-based components as well as higher demands on computational power. Additionally, there is also a high demand for connectivity to the external world through various forms of wireless communications technologies such as Cellular / mobile networks, WiFi, Bluetooth and GPS. On the down side, the addition of these new features and connectivity is making the vehicle open to cybersecurity threats through a huge number of the available attack vectors and attack surfaces.

This transition of a vehicle from a completely closed system to a system that is a component of the Internet of Things (IoT), is already resulting in a tremendous increase in the complexity of the vehicular software as well as the hardware. This is evident from the use of embedded operating systems on the ECUs and with the development of Advanced Driver Assistant Systems (ADAS) and autonomous driving which will further be supported by (Adaptive) AUTOSAR. At the same time, with the addition of new functionalities and external as well as internal communication interfaces, the security threats to modern vehicles are also increasing considerably. Considering that a modern vehicle is part of the cyber physical system, with the possibility of being attacked and hacked from the cyber space, there is a need for establishing sound security practices in the automotive domain. This can be achieved by following standard risk analysis techniques to assess and prioritize the risks. Additionally, there is a need to follow standardized approaches for software design, development and testing of automotive software.

These security threats and risks are better addressed by following the standard software development guidelines and methodologies and verifying this using standardized software testing practices. Moreover, the security is also enhanced by the use of standardized networking protocols. Some standards have been developed, and some are still under development, to address and enforce security in the automotive engineering process. These include the standards specifically designed for the automotive domain such as SAE J3061, ISO/SAE 21434 and ISO 20078, aside from various other recommendations, best practices and guidelines. There is a need to understand the various security standards and study their applicability to the automotive domain.

Additionally, as the use of software is ever increasing in the automotive domain, it is necessary that the automotive software should be developed with security in mind, in addition to safety which is already highly valued in the automotive industry. The development of software must follow standardized approaches, best practices and guidelines. This will allow the software to be testable so that the quality of software can be measured and it can be assessed that the software is reliable also from the security perspective.

In this paper, the existing and upcoming major security standards and guidelines, for road vehicles, are identified and discussed. At the time of this writing, a survey or comparison of the standards is missing in the literature. This paper aims to give the reader an introduction to the important and interesting topic of security in road vehicles.

The paper is organized as follows. In Section II, ISO/SAE 21434 is discussed, which is an upcoming standard for cybersecurity engineering of road vehicles. In Section III, SAE J3061 is discussed, which is a cybersecurity guidebook for cyber-physical vehicle systems. Section IV discusses ISO 20078, which is a standard for extended vehicle, including the

vehicle and the backend. Finally, the paper is concluded in Section V.

II. ISO/SAE CD 21434: Road Vehicles - Cybersecurity Engineering

The most awaited ISO and SAE standard, ISO/SAE 21434 [1], focuses on the cyber security engineering aspects of a modern road vehicle. The standard is still under development and is planned to be released in May 2020. It is a joint effort between ISO and SAE, which have previously developed standards for safety of road vehicles. The standardization committee also includes representatives of major automotive manufacturers and Tier 1 suppliers.

The intention behind the standard is to focus on the specification of requirements for cybersecurity risk management for road vehicles, their components and interfaces. The standard aims at the complete cybersecurity engineering (i.e., concept, design and development phases), but also on the production, operation, maintenance, and decommissioning phases. The intention of the standard is also to define a framework that will include requirements for cybersecurity process and the development of a common language for communicating and managing cybersecurity risks among the automotive stakeholders. ISO/SAE 21434 will be applicable to modern road vehicles that include electrical and electronic systems. It will focus on their interfaces and communications but it will remain independent of any specific technology or solutions related to cybersecurity. A good summary of ISO/SAE 21434 and the progress has been reported in [5].

The activities of the standardization are split into four parts, i.e., risk management, product development, operation and maintenance, and process overview and interdependencies.

A. Risk management

Risk management is the basic and most important activity of any cybersecurity engineering process. The goal is to identify the risks, rate them with the aim to prioritize the most serious ones and to ensure that they are addressed and brought under control and acceptability level. The risks may come from many inside or outside factors such as external interfaces of the vehicle to the user, external communication to other vehicles, infrastructure or the backend and the ability to perform a software update.

ISO/SAE 21434 will interact with ISO 26262 and borrow from ISO 15408 for the risk assessment and may also adapt ISO 27000 to the automotive domain.

B. Product development

The product development is based on the V-model, which is also used in general in the IT industry, but more specifically in the safety systems. It has been discussed well for the safety engineering process in ISO 26262, which has also been adopted recently to the automotive domain (i.e., ISO 26262-1:2018).

A cybersecurity aware v-model starts with the system concept, where the threat analysis and risk assessment method (e.g., as in SAE J3061) is performed. This information is then used for system specification for software and hardware. The hardware and software development is performed and the system is verified for residual risks, which if possible, may be mitigated further. This is finally followed by validation of the system. Testing might include automated testing as well as pen-testing.

C. Production, operation and maintenance

During the vehicle production, the standard tackles the cybersecurity topics such as who access the software and hardware of the vehicle. After the vehicle has been produced, there are chances that vulnerabilities are introduced during the operation and maintenance. The topics handled by the standard include the whole supply chain such as the supplier, vehicle manufacturer, as well as the customer. While the vehicle is in operation, there might be new vulnerabilities introduced or uncovered and exploited. The manufacturer or the supplier should be able to develop patches for the software to address the vulnerabilities.

D. Process overview and interdependencies

This section includes the topics which might not fall under a concrete cybersecurity activity. They are however necessary for the achievement of cybersecurity such as development of a cybersecurity culture and cybersecurity management across the organization. A parallel to this is the safety culture and safety management of the ISO 26262.

III. SAE J3061: Cybersecurity Giudebook for Cyber-Physical Vehicle Systems

This cybersecurity guidebook [2] recommended practice defines a set of high-level guiding principles for cybersecurity in automotive cyber-physical systems which are to be used in series production. It defines a framework for inclusion of cybersecurity into the lifecycle of automotive cyber-physical systems. Furthermore the guidebook provides information on tools and methods for designing and validation of cyber-physical automotive systems. It provides basic guiding principles on cybersecurity in automotive systems and finally, it provides the base for further standards development activities for automotive cybersecurity.

SAE J3061 recommends application of a cybersecurity process for all automotive systems responsible for functions that are Automotive Safety Integrity Level (ASIL) rated per ISO 26262 [3], or that are responsible for functions associated with propulsion, braking, steering, security and safety, as well as automotive systems that handle Personally Identifiable Information (PII).

A. Safety critical vs. Security critical systems

A safety-critical system is usually defined as a system that may cause harm to life, property, or the environment if the system does not behave as intended or desired. On the other

hand, a security-critical system is a system that may lead to financial, operational, privacy, or safety losses if it is compromised through a vulnerability of the system. Some systems are both, safety and security critical, i.e. steering assist system. Some systems are only security, but not safety critical, such as the entertainment system. An autonomous vehicle can be both safety as well as security critical, e.g., rogue cars on the road, controlled by hackers are a big safety hazard for other traffic participant and road users.

Safety handles potential hazards by introduction of safety mechanisms into the design of automotive systems. Safety often utilizes the detailed hazard analysis technique called Fault Tree Analysis (FTA) [3] to identify potential causes of the top hazard events and look for single-point and multipoint random hardware failures.

System cybersecurity considers potential threats from a malicious attacker (intentionally induced failures) aiming to cause harm or gain financial benefits. Cybersecurity, in parallel to safety, utilizes detailed threat analysis technique called Attack Tree Analysis (ATA). ATA determines potential paths that an attacker could take through the system to lead to the top-level threat. Despite differences, similarities can be found between the approaches of safety and security.

B. Guiding principles

Guiding principles can be expressed in a following way:

- Know your system's cybersecurity risks
- Understand the key cybersecurity principles
- Consider vehicle owners' use of system
- Focus on cybersecurity in the concept and design phases
- Implement cybersecurity in the development, verification and validation phases
- Consider cybersecurity in incident response such as establishing an internal response team but also communicating security incidents to Auto-ISAC
- Cybersecurity considerations at the end of vehicle's life

C. Cybersecurity process overview

Management of cybersecurity consists of two aspects: the overall management of cybersecurity and management of cybersecurity activities within specific stages of the development life cycle.

The concept phase is the initiation of the cybersecurity lifecycle includes the development of a cybersecurity program plan. This describes the activities to be carried out as part of the cybersecurity lifecycle. Thereby, the Threat Analysis and Risk Assessment (TARA) activity is used to assess the potential threats to the system and to determine the risk associated with each of the threats.

Product development considers systems level, hardware level and software level.

A System Context (system level) defines interfaces between the system's hardware and software, the crucial data flows, as well as storage and processing within the system. Using the System Context, the system-level technical cybersecurity requirements are then allocated to hardware and software or to both.

Hardware security requirements are specified from the cybersecurity requirements of the hardware during the system level development. Following hardware design, a vulnerability analysis can be performed to help identify potential vulnerabilities in the design and to address the potential vulnerabilities.

Software security requirements can be specified from the cybersecurity requirements of the software during the system level development. Following software architectural design, a vulnerability analysis can be performed to help identify potential vulnerabilities in the software architectural design and to address the potential vulnerabilities.

The operation phase includes: operation and service consisting of normal maintenance activities and repair maintenance and repair activities.

Service that could affect cybersecurity includes re-flashing ECU's, connecting to the on-board diagnostics port, telematics system updates, update of the battery management system of fully electric or hybrid vehicles, vehicle to cloud computing interfaces, etc.

Supporting processes include configuration management, documentation management, change management, management of cybersecurity requirements and requirements for dealing with distributed development.

The gate reviews aim to ensure that appropriate activities have been performed and completed correctly and consistently before the next step of development begins. They may be conducted by a small team of technical experts that should be independent of the feature development.

D. Overall management of cybersecurity

The guideline provides detailed recommendation on following concepts:

- Creating, fostering, and sustaining a cybersecurity culture
- Establishing methods to help ensure compliance to an adopted cybersecurity engineering process
- Identifying and establishing needed communication channels with respect to cybersecurity, both internally and externally
- Development and implementation of training and mentoring to achieve a competence in cybersecurity for cyber-physical vehicle systems

- Incorporating a field monitoring process that includes monitoring hacker chatter, media articles, reporting unsuccessful attacks, etc.
- Incorporating an incident response process that includes an attack incident reporting procedure, and attack incident investigation, resolution, and action procedures.

E. Process Implementation

Process implementation consists of three types of implementations: applying a cybersecurity process separately with integrated communication points to a safety process, applying a cybersecurity process in conjunction with a safety process tailored according to ISO 26262 and some cybersecurity processes and steps are shared with safety and some that are unique to cybersecurity only.

IV. ISO 20078: ROAD VEHICLES - EXTENDED VEHICLE

ISO 20078 [4] is the extended vehicle (ExVe) standardization project. The project considers additional benefits of diagnostic data and telematics, such as emergency Call (eCall), roadside assistance, pay how you drive, remote door lock / unlock, diagnostic help desk, early field warning, preventive diagnostics, remote diagnostics, remote software or firmware update (Over-the-Air), diagnostics at the reception, digital service booklet, maintenance, service Call (sCall) and breakdown Call (bCall).

The standard helps in solving the following problems:

- Customer's access: the customer has right and a software tool for controlling his vehicle and personal data
- Security of the data connection: End-to-End security has to exist
- Access to the vehicle: technology used in different cases
- Definition of the vehicle data structures: data available by the vehicle electronics and processed for the customer.

Three different optional solutions concerning vehicle access have been discussed so far:

- In-Vehicle Interface: a customer reads and writes data into and from the vehicle
- Application Platform: a customer and an OEM, 3rd party or neutral server read and write data into and from the vehicle
- Extended Vehicle: a customer and a 3rd party server use a standard interface (ExVe) to read and write data to and from vehicle's telematic units, which are OEM specific.

ExVe defines:

- ExVe content: the data content in a human readable data format
- ExVe access: defines the mechanism to read and alter data
- ExVe security: defines an end-to-end security mechanism
- ExVe control: defining the customer portal; protection of data privacy and OEM's

ExVe is implemented to enable the 3rd party stakeholder to access customers, independent operators and vehicle manufacturers. Server-to-Server intercommunication allows for any connected 3rd party stake-holder to handle data in his own manner, e.g., through apps, web services, or other analysis methods.

V. CONCLUSION

In this work, the currently available major automotive security standards as well as those currently under development are briefly discussed. This is followed by a brief overview of their objectives and their domain of applicability. The major domains covered by these standards include threat analysis, cybersecurity engineering, software development, internal and external network communications and connectivity to the backend servers.

Security has not been given a higher importance in the automotive industry as compared to other industries such as IT and manufacturing. Currently there is no study available to compare the present and future security guidelines and standards in the automotive domain. Such a detailed comparison including in-depth analysis of security in the automotive world is planned for future.

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Investigating modern cars

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***Abstract* - Car forensic is one of the branches of digital forensics that is recently becoming more and more popular and important. Because of the accelerated growth of technology and its implementation in various industries, modern cars have additional features to raise the level of security, improve the driving experience, and now add the advanced option to connect the car to the internet. The possibilities today are much more advanced, which means that today's cars can drive autonomously, read the email, respond to messages, automatically receive software updates over the internet that provide new features. Today "smart" cars can even be controlled over the key fob or mobile app. This paper will show common information that can be found in the car; who drove it, how he drove, where and in what state did he drive, information that is related to the car and its mechanics, all the synchronized information etc. It will also explain the extraction process, software used for the extraction, and which difficulties the forensic examiner can encounter during the extraction. Furthermore, the information extracted may prove to be useful in resolving different types of crime, and it can show the importance of digital forensics of cars.**

Index Terms - Car, forensics, digital forensics, investigating cars, modern cars, car forensic, information technology, information

I. INTRODUCTION

In this paper the reader will be introduced to the field of car forensics. Another focal point will be the cars onboard systems which will explain what security features can be found on car systems, and how they can be manipulated with. The next thing that will be explained is the digital evidence that can be found in a car during a forensic investigation and how the car's systems can be accessed to find as much evidence as possible. After that, each phase of the forensic process will be covered and explained, and what a forensic investigator has to do and what procedure to follow during the acquisition process. The final part of this paper will explain a use case for the car forensic process and how to acquire evidence or data from a car's system, what tools and methods for the acquisition process can be required. Then the data acquisition of a car's infotainment system will be explained and what tools can be used for the procedure. Additionally the connection between the car's system and infotainment system will be explained.

The main goal of this paper is to introduce the field of car forensics to the reader and especially to forensic investigators and ultimately to raise awareness of the importance of car forensics.

II. CAR FORENSICS

Today we have all kind of smart things like; smartphones, smart television, smart watches, smart bracelets. These technological gadgets are very common these days. But today the common public does not realize that modern or "smart" cars can also store a lot of data and even have the capability to be connected to the internet. On top of that, cars store all the data about situations that happen around and inside them, and this is the reason why modern cars are considered to „know more" about their owner or driver than a smartphone does. Car forensic is a newer and less known branch of digital forensics. Vehicles are becoming more important sources of digital evidence in criminal investigations. Traditionally if a car is connected to a crime, the investigators focus more on DNA, fingerprints, and other physical materials that are not of digital nature. Cars have just recently become interesting for attackers, but the most important fact of all that has made car forensics more popular is that the older cars did not save data that can be of use for the investigators. Because modern cars have more and more security and entertainment features, this paper will describe some of the challenges that an investigator may come across. Some case studies on the forensic acquisition and data analysis of an entertainment system of a modern car will be described.

III. EMBEDDED ONBOARD CAR SYSTEMS

First, it is important to mention embedded car systems which come in a huge variety of shapes and functions and serve in a specific purpose. Because of the low cost of equipment that is used to produce these kinds of systems, they are now included in many devices used today. These systems have an extremely varied degree of technical quality especially regarding systems which are important for safety while driving. These systems can often be overlooked by an unaware observer. Embedded car systems can also be problematic for the examiner. This can occur because some systems need to be connected to the car they are made for and the components of the car that they control, in order to enable the examiner to extract data saved on them. Another thing specific to the car systems is the fact that the data and the state of the system are susceptible to the environment with which the system interacts. For example, if the car door is opened, or the

engine is turned on, it can delete the records saved in the recent history. Modern cars are also equipped with all kind of sensors which can create a lot of information that can be found in the car's system. [1]

A. *Security related to car's onboard system*

The security system of a car is very important because not only can it affect the car, it can also affect the people that are resident in the car. This means that in case of some event or crime law enforcement officers from multiple departments can have jurisdiction. It is interesting to mention that the security aspect was not always so important, because the older cars did not have the ability to connect to the internet or to the outside world. Today car manufacturers must take in consideration the vulnerability of modern cars to hacker attacks, because the more features are added to a car, the bigger the chances are that some attacker will find a "weak-point" and compromise the car system in order to steal the data, steal the car or take control of the car which can endanger the passengers. The danger for the passengers can be even higher if the car is remotely driven, because signals or commands sent from the attacker to the car go through network, which causes a delay from the time the attacker inserted a command to the time when the car reacts.

The improvement can not only be seen in the car systems, but also in the attacks that are becoming more advanced which makes the system manufacturers job harder. The attackers can also target the vehicle system by compromising the entertainment system. But there is also a chance of that attackers will compromise data that is collected from mobile devices connected to the entertainment system. Since the threats are getting more and more serious, the company Arxan has published information about the threats to modern cars with connectivity features and how the drivers can protect themselves from these risks. [11] There are multiple ways that cars can be connected to the outside network:

- vehicle to vehicle using wireless standard WAVE environment (802.11p),
- vehicle to the device using USB, Bluetooth, WIFI, NFC,
- vehicle to the environment over the GSM network and 802.11p (WAVE).

Essentially, if car has an onboard computer it creates new security vulnerabilities. The Center for Automotive Research (CAR) stated that modern, connected cars have 16 possible points of vulnerability. Some of these points are already stated above. There is also car system called CAN-BUS which is a bus standard designed to allow microcontrollers and devices to communicate with each other in implementation without a host computer that manages their communication. It is used as an internal network for the car's system that controls the car or its actuators using packets or signals sent from ECU to other parts of the car. The CAN-BUS or BUS-system is also used for automotive diagnostic and to flash applications. It operates according to ISO 11898, ISO 11898-1, ISO 11898-2, ISO 11898-3 standards. [12] On top of that, the modern cars can have several other systems that are used and have their own purpose:

- K-Line is one of the first mechanisms that enable access to the ECU (replaced by the CAN) [3]
- LIN is an inexpensive and slow communication that enables the control of less independent systems like door modules, window control, seat control which are connected to the cars main system
- SAE J1850 is used to provide access to vehicle networks for onboard-diagnostics (ODB) [4]
- FlexRay is a very fast network bus system for security-critical applications (drive by wire)
- Media-oriented system transport (MOST) is a large data transmission for infotainment and other data-intensive systems
- Ethernet is used for diagnostic and flash programming at high bandwidth

As stated above, these systems are included in the car system that can be compromised and allow control of locks, breaks, airbags, steering wheel sensor, stability control, engine, and more. To reduce the risk of a car being hacked, the owner or driver can keep the car's software updated, not connect a smartphone device that is jailbroken or rooted, check the outlets (USB, ODB2 Port) periodically, verify that the pre-installed or third-party apps used in the vehicle are hardened [1][2].

B. *Digital evidence in a car's onboard system*

Digital evidence in a car's onboard system is similar to the digital evidence which can be found in a classic forensic scenario. In this case digital evidence can be found in the car computer system. The data in car systems seem to be volatile because the important information when car is in working mode (such as acceleration, speed, etc.), are saved in the RAM.[1] This does not mean that a skilled attacker will leave no traces or evidence, but this evidence will be harder to collect. As mentioned before, some data is constantly being saved in car's volatile memory (RAM), and in case of a collision, the last 5 seconds are saved to permanent memory (EEPROM) and can be further examined to clarify the circumstances of the accident. This device is called the "Event Data Records" (EDR).

Evidence that can be saved on the EEPROM permanent memory is:

- The status of various vehicle systems
- What seats were occupied in the vehicle
- If, and how was the individual safety equipment used
- The position of the vehicle controls that were actuated by the driver or passenger
- The speed, direction, position and spatial attitude of the vehicle

The device called CDR (Crash Data Retrieval Tool) shown in Figure 1 which consists the "box" or CDR

hardware and of software that operates on Windows operating system can be used by the investigator directly in the field or in the laboratory. It is used to retrieve the data that was recorded before the crash into the car's embedded system. This device can also be directly connected to the EDR module of the vehicle in a situation when the vehicle is too damaged and the EDR can't be accessed through the diagnostic port of the vehicle.



Figure 1. Module interface of crash data retrieval (CDR) [10]

The difficulties that can occur during the extraction of data are the differences in this system from one car manufacturer to another and from one model of vehicle to another. This is because every car model of one make can have different d*at*a saved to *its* system. Which is common because these embedded systems are not standardized. Today's infotainment systems are found to have complex software - these systems can run programs that contain more than 2 million lines of code.[1] And as for all complicated systems goes, the more they are complicated the more room for errors they leave.

Data that can be found on the infotainment system (infotainment system hard disk) can also be very useful in situations where it is required to place a suspect in the vehicle used to commit a crime. Data that can be found in these infotainment systems are:

- GPS data which can be recorded even if a car doesn't have a navigation system. That is possible because some manufacturers create the same navigation/GPS module for a car model, but they enable them for customers only if the car is supposed to have the equipment package that includes a navigation system.
- The information that can be retrieved from the navigation system are tracklogs and track points, saved location's, previous destinations, active and inactive routes.
- List of established connections (devices) using the Bluetooth to connect the smartphone or some other device to the car, if the system is set up to do so, which is the case in most of the newer cars. This way the car can collect the make, model, Bluetooth name of the device, IMEI number, and serial number.
- All connected devices that were connected via USB port or memory card slot to the car i.e. listening to music from a USB flash drive if the car is configured so, will have record that this USB flash drive or SD card was connected.
- Data that can be found from installed applications or multimedia system: information about applications that were run, contacts, messages, emails, credentials, weather information, social networks, browse history, traffic, multimedia files (music, video, images) etc.
- Wi-Fi Access Points (AP's) where the car was connected and it can include information of a smartphone device if it was used for internet teetering.
- Key fobs can also be the source of forensic evidence because they can contain information about the vehicle which is: VIN number, mileage, fuel level, last time the vehicle was driven, GPS data [5] [9].

IV. CAR FORENSICS PROCESS

The car forensic process, in general, is similar to the traditional approach for systems that are inactive at the time of analysis, because the analysis is done on a copy of the systems state in the specific time. To do an examination of embedded and infotainment systems it is important to have extensive knowledge of electronics, digital systems, automation, and control. It also requires the specific skill of field research that needs to be constantly updated by professionals. Like the process of computer forensics, the process of car forensics can also be divided into five stages shown in Figure 2 that were created for the analysis of a car's onboard computer of the embedded system [1].



Figure 2. Stages of digital forensics

A. *Preparation*

At this stage of the forensic process, the investigator has to know all the potential sources of evidence that can be stored in the car system, as well as any other system in the car that can be connected to the car system and can reveal new evidence from those separate systems. This also includes the knowledge of access to the computer board [1].

B. *Identification*

At the beginning of the identification process, the investigator has to identify the type of system that is present during the investigation. The main objective is to separate and recognize data and information that is relevant to the case before starting the process. It is also required that the tools that are going to be used to examine this data, are defined and updated. It is important to use appropriate techniques, so that the files are accessible to forensic analysis in the next phase. In case of car forensic, the vehicle identification number (VIN) can be helpful for finding the right forensic tools to do the acquisition with. The VIN number consists of letters and numbers which all have their own meaning. The data that can be found just

by reading the VIN number (left to right, respectively) is: the country, manufacturer, vehicle type, body type, engine, series, model, check digit, model year, plant, and the last six numbers are the serial numbers. The next step is to identify the used operating system and the type and manufacturer of the computer board. This identification process can include reviewing the manufacturer's documentation, reviewing the design specifications, diagrams, and the human-machine interface [1]. The VIN number can also be helpful during this process if the vehicle examined is destroyed or unrecognizable.

C. Collection

This phase includes the collection process of evidence or data from the systems which have memory and contain digital evidence. During this process, it is recommended to maintain the chain of custody that is basically a generated report containing information about seized evidence, and it also creates the complete documentation about the people involved in the evidence handling.

In this phase, the traffic, that is sent between the car computer board system and the car's infotainment system, is identified and captured. That process also captures the traffic between the car's infotainment system and the Internet. Because these two systems make a closed network it is important that the investigator captures that traffic to gather as much evidence as possible.[1]

D. Analysis

When the process of identifying and collecting is done, the analysis process begins. In this process the data that was previously seized, will be analyzed in order to find useful information that can be helpful for the investigation. The next step is to find a connection or correlation between the found data, so if there is a need to reconstruct the event to establish a link to the suspect and create a conclusion, it is possible to do so. This can be done if the investigator wants to use data from the EDR and infotainment system to prove that a person was in the exact vehicle at the exact time the incident happened, so the suspect can't deny his or someone else's presence in the vehicle.

Analysis of results is the process of gathering all collected, examined, and analyzed evidence so they can be presented in the report that will contain all the truth about the analyzed data and to prove the link to a crime so that irrefutable proof can be presented. During this process, it will also be required to provide information about the tools, and techniques used to prove the integrity of the information. The report should point to the result and conclusion based on the found evidence, but it also should present all the techniques used to preserve, extract, and analyze the content of digital media [1].

E. Documentation

It is crucial that each analysis step has in-depth documentation which includes detailed notes, chain of custody, recording the time, date, and name of the person responsible and other essential information. The documentation is important because the evidence can be compromised during the post-incident analysis, and the documentation can also serve as a reference for future incidents with a similar situation [1]. After everything is analyzed and documented the investigator has one more step to do - write the report. The report is the final document in which the investigator states the facts and conclusion of the entire investigation. The report has to be clear, concise, and enable the non-technical readers to understand it. The report can also be a document that is submitted to a police unit or to the court.

V. CAR FORENSICS USE CASE

As mentioned in the introduction, this paper will describe what possibilities does the investigator have while carrying out the investigation or the recovery of data, which methods can be used to recover the data that is stored in the car infotainment system or the embedded car system.

A. Recovering the data from the vehicle system

The acquisition of data from the car's internal system can be done in three different ways, depending on how the car is designed and what information can be collected:

- Connecting to the OBD-II port
  Using this method the investigator gains access to the standard vehicle network interface. Connection to the OBD-II port can be established via cable or by a wireless connection. Often the data retrieved via this method are data packet identification number (DPID) which is a representation of the NVRAM data but not the actual data. For the access to the actual NVRAM data, there is usually a special mode and security feature incorporated into the serial access protocol.
- Umbilical-to-ECU
  In this case the investigator is connected directly to the ECU using a cable, and this method incorporates the security feature. This method is not forensically sound because the data in the ECU can be changed if the ECU recognizes an incompatible environment, and it can also wipe the data.
- Umbilical-to-EPROM
  Using this method the investigator makes a direct connection to the printed circuit board (PCB) within the EDR assembly. This method requires the disassembly of the ECU to gain access to the printed circuit board (PCB), cleaning the contacts for the EPROM with solvent and operates by using a direct connection of the EPROM device. Using this process, it is possible to retrieve the raw binary data in hexadecimal format. This process is much more time-consuming than methods mentioned above, but the plus side is that using this method the investigator can overcome the serial security access control by avoiding it completely. Now the actual raw NVRAM binary data is recovered in hexadecimal format [6].

B. Recovering data from a vehicle infotainment system

The data that can be recovered from the vehicles infotainment system is the most useful data for an investigator. The reason why is that the car's computer system stores the information about all the devices that were connected to the vehicle, and the data from their memory such as contacts, emails, call records, application data, GPS locations and more. Even the changes in some sensors like open/closed doors, gear shifts, force of acceleration and breaking are being stored to the cars computer system. Using this data, the investigator can easily place a suspect to a car at a specific place, time, and date only by looking at connected smartphone devices via Bluetooth and other activities logged through the vehicle's infotainment system. For the process of acquiring data from the vehicle infotainment system, the "Berla iVe" forensic software and the forensic toolkit that comes with the software is used. After that, the first step is to disassemble the vehicle to gain access to the vehicles infotainment system. This can be done easily because the previously mentioned software (iVe) is equipped with detailed instructions. After the disassembly is finished and the investigator gains access to the infotainment system, starts the process of connecting the infotainment system or the vehicle's hard drive (which depends on the vehicle) to the forensic station. Before the extraction starts, it can be required to open the infotainment housing to gain access to the PCB where the specific pads covered with insulating material are located (by following the instructions from the iVe software and using a specific fiberglass brush). After the contact pads are exposed, it is required to connect the iVe "Device interface board" (DIB) to the PCB and align it properly on the exposed pads. The next step is to power the PCB with the variable power supply that is included in the kit. It is very important to adjust the voltage to 12V prior to connecting the leads to the PCB power connector.

If the infotainment system has a hard drive built in and the investigator has extracted it, the hard drive needs to be connected to the iVe tool to be mounted because it is encrypted and cannot be mounted, examined or imaged otherwise.

The iVe tool has a built-in acquisition wizard that goes through the setup of the acquisition process to make sure everything is set up properly. When the iVe DIB is connected to the forensic station and the infotainment PCB, the connection has to be tested through the acquisition wizard by pressing the "Detect" and "Test" buttons shown in figure 3. The next step is to start the logical image extraction from the human machine interface (HMI) module. After the extraction is completed, the analysis can be performed. iVe's data export functionality supports CSV, tab-delimited, and KML file formats for GPS data. Reports can be exported in HTML or PDF format.

During the investigation, the investigator can come across all kinds of data from the connected smart devices. Fortunately, iVe forensic tool has functionality to search through system folders of the infotainment system, content (applications, connections, devices, events, navigation), search tab, and the timeline which includes filters that enable the investigator to visually show the results and connections to the suspect. In the figure 4 is an example of the GPS positions that were recorded during the use of the car. Every circle in the figure represents a GPS location that contains some events of opening/closing the doors, engine state, gear change (from drive to reverse). Figure 5 shows details about the devices that were connected to the vehicle [7] [8].

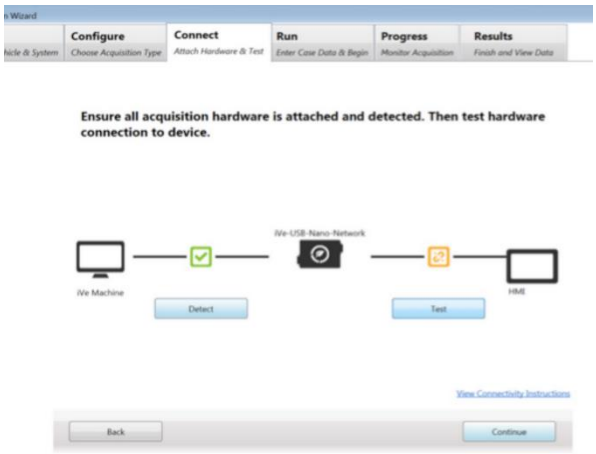

Figure 3. iVe Acquisition wizard [7]



Figure 4. iVe analysis (GPS tracking)

Flags	Device Name	Device Type(int)	Device Type	Unique Number	Unique Number Type	Manufacturer	Model	InterfaceTyp
	BLACKBERRY-1ED2			A4E4B86C5A5B	Bluetooth Address	BlackBerry Limited, MAC-> Blackber	RIM BlackBerry Device	Bluetooth
	Davyytona			80C5E6F4FC71	Bluetooth Address	MAC-> Microsof		Bluetooth
	Galaxy A5 (2016)			D8C4E9E557D8	Bluetooth Address	samsung, MAC-> SamsungE	SM-A510F	Bluetooth
	Galaxy J5			BC54510D53A9	Bluetooth Address	samsung, MAC-> SamsungE	SM-J530F	Bluetooth
	Honor 8 Black			5001D93D5B76	Bluetooth Address	HUAWEI, MAC-> HuaweiTe	FRD-L09	Bluetooth
	iPhone od Katarina			8C8EF2100F67	Bluetooth Address	"Apple Inc.", MAC-> Apple	iPhone8,1	Bluetooth
	iPhone od tpapac			285AEB878F5D	Bluetooth Address	"Apple Inc.", MAC-> Apple	iPhone7,2	Bluetooth
	iPhone od tpapac			Device_ID_8				Bluetooth Au
	iPhone od tpapac			Device_ID_1003				Bluetooth
	iPhone od tpapac			Device_ID_1007				Bluetooth
	Mobile_Device_1_BT			Mobile_Device_1_BT				
	SM-G950F			ce051715e125903403	Serial Number	SAMSUNG	SAMSUNG_Android	USB

Figure 5. iVe analysis (connected devices via Bluetooth)

VI. CONCLUSION

In today's modern world the digitalization of everyday things is growing more and more. This effect did not bypass the car industry. Modern cars are getting more digitalized, with every new model a new feature or upgrade of the previous infotainment or security system is added to make the everyday traveling and commuting safer and easier for users or drivers. Because of this, the cars are having more and more code that keeps all the added functionality running, which ultimately gives room for errors, and security oversight that hackers can use in malicious ways. Therefore, the branch of digital forensics of vehicles has developed in these pasts few years. But the main reason is not only to recover the hacker attacks on cars - car forensic is mainly used to solve crimes by connecting the criminals or the suspects to crimes committed while using a car. Extracting data from embedded car systems is done because it contains security logs of the vehicle moments before an accident happened. There is also the data from the infotainment systems that is more interesting for car forensic in cases different than traffic disputes. That is because it contains all kind of data and logs from the vehicle and devices that the vehicle was connected to. Ultimately, the car is one of the best sources of information or digital evidence today. And can be very useful if the forensic investigator knows the where to look for evidence and is familiar with the methods for data acquisition from a vehicle.

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Information Systems Audit in Higher Education Institutions

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Abstract - **Information systems are an integral part of higher schools. Effective management of information systems helps higher education institutions to optimise their activities, to manage resources correctly and to achieve outlined objectives properly. However, information systems not only provide benefit but also cause risk. The development of higher education, growing requirements for higher education institutions encourage the installation of new information systems. However, it is not enough only to install a new system, it is necessary to adjust it in accordance with institution activity processes in order to use all the advantages. It is necessary to evaluate changes and be sensitive to them. In order to reduce risk, information systems audit in higher schools becomes very important. Scientific literature often relates information systems audit with business companies and pay little attention to educational institutions. The paper analyses existing methods of information systems audit, evaluates the need for and specific character of information systems audit in higher education institutions. The aim of the paper is to assess the possibilities of the applying of information systems audit in higher education institutions.**

Keywords - information systems; audit; audit methods; risk evaluation

I. INTRODUCTION

While public digitalization increases and data amount constantly grows, information gains greater importance. Accurate, reliable and timely information is vital to effective decision-making. Effective information management is essential not only for business companies but also for higher education institutions. As the importance of information systems grow the task of information systems assessment, which is done by conducting the audit of those systems, becomes more and more topical [2].

The main task of information systems audit is to make sure that information systems are effective and significant for the achievement of organization purposes [9]. Information systems auditing is the process of collecting and evaluating evidence to determine if a computer system safeguards asses, maintain data integrity, allow organizational goals to be achieved effectively, and use resources efficiently [2]. Auditing of information system (IS) is a form of IS measurement. Higher education institutions also take an advantage of information technology (IT) in performing academic services as their main activity [6].

Scientific papers usually analyse the performance of the information systems audit of business companies and pay little attention to the assessment of the information systems of higher education institutions. Information systems in higher education institutions can be considered more complex than the usual information systems used in commercial organization [1]. But still it must pay the same attention to its customers (students and members) [1]. As competition among higher education institutions grows the quality of information systems in use becomes an important condition in order higher education institutions gain competitive advantage. Thus, the paper analyses the existing methods of information systems audit and their applicability evaluating the information systems of Lithuanian higher education institutions.

Research object: information systems of higher education institutions.

Research objective: to evaluate the possibilities of the application of information systems audit methods in higher education institutions.

Research tasks:

- To carry out the analysis of information systems being used in Lithuanian higher education institutions.
- To evaluate the need for information systems audit and the situation in Lithuanian higher education institutions.
- To compare various information systems audit methods and evaluate the possibilities of their application in Lithuanian higher education institutions.

Research methods: analysis of scientific articles, comparison, statistical data analysis.

The paper is structured as follows: Section 2 presents the analysis of information systems being used in Lithuanian higher education institutions; Section 3 reviews the need of information systems audit and the situation in Lithuanian higher education institutions; Section 4 compares various information systems audit methods and evaluates possibilities of their application in Lithuanian higher education institutions; and the last section concludes and summarises the paper.

II. THE ANALYSIS OF INFORMATION SYSTEMS BEING USED IN LITHUANIAN HIGHER EDUCATION INSTITUTIONS

According to AIKOS data, in 2018 there were 40 higher education institutions in Lithuania (26 state and 14 non-state institutions). The analysis of information systems being used in higher schools rests upon the Report prepared in 2017 on request of the Ministry of

Education and Science of Lithuania, and the information published on the websites of Lithuanian higher schools. The conducted research showed that higher education institutions of Lithuania use both information systems adapted for the needs of a certain institution (internal), and interinstitutional information systems (common) for the planning and management of studies [11]. The abovementioned information systems have been created by institutions themselves or purchased from the companies that create information systems for Lithuanian market using world-recognised technologies and solutions.

Analysing information systems used in higher education institutions of Lithuania it is possible to notice that information systems of both business companies and higher education institutions computerise finance management, bookkeeping, salary accounting, human resource management, management of documents and processes. Assessing the solutions chosen by higher schools it is possible to notice that for finance management, bookkeeping, salary accounting, human resource management the greater part of Lithuania's higher schools use information systems created for Lithuanian market and adapted for public institutions such as DB apskaita, Stekas, Labis III, Debetas, Biudžetas, Alga HR. 24 percent of higher education institutions use Oracle/PeopleSoft Campus Solutions solution – interinstitutional information system EDINA created in order to satisfy frequently changing needs of higher education institutions.

The conducted analysis showed that in Lithuania's higher schools document management and activity analytics spheres are the least automatized. Document management is not automatized in 32 percent of Lithuania's higher schools, and 56 percent of higher schools do not use special-purpose information systems for activity analysis [11]. Kontora and Webpartner are the most popular document management systems.

As contrasted with information systems of business companies, information systems of higher education institutions also computerize activity sphere essential only for higher schools – administration of studies. The statement that administration of studies in higher schools is one of the most important activity management functions is also proved by the fact that this sphere is computerized almost in all Lithuania's higher schools, only 8 percent of higher education institutions have not computerized administration of studies yet [11]. Even 40 percent of Lithuania's higher schools use their own created and meeting their needs information systems for the administration of studies [11]. 36 percent of higher schools also choose interinstitutional information system EDINA for the administration of studies [11]. Information systems used in Lithuania's higher schools for study administration are shown in Figure 1.

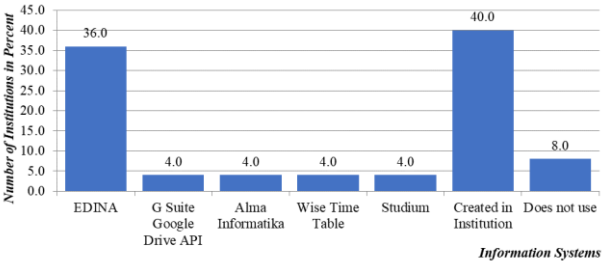

Figure 1. Information systems used for study administration in Lithuania's higher schools [11]

For the implementation of distance learning, higher schools use virtual learning environments. The greater part of Lithuanian higher schools have installed virtual learning environment Moodle or use LieDM e-study information system (ESIS) which includes virtual learning environment Moodle.

National policy and strategy to combine higher education institutions encourage the development of the infrastructure of higher schools information systems, the main trends of which are IT resource consolidation, and transfer to centralised information systems. Table 1 shows interinstitutional information systems higher schools are encouraged to use.

TABLE I. THE LIST OF INTERINSTITUTIONAL INFORMATION SYSTEMS OF LITHUANIA'S HIGHER SCHOOLS

No	*Name*	*Description*
1.	eLABa	Lithuanian Academic Electronic Library in which educational and study documents and/or their metadata are kept and provided for public access.
2.	KVIS	National career management information system which consists of graduate career monitoring component, career management component (personal, employer and career centre specialist spheres).
3.	MIDAS	National open access scientific (educational) information data archive established to collect, save and provide empirical data of scientific (educational) researches and other information related to scientific (educational) researches, to form statistical data reports, provide mathematical algorithms intended for data processing in very fast high-capacity calculating environment.
4.	LieDM (ESIS)	E-studies information system (ESIS) which consists of video conference solution, system of video lectures, *Moodle* e-learning environment, open education resources subsystem.
5.	EDINA	Lithuanian education, studies, activity and process management system the separate modules of which are intended for bookkeeping, personnel management, administration of studies, documents management, activity analytics.

Thus, summarizing the above it is possible to state that except for usual information systems and information systems applied in business companies, Lithuania's higher schools use special-purpose information systems, which computerize exceptional spheres of the activity of higher education institutions such as administration of studies, implementation of distance learning, graduate career monitoring. More and more Lithuania's higher schools apply interinstitutional information systems that are

administrated centrally and higher education institutions do not have to take care of their maintenance.

III. The need for information systems audit and the situation in Lithuania's higher schools

Information systems audit is the audit of an organization's IT systems when collected evidences and conducted assessment allow deciding if information systems effectively use organization resources, ensures their safety, data integrity and helps to pursue organization aims in an efficient way. Main objective of IS auditing activities is to review the company's control procedures associated to IS, collect analytical evidences about possible misuse, evaluate the level of operational risks for different control areas and suggest to company executives corrective control counter-measures [10]. The need for information systems audit appeared because information systems became an integral part of each organization activity and one of the most important activity execution tool. The heads of organizations and IT departments understood that computers and information systems are valuable resources that should be managed as well as other organization property, so economic feasibility, efficiency and ability to deliver good results of information systems creation, installation and application were started to be assessed.

The requirements of ISO 9001 standard are used in 96 percent of quality management systems of Lithuanian higher schools [7]. Higher schools provide procedures related to information systems management and maintenance, but defined procedures do not include processes necessary for comprehensive information systems audit and do not perform information systems audit or perform it only superficially. Interinstitutional information systems audit should be conducted centrally because their manager is not higher education institutions. Information systems of higher schools should satisfy the requirements for information systems safety provided by laws. These requirements are related to electronic data security, personal data security, organizational and technical cybernetic security parameters, accidents management, etc. Thus, information systems audit is necessary in order to check whether information systems meet the above-mentioned requirements and whether their owners use necessary technical and organizational means.

IV. The methods of information systems audit

In order to form recommendations for the process of information systems audit in higher education institutions, it would be desirable to make assessment of existing methods, standards and models taking into account already identified needs and specific character of higher education institutions. The most widely used standards and methods are COBIT, ITIL, and ISO/IE [5].

COBIT (Control Objectives for Information and Related Technologies) is a framework made by ISACA (Information Systems Audit and Control Association) and ITGI (IT Governance Institute) with the aim to assist management of information systems [3]. It represents one of the most popular frameworks for information system control published for the first time in 1996, while actual version 5 was published in 2012. COBIT 5 is a comprehensive framework that helps enterprises to create optimal values from information systems, by maintaining a balance between realizing benefits, optimizing risk levels and resource use [4].

COBIT 5 contains 34 control objectives and 37 processes, the fulfilment of which allows the succesful achievement of the objectives of functional information systems [3]. These are grouped into five domains [3]:

- Evaluate, Direct and Monitor – EDM,
- Align, Plan and Organise – APO,
- Deliver, Service and Support – DSS,
- Monitor, Evaluate and Assess – MEA,
- Build, Acquire and Implement – BAI.

ITIL (IT Infrastructure Library) presents a set of best practices for IT service management. ITIL is based on defining best practice processes for IT service management and support, rather than on defining a broad-based control framework [8]. It focuses on the method and defines a more comprehensive set of processes. IT service management is concerned with planning, sourcing, designing, implementing, operating, supporting and improving IT services that are appropriate to business needs. The basis of ITIL consists of five main processes described in 5 volumes of ITIL [3]:

- ITIL Service Strategy;
- ITIL Service Design;
- ITIL Service Transition;
- ITIL Service Operation;
- ITIL Continual Service Improvement.

The family of ISO/IEC 27000 standards deals mainly with setting up of a valid system for management with information security called Information Security Management System [3]. The family of ISO/IEC 27000 standarts includes: ISO/IEC 27000 Information security management systems – Overview and vocabulary; ISO/IEC 27001 Information security management systems – Requiments; ISO/IEC 27002 Code of practice for information security controls; ISO/IEC 27003 Information security management system implementation guidance; ISO/IEC 27004 Information security management – Measurment; ISO/IEC 27005 Information security risk management; ISO/IEC 27006 Requiments for bodies providing audit and certification of information security management systems; ISO/IEC 27007 Guidelines for information security management systems auditing; ISO/IEC TR 27008 Guidelines for auditors on information security controls; ISO/IEC 27010 Information security management for inter-sector and inter-organizational communications; ISO/IEC 27011 Information security management guidelines for telecommunications organizations based on ISO/IEC 27002; ISO/IEC 27013 Guidance on the integrated inplementation of ISI/IEC 27001 and ISO/IEC 20000-1; ISO/IEC 27014 Governance of information security; ISO/IEC TR 27015 Information security management guidelines for financial services;

ISO/IEC TR 270136 Information security management – Organizational economics.

The family of ISO/IEC 27000 standards is much more different between COBIT and ITIL, because it has smaller but deeper domain compare to COBIT and ITIL. Its goal is to provide information to parties responsible for implementing information security within an organization. It can be seen as a best practice for developing and maintaining security standarts and management practices within an organization to improve reliability on information security in interorganisational relationships.

Comparative analysis allows stating that COBIT methodology ensures the efficiency of institution information systems, helps to define IS processes, practice and control methods. As information management in higher education institutions is regulated by laws, the use of COBIT methodology for information systems audit is a proper solution. ISO/IEC 27000 standard requirements emphasize information safety and risk management. ISO/IEC 27000 standards cannot be considered as comprehensive IS management tool. For the management of the information systems of higher education institutions it would be worthwhile to combine COBIT methodology and the requirements of ISO/IEC 27000 standards. ITIL methodology is oriented towards work optimization and quality assurance in IT companies IT departments. This methodology is more suitable for business companies that render various services.

The greater part of Lithuanian higher education institutions have already installed quality management systems with regard to the requirements of ISO 9001 and Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG), have prepared procedures specifying requirements for processes, responsibility for performed actions, links with other internal and external documents. So, it would be advisable to integrate information systems management processes provided by COBIT methodology into higher schools quality management systems. Whereas higher education institutions use information systems every day and perform a lot of action on the Internet they must take care of information safety rest upon the requirements of ISO/IEC 27000 standards when preparing the description of procedures related to information systems and data safety.

V. Conlusion

The conducted analysis of higher education institutions information systems showed that higher schools use both their own created information systems and purchased and interinstitutional information systems. Both business companies and higher education institutions apply information systems for finance management, bookkeeping, and management of human resources, documents and processes. As contrasted with information systems of business companies, information systems of higher education institutions also computerize activity sphere essential only for higher schools – administration of studies, remote studies implementation etc.

The evaluation of the information needs of higher schools shows that in order to satisfy the requirements for information systems safety provided by laws, to reduce information systems safety problems, to eliminate risk related to information systems and to increase the effectiveness of higher education institutions activity, higher education institutions must conduct information systems audit.

The comparison of various methods of information systems audit and the assessment of their applicability in information systems audit in Lithuania's higher schools show that for the conducting of information systems audit in Lithuanian higher schools it is desirable to apply COBIT methodology and the requirements of ISO/IEC 27000 standards.

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A security model for Wireless Sensor Networks

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***Abstract* – State-of-the-art security frameworks have been extensively addressing security issues for web resources, agents and services in the Semantic Web. The provision of Stream Reasoning as a new area spanning Semantic Web and Data Stream Management Systems has eventually opened up new challenges. Namely, their decentralized nature, the metadata descriptions, the number of users, agents, and services, makes securing Stream Reasoning systems difficult to handle. Thus, there is an inherent need of developing new security models which will handle security and automate security mechanism to a more autonomous system that supports complex and dynamic relationships between data, clients and service providers. We plan to validate our proposed security model on a typical application of stream data, on Wireless Sensor Networks (WSNs). In particular, WSNs for water quality monitoring will serve as a case study. The proposed model can be a guide when deploying and maintaining WSNs in different contexts. Moreover, this model will point out main segments which are most important in ensuring security in semantic stream reasoning systems, and their inter-relationships. In this paper we propose a security framework to handle most important issues of security within WSN. The security model in itself should be an incentive for other researchers in creating other models to improve information security within semantic stream reasoning systems.**

Keywords – wsn security; security framework; security model; authentication, inference

I. INTRODUCTION

The Web is highly dynamic: new information is constantly added, and existing information is continuously changed or removed. It has been estimated that every minute on the Internet 600 videos are uploaded on YouTube, 168 million e-mails are sent, 510,000 comments are posted on Facebook and 98,000 tweets are delivered in Twitter [23]. In these scenarios information changes at a very high rate, so that we can identify a stream of data on which we are called to operate with high efficiency. In the last few years, several researchers and practitioners have proposed solutions for processing streams of information on-the-fly, according to some pre-deployed processing rules or queries [14]. This led to the development of various Data Stream Management Systems (DSMSs) [15] and Complex Event Processing (CEP) systems [17] [16] that effectively deal with the transient nature of data streams, providing low delay processing even in the presence of large volumes of input data generated at a high rate. However, DSMSs lack the support of performing complex reasoning tasks, CEP do not support reasoning, while Semantic Web caches all the knowledge base. As a result, a number of recent works propose to unify reasoning and stream processing, giving birth to the research field of Stream Reasoning [6]. In 2009, stream reasoning was defined as an "unexplored yet high impact research area". A number of its implementations are currently in place including C-SPARQL [21], StreamRule [20], StreamJess [8], C-SWRL [9], ETALIS [18], EP-SPARQL [19] etc.

Typical applications of stream data are Wireless Sensor Networks (WSNs). WSNs are spatially distributed autonomous sensors to monitor physical or environmental conditions, such as water quality, temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. Modern approaches are bi-directional, also enabling control of sensor activity [10].

There is a need to develop a model which would provide Semantic Web services that are relevant to the user request, and only to those users who have got the access rights. Different authors have indicated different aspects that should be considered while designing an access control mechanism for the Semantic Web services [11]. For instance, [11] points out the need that Access Control Mechanism should satisfy composite web services. The author afterwards turns the focus on semantic relations among concepts, than the incorporation of policies in Access Control. He also emphasizes the need to consider credentials, and at the end the fact that authorization should be considered over authentication, etc. Thus, there is an inherent need for a unique mechanism or model that is able to satisfy the complex requirements of an access control of WSN network.

When creating a WSN network, many times we see a focus on data encryption, which is important too. But, say after successful encryption of data chances of device itself being hacked still exist. If there is no way to establish the authenticity of the data being communicated to and from certain WSN node, security is compromised [22]. For example, if we build a temperature sensor for smart homes. Even though you encrypt the data it transfers, if there is no way to authenticate the source of data then anyone can make up fake data and send it to your sensor instructing it to cool the room even when its freezing or vice versa. Authentication issues may not be upfront but they definitely pose a security risk. There are several

researches in this direction, more notably in recent years the PAuthKey authentication scheme. They propose a pervasive lightweight authentication and keying mechanism for WSNs in distributed Internet of Things (IoT) applications, in which the sensor nodes can establish secured links with peer sensor nodes and end-users. The established authentication scheme PAuthKey is based on implicit certificates and it provides application level end-to-end security.

In WSNs we also need secure XML. According to [12], access must be controlled to various portions of the document for reading, browsing and modifications. There is research on securing XML and XML schemas. The next step is securing RDF (Resource Description Framework). Now with RDF not only do we need secure XML, we also need security for the interpretations and semantics.

We also need to examine the inference problem for the Semantic Web. Inference is the process of posing queries and deducing new information. It becomes a problem when the deduced information is something the user is unauthorized to know. With the Semantic Web, and especially with data mining tools, one can make all kinds of inferences [13].

There are hardware issues also. From the very beginning the internet of things hardware has been the problem. The problem is with modern architecture of the chips made specifically for the IoT devices, the prices will go up making them expensive. Also the complex design will require more battery power which is definitely a challenge for IoT applications. Affordable wearable IoT devices will not use such chips meaning there is need for better approach [22].

While there are dozens of research in different aspects of security within Semantic Web applications in general and WSNs in particular, like the ones described by [4], [1], [2], [3] and [5], there is still no integrative model which takes in consideration different segments of security within WSNs. In this research we aim to create a unique security model, which could be implemented anytime we need to deploy new WSN system. The idea is to firstly validate the model on WSNs for water quality monitoring and then in other domains. Finally, we will generalize the findings of the research, and make the model applicable in different stream reasoning domains.

II. AIMS OF THE MODEL

The main aim of this research work is to develop an integrative security model for stream reasoning systems in general and WSNs in particular. In our model, we try to include at least these segments: secrecy, privacy, authentication, authorization, encryption and inference.

The research sub goals include security issues on data, semantic security and secure information integration, which are components of the secure Semantic Web and thus stream reasoning within WSN.

III. HYPOTHESES

We have come up with two hypotheses which concern the quantitative part of the research, and two research questions for the qualitative part of the research.

Hypotheses:

- Creation of an integrative security model for stream reasoning systems in general and WSNs in particular will improve security in steam reasoning systems.
- Current approaches to security within WSNs are isolated and not completely efficient for WSNs.

Research Question 1: Are current security foundations of Semantic Web also relevant for Stream Reasoning systems?

Research Question 2: Are current Semantic Web security measures valid for the data, ontologies and rules layer of the stream data applications?

IV. RESEARCH METHODOLOGY

This research employs mixed method approach. We use qualitative methods when analyzing different findings on security within WSN, and we use quantitative methods when we conduct observation and experimentation in the acquisition of new knowledge.

The model of the research will be organized with the following hierarchy of tasks:

- *Task 1. Security models on Semantics Web Applications*. A research on Semantic Web Security Issues and privacy mechanisms will be done at this task.
- *Task 2. Security aspects on WSNs.* A research on main security aspects of WSNs will be done at this task.
- *Task 3. Analysis of WSNs and DSMS security models.* The works on this task will identify the appropriate security issues and mechanisms applicable on the domain of Stream Reasoning within WSNs.
- *Task 4. Build a valid and consistent security model for WSNs.* This is the main thesis task. We will build a valid and consistent security model based on the best practices on Semantic Web and DSMSs, and outline specific security and privacy mechanisms for the domain of WSNs.
- *Task 5. Validate the model on Stream Reasoning systems.* The model build on Task 4 will be validated in others stream reasoning domain.

V. TENTATIVE MODEL AND CONTRIBTION

Based on the research so far and literature review, our model will have these components: Authentication, Authorization, Encryption, Privacy, Inference Security, Physical security.

While all these components have their own importance, the idea is to test the model in the real world, and prioritize components by comparing in which scenarios - which components are more vulnerable and need more attention. As the research progresses, the number of components of the model might increase or decrease, and the priority of the components can be re-organized. At “Fig.1” there are presented the components of the model.

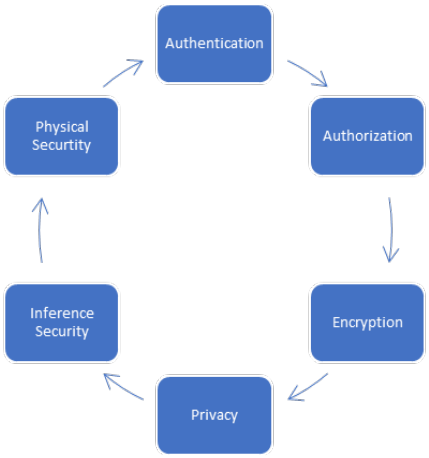

Figure 1. Components of the model

In the research to follow, we plant to do thorough analysis for each component, and their inter-relationships, and how that affects the overall security of a WSN network.

The design of an integrative security model for WSNs and stream reasoning systems will contribute on the community of Semantic Web and stream reasoning. Namely, our model can be a guide when deploying and maintaining WSNs in different contexts. The model will be validated on WSNs for water quality monitoring and other similar sensor networks. We have chosen water quality because of previous research that has been completed on it, on which data we plan to do additional analysis [8].

We think it is very important to create an integrative security model for stream reasoning systems in general, and WSNs in particular, because that will improve security in stream reasoning systems. Secondary, this model will point out main segments which are most important in ensuring security in semantic stream reasoning systems, and their inter-relationships.

Another contribution will be thorough analysis of current approaches to security. We intend to confirm that focusing on certain segment and overlooking other segments of security contributes to semantic stream reasoning systems being vulnerable to security breaches. These analyses in turn should be an important part of the contribution.

As we intend to research if current security foundations of Semantic Web are also relevant for Stream Reasoning systems, we hope to come up with valuable findings in this direction too.

Both qualitative part and quantitative parts of the research should result with important findings, which should also contribute in future directions of research in security in semantic stream reasoning systems. The security model in itself should be an incentive for other researchers in creating other models to improve information security within semantic stream reasoning systems.

VI. CONCLUSIONS

This research will strive to create an integrative security model for stream reasoning systems and WSNs. In our model, we will try to include at least these segments: Authentication, Authorization, Encryption, Privacy, Inference Security, Physical security.

The WSNs continue to grow and become widely used in many mission-critical applications. So, the need for security becomes vital. However, the wireless sensor network suffers from many constraints such as limited energy, processing capability, and storage capacity, as well as unreliable communication and unattended operation, etc [4].

Traditional security models do not provide adequate protection in this dynamic and open environment that is WSNs. While there are significant efforts under way that should make WSNSs more secure, there is a lack of a model which takes into consideration all main aspects of security.

We hope to develop and implement a security model which has all main segments of security for stream reasoning systems, and which can be used when we deploy or need to maintain a WSN in different contexts. While creating this network we aim to evaluate authentication, access control, inferences, etc, and try to mitigate against any threats related to these components.

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Utilizing a Vulnerable Software Package to Teach Software Security Design Analysis

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***Abstract* – As the number of threats and attacks to software systems increases, more attention is given to secure software engineering practices, such as secure coding and security testing. More abstract activities, such as security design analysis, require extensive security expertise from software engineers. Unfortunately, such knowledge is scarcely available, as it is an area that is both difficult to teach and learn.**

We developed a framework for teaching security design analysis, which is built around the hybrid flipped classroom and case study analysis. This paper enhances our framework by utilizing freely available vulnerable software packages as case studies for security design analysis. We illustrate the enhancement by using a mature vulnerable software package to construct a laboratory exercise dedicated to the security design analysis of threats originating from injection-based attacks. We provide guidance for the usage of our enhanced framework and outline a lab that can be utilized for a university course or a corporate training program dedicated to secure software engineering.

Keywords – security design analysis; threat modeling; vulnerable software package; education; secure software engineering

I. INTRODUCTION

As much of society is becoming digitalized, malicious agents interested in war, terrorism, and crime are moving their sights to the cyberspace. Motivated by profit, political gains, ideology, or malice, these individuals and organizations harm society by sabotaging industrial control systems, stealing data from information systems, and hampering individuals in their everyday lives [1].

Attacks on software systems are prevalent and are increasingly the subject of news headlines, scientific research, and discussions regarding business investments [2]. As a result, businesses have become more aware of cyber threats and are making the security of their software systems a strategic priority. A recent study surveyed 31 large corporations and showed that 81% of the surveyed businesses had upper-level management that was supportive of cybersecurity efforts conducted in the firm [3].

To fulfill the requirements for increased security, software vendors are introducing a set of security tools and activities to their software development lifecycle. This set is often referred to as the security development lifecycle (SDL) [4], and it represents a way to systematically address security concerns from the software's inception and design, down to the implementation and deployment.

Software security requirements are usually derived from relevant industry standards, regulations, and best practice documents. As these requirements are centered around assets and can be ambiguous to software developers [5], an essential activity in the SDL is security design analysis (SDA), which is sometimes called threat modeling [6]. By performing SDA, software engineers examine how the software's design fulfills the high-level security requirements, and plan work items to better fulfill the requirements. This activity discovers security issues before they are coded and when they are least expensive to fix [7].

An applicability issue with SDA stems from its complexity, where engineers need to maintain security knowledge and practice attacker-oriented thinking. This security mindset is difficult to learn and teach, hampering the efficient application of SDA in the industry [6][8].

In our previous work [9], we presented a framework for teaching security design analysis, using a combination of the case study analysis technique and the hybrid flipped classroom. Through our framework, we created laboratory exercises for a course dedicated to secure software engineering, with a focus on SDA. Our experimental results showed that labs constructed following our framework provided better learning outcomes for SDA, compared to the traditional teaching method. A significant limitation of our approach is its complexity, where additional effort is required to create the lab exercises when compared to the conventional classroom. In subsequent work [10] we tackled this limitation by offering low-level guidance for the efficient use of our framework. In [10], we illustrated the execution of our framework to create a laboratory exercise dedicated to finding and resolving repudiation threats.

This paper expands on the work presented in [9] and [10] by further reducing the complexity limitation of the SDA teaching framework. In this paper, we examine how freely available vulnerable software packages, dedicated to teaching software security, can be integrated with our SDA teaching framework. To illustrate this, we utilize our enhanced framework to generate a lab using a well-known and mature vulnerable software package. We demonstrate how the OWASP Juice Shop [11] vulnerable web

application can be used to simplify the process of developing labs, increase their overall quality of the lab, and reduce the complexity of using our framework. Through this demonstration, we offer secondary contributions through this paper, which include further guidance on how to use our SDA framework and an outline of a lab dedicated to identifying and mitigating threats caused by injection attacks. While this lab can be used as part of a university course, it can also be realized as a workshop in a software vendor's training program.

The rest of the paper is organized as follows: Section II provides an overview of SDA and presents our framework for teaching it. Here we also discuss vulnerable software packages dedicated to educating on software security and examine their use in the classroom. In Section III, we present our enhanced SDA teaching framework and illustrate how it integrates with vulnerable software packages. Here we incorporate the Juice Shop project into our framework and apply the enhanced framework to generate a laboratory exercise dedicated to examining injection attacks and defenses. In Section IV, we discuss our enhanced framework and note the limitations of its use. Section V lists related work, where we examine courses and labs that have utilized vulnerable software packages in the classroom and compare them with our work. Finally, in Section VI, we conclude our work and present directions for further research.

II. BACKGROUND

The following Section presents the concepts and necessary background required to understand our work. Section II-A provides a brief overview of security design analysis (SDA), focusing on the activity's purpose, its inputs, and outputs. In Section II-B, we present our framework for teaching SDA, explaining its components and workflow. Finally, in Section II-C, we examine different vulnerable software packages and explore their use in the classroom.

A. Security Design Analysis

SDA is an activity for assessing the design of a software module and its ability to resist attacks from threat agents and protect the security properties (i.e., confidentiality, integrity, availability) of its sensitive assets [6][9]. A module in this context can be a software application component, a complete application, or an enterprise system.

The inputs for SDA consist of the module's design artifacts (e.g., data flow diagrams) and high-level security requirements. The output of SDA is a list of work items (e.g., design changes, user stories, research spikes) that need to be completed to increase the security posture of the examined module. For successful SDA, the input design artifacts need to be correct, where the team performing SDA has a clear understanding of the module they are analyzing.

In general, the software engineers performing SDA needs to answer the following questions [6]:

- What is being built? – The scope of the module.
- What are the security issues? – The applicable threats and attacks that realize them, as well as the module's vulnerabilities that can be exploited.
- What will be done about it? – The work items to resolve discovered vulnerabilities.
- Did we do a good enough job? – A retrospective regarding the quality of the previous steps.

B. Teaching Framework for SDA

In [9] and [10], we demonstrated a framework that combines the hybrid flipped classroom with the case study analysis method to generate lab exercises dedicated to teaching SDA. The framework components include:

1. The SDA method which is the learning objective.
2. Preparatory materials describing security concepts (i.e., attacks, vulnerabilities, countermeasures), which the trainees examine before the lab.
3. Case studies, representing modules under analysis.
4. The labs which define how to apply SDA on the case studies, using the knowledge from the preparatory materials.

The selected SDA method (1) is decomposed into aspects. An aspect is the learning objective of one or more laboratory exercises. Each aspect is analyzed to define relevant security concepts (i.e., attacks, vulnerabilities, countermeasures), for which preparatory materials (2) are created. The materials can take the form of textbook chapters, public articles, videos, etc.

Based on the SDA aspects and related security concepts, the requirements for the case study (3) are elicited. The goal is to construct a relevant case study for SDA analysis. For example, when examining injection attacks [12], an essential requirement for the analyzed case study entails the use of command interpreters that handle externally-supplied input (e.g., SQL database receiving SQL queries, XML parsers receiving XML documents, LDAP interpreters for LDAP queries).

The final step combines all the previous work into a lab exercise (4). As demonstrated in [10], the general lab flow entails that the trainees go over the preparatory materials before attending the lab so that they can use this knowledge during the lab. At the start of the lab, the trainer discusses the preparatory materials with the trainees, after which the case study is presented. The trainees, guided by the trainer, perform SDA on the case study, and additional assignments are defined for the trainees to achieve successful learning outcomes. At the end of the lab, the participants conduct a retrospective of the lab, and the trainer presents any additional materials that the trainees can examine after the lab.

We have evaluated and successfully applied our teaching framework at our university, to develop laboratory exercises for an undergraduate course covering secure software engineering, with a focus on SDA. One limitation of the approach detailed in [9] and partially addressed in [10] is the complexity of the framework

when compared to the conventional classroom. To create a lab, the trainer needs to build a suitable case study, construct the preparatory materials, and plan the lab flow to determine assignments that bring everything together to achieve better learning outcomes.

C. Vulnerable Software Packages

Vulnerable software packages offer software engineers, security auditors, and penetration testers a playground to practice software security skills, both from the attacker's and defender's perspective and for this reason, are often used in training programs [13][14]. Additionally, these packages are used to test the efficiency of hacking tools, such as vulnerability scanners [15] as well as security controls which mitigate the vulnerabilities of the software package [16].

Due to a large number of vulnerable software packages, several attempts have been made to classify them and offer guidance on how best to utilize them. In [13], the authors review resources in secure software engineering education, listing and examining different hands-on exercises provided by these software packages and discussing a roadmap on how to best integrate them into the classroom. Next, a dedicated OWASP project was set up in 2013, providing and maintaining a directory of vulnerable software packages [14], which includes over sixty packages, as of January 2019.

These packages vary in their maturity, from basic examples demonstrating a few attacks and vulnerabilities, to sophisticated systems containing a vast plethora of teaching assignments. Furthermore, they differ on the security concepts that they cover, as well as the underlying technology on which they are built. Out of all the available options, we selected the OWASP Juice Shop Project [11] to integrate with our framework, due to the following reasons:

- It is mature, categorized as a Flagship project by the OWASP organization, signifying its value to the field of application security. Furthermore, it has previously been utilized in the classroom [11][13], as a tool for testing the efficiency of a hacking tool [15] and a security defense [16].
- It is rich with content, covering a wide array of attacks and defenses and containing 74 challenges as of version 8.3, released in January 2019.
- It is easy to use, offering detailed documentation, presentation, and video material to aid with its use and a companion guide which details each challenge and its solution [11].
- It is built on a technological stack (Angular, Node.js, SQLite) familiar to our students.
- It is a fully functioning web shop, offering browsing and shopping functionalities similar to applications which the students built on earlier courses.

III. Enhancing the Teaching Framework with Vulnerable Software Packages

In this Section, we propose an enhancement to the teaching framework presented in [9], by utilizing publicly available vulnerable software packages (VSP) to offload some of the work required from the lab constructor. Namely, we propose that the vulnerable software package can be used as a case study and the target of security design analysis. Once requirements for the case study are gathered, the lab constructor searches for a suitable VSP instead of manually constructing a case study. Furthermore, when determining the lab flow, assignments for the lab trainees can be derived directly from the features of the VSP.

To illustrate the enhancement to our framework and provide low-level guidance, we demonstrate its usage by constructing a lab with the learning objective of examining and mitigating injection attacks and vulnerabilities [12].

The preparatory materials for this lab are created by utilizing the latest OWASP Top Ten list [12]. This list is an authoritative document that presents a broad consensus regarding the most common and most critical security risks for web applications. It is updated and published every several years to keep up with the shifting threat landscape.

The OWASP Top Ten list provides a thorough overview of each class of security risks, offering insight into the risks impact, examples of attacks, pointers for vulnerability discovery and mitigation planning. For our context, trainees are meant to go over the following categories before attending the lab:

- A1 – Injection, as the primary subject matter of the lab.
- A4 – XML External Entity, due to its similarities with XML injection attacks from A1.
- A7 – Cross-Site Scripting, which can be seen as an injection attack aimed at the browser's command interpreter.

Furthermore, trainees are required to find and examine at least one example of each of the listed attacks (e.g., SQL injection, LDAP injection, Stored XSS) to get a sense of what the attack vectors look like and how they might be deployed.

Guided by the learning objective and preparatory materials, we go over the list of different attacks and vulnerabilities and define the following requirements for a suitable case study:

- It should provide a web user interface, to demonstrate cross-site scripting issues.
- It should have an SQL database where at least one command sent from the application is dependent on user-supplied input, to explain SQL injection issues.
- It should process XML documents supplied by external entities, to demonstrate XML injection issues.

- (Optional) It should provide functionality suitable for showing additional injection issues (e.g., OS command injection, LDAP query injection).
- (Optional) It should be built using modern technologies, ideally those directly utilized by the trainees, to increase the perceived relevance and their engagement.

As noted in Section II-C, we selected the OWASP Juice Shop [11] VSP as a suitable case study that fulfills both the mandatory and optional requirements listed above.

The lab constructor utilizes the companion guide to select challenges related to the learning objective and marks them as assignments for the lab. With these assignments, the final lab flow can be created, as illustrated in Figure 1.

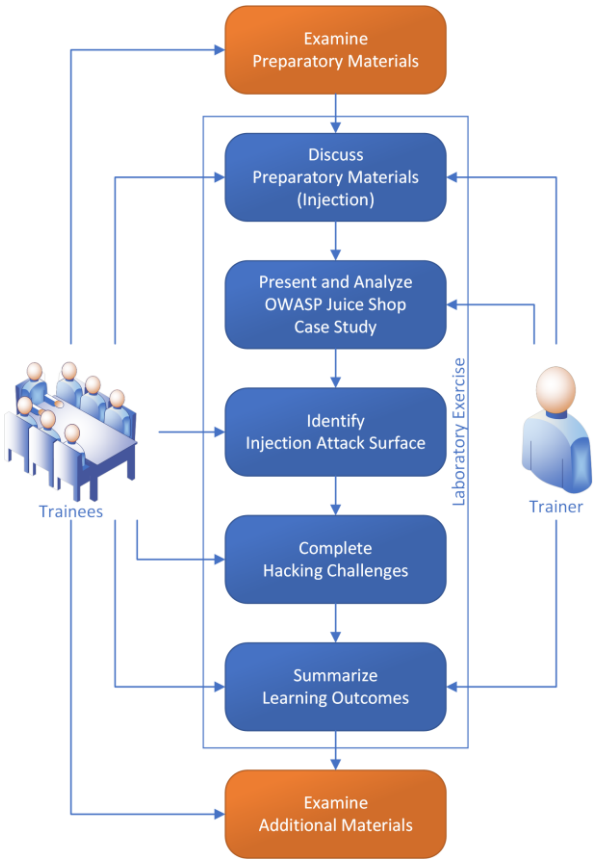

Figure 1. Lab flow for security design analysis of injection issues

At the start of the lab, the trainer goes over the different injection attacks and answers any questions which the trainees might have.

Next, the trainer introduces the OWASP Juice Shop and demonstrates the basic functionality of the application, after which the architecture and data flow diagrams of the module are presented (available at [11]).

The first assignment for the trainees is to identify the attack surface where injection attacks might be deployed, as part of a group discussion.

Once much of the attack surface is discovered, the trainees are given a list of challenges from the companion guide to complete on the laboratory computers.

At the end of the lab, the trainer highlights the learning objective, summarizes the activities conducted during the lab and notes the crucial takeaways. During this discussion, the participants:

- Define the impact of the attacks they performed;
- Determine which vulnerabilities exist in the software to allow those attacks to succeed;
- Specify mitigations which resolve the vulnerabilities and discuss ways in which the mitigations can be circumvented.

IV. Discussion

In this Section, we examine the benefits that the presented enhancement brings to our framework, describe the evaluation of the enhancement, and list the limitations that prevent the enhancement from being utilized in all cases.

By integrating a vulnerable software package (VSP) into our lab, we drastically reduced the amount of time it takes to prepare a lab using our framework. Initially, before enhancing our framework, the lab constructor needed to invest significant time (approximately a week) to build the case study, the assignments and related code samples for the lab covering the topics of injection attacks. With the Juice Shop application, the build time was reduced to a single day, which included the time it took to find and explore the VSP.

Furthermore, by introducing a mature VSP to our lab, we have increased its quality and the quality of its learning outcomes. Examples of isolated, vulnerable code were replaced by a fully fleshed out web application with vulnerabilities hidden across its various functions. The result is that the trainees can fully grasp the impact of the different vulnerabilities and attacks, which is more difficult when presented on a code sample that exists in a vacuum.

We conducted an informal evaluation of our enhancement by analyzing observations of the trainers and conducting semi-structured interviews with the trainees. During the exercise, the trainers noted a higher than expected level of engagement from all trainees. Concretely, the VSP with its challenge system facilitated a competitive atmosphere, where trainees were rushing to complete the next challenge before their colleagues. For more difficult challenges, the trainees gathered in smaller groups to brainstorm solutions, maintaining the competitive spirit by contesting other groups. Near the end of the lab, the participants summarized the learning outcomes, where the trainer noted that the trainees clearly understood the impact injection attacks could have on the software, why they occur and how to conduct them. Finally, the trainer facilitated a discussion around the quality of the lab and the use of the VSP. The consensus was that the lab was fun and engaging, where trainees made requests for similar labs in the future.

The main limitation of our enhancement is the relative shortage of VSPs. While web technologies and common web security issues [12] are covered by several high-quality VSPs [14], domains such as mobile or embedded application are scarcely covered. While basic code samples and toy projects can be found, sophisticated solutions reaching the quality of the OWASP Juice Shop project are few and far between.

V. Related Work

In this Section, we examine other teaching approaches which utilize a vulnerable software package (VSP) and discuss how their approach differs from ours.

In [17], the authors present BREW, a VSP designed to teach trainees how to find and exploit vulnerabilities as an attacker and to subsequently identify the issues in the code and resolve them as a defender. The authors define different educational usage scenarios, offering guidance on how to integrate BREW into different classrooms. Furthermore, they list settings where BREW has been successfully integrated into lectures and lab exercise.

Compared to the OWASP Juice Shop, BREW covers a broader scope by addressing both the hacker (attacker) and the developer (defender) perspective. While our lab design addresses the defender perspective with the discussion held at the end of the exercise, the ability to mitigate vulnerable code after exploiting it would improve our exercise. However, BREW has several disadvantages compared to the OWASP Juice Shop. Most importantly, its code repository has not been updated for five years, there is a lack of documentation regarding installation and deployment, and the collection of challenges is significantly smaller.

In [18], the authors utilized the OWASP WebGoat VSP to teach web security attacks and vulnerabilities, focusing on SQL injection attacks. They created several labs, where they attacked WebGoat manually and with the aid of security testing tools.

The OWASP WebGoat is a maintained VSP, currently standing as a medium-level project in the OWASP organization. While it provides an impressive array of challenges, it is less developed than the OWASP Juice Shop. Most significantly, its challenges are presented as a collection of vulnerabilities “in a vacuum,” meaning that unlike Juice Shop, they are not integrated into a setting that makes it appear as a real application, but rather a collection of tasks.

VI. Conclusion

Secure software engineering is a growing field that is faced with significant obstacles, from insufficient budgets to lack of expertise. Due to the continually rising number of cyber threat agents and their economic impact on the civilized world, it is a field that requires much attention. With our teaching framework, we strive to thwart cyberattackers, by providing an efficient way for software engineers to learn about security design analysis.

In this paper, we presented an enhancement of our framework for teaching security design analysis, by introducing vulnerable software packages to the lab. Vulnerable software packages enable trainers to demonstrate security issues in a real-world context and allow trainees to apply their security knowledge to both perform attacks on and build defenses in a real-world software system. Thus, vulnerable software packages serve the first principles of instruction [19] to increase trainee learning.

By utilizing these tools, we have reduced the effort it takes to develop a laboratory exercise through our framework. Additionally, we have increased the overall quality of the lab by replacing a case study description and vulnerable code samples with a fully functioning application that contains vulnerable code.

Concretely, we have demonstrated how the OWASP Juice Shop vulnerable software package can be integrated into a lab, generated using our framework, that covers the topic of injection attacks and defenses. The Juice Shop application is the case study of the lab and offers challenges which are mapped to assignments for the lab. An outline of the injection lab is given, explaining how the Juice Shop is utilized. The presented lab can be used for a university course or any training program for software engineers.

As part of our further work, we plan to explore gamification to see if it can increase the quality of the learning outcomes. Secure software engineering workshops are often created around hackathons and capture the flag events, and we plan to examine and evaluate this approach. As some vulnerable software packages, such as the OWASP Juice Shop, provide capture the flag infrastructure out of the box, we feel that our framework can be further expanded to utilize this teaching approach.

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Implementation of virtual digital forensic class and laboratory for training, education and investigation

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***Abstract* - In this paper, we present theoretical development and practical implementation of digital forensic laboratory computing infrastructure in a private cloud environment. The idea is to develop a scalable environment of forensic workstations and management facilities to support both the learning process and practical work in digital forensic education. Experience gathered in this process will be later used for setting up a production digital forensic laboratory in a cloud environment. To gauge student perception and experience in online learning and using virtual digital forensic classes and laboratory students filled the Student Perception Survey. The results are analyzed, and suggestions and conclusion used to improve future use.**

Keywords: Digital forensic laboratory, cloud infrastructure

I. INTRODUCTION

Digital forensics is defined differently and according to some authors, there are as many definitions as the digital forensic practitioners [2]. For this paper, it is important to choose definitions which address essential of the digital forensics and relations to training and education. Some of the definitions, like the following two, in our opinion, give the best definition of digital forensics:

- Digital Forensics is considered the application of science to the identification, collection, examination, and analysis of data while preserving the integrity of the information and maintaining a strict chain of custody for the data [3].
- The application of computer science and investigative procedures for a legal purpose involving the analysis of digital evidence after proper search authority, chain of custody, validation with mathematics, use of validated tools. Repeatability, reporting, and possible expert presentation [4].

For the understanding of digital forensics education and training, it is important to see that digital forensics is an engineering science, which is again part of computer science [6]. The profession of digital forensics requires continued education, training, and practices also it needs to smooth differences which practitioners from different fields have in their previous education and training [6]. At the moment there are issues with definitions, meanings, terms. Important concepts like case, evidence, etc. comes from law enforcement but lacks in technical implementations. All this issue must be addressed and solved in the practical implementation of digital forensic classes and related laboratory.

Since 2008 authors have been involved in digital forensics, digital forensic training, and education in various environments. Through this experience, various methods of deploying training infrastructure were tested. This experience is the core of the ideas presented in this article. Different approaches were used in different scenarios as various training and consulting contracts were done, from vendor defined professional training, to academic lectures and workshops.

II. DIGITAL FORENSIC LABORATORY AND DIGITAL FORENSIC EDUCATION

Digital forensic laboratory or DFL is hard to define, especially in the context of training and education. Based on the definitions of digital forensics and current practices digital forensic laboratory is an organization which provides digital forensic services. With such broad definitions, it is easy to implement different types of forensic services under a same legal and organizational umbrella, it is even possible to virtualize part or full laboratory processing in the legal limits and in the limits of best practices and standards [7]. Core services are processing digital forensic artifacts and digital evidence. If we want to provide this service, the laboratory must be organized and deployed in such a way that tools, procedures, infrastructure, and tasks can be easily executed.

Organization of the DFL is a complex issue where many factors interfere, the most modern approach is to define DFL as a business process based on the related business plan and metrics as it is suggested in [7], but problem is that this does not guarantee success since many historical, technical and legal issues can create huge problems.

Historically, the digital forensic lab is based on law enforcement practices, since 19th-century forensic science is introduced into the law enforcement process. Since than forensics is used as a tool to reconstruct events not only for legal reasons [6]. In practice, that means slow and incremental growth of law enforcement laboratory based on adding a new service into existing organizations. Such a model works well with traditional science. Introduction digital forensics creates a conceptual problem in using not optimal models of data processing. This practice has caused backlog crises in about early 2000 since the volume of digital artifacts needed to be processes raised exponentially while procedures, infrastructure, and tools were capable only on slow linear growth [8]. Introduction of the new concepts like digital forensic triage, parallelism in processing and laboratory management tools solved backlog situation, but the basic source of the problem is still there. As current trends of digitalization get the momentum we can soon expect again performance problems.

Digital forensic education requires practice in a controlled environment as close as possible to current real situations. Many vendors who are providing such training recently developed a classroom configuration as close as possible to production labs, since procedures and tools are taught as soon as it is operational. The same approach can be seen in the academy, at least at some institutions where cybersecurity centers are closely linked with academic programs, Rochester Institute of Technology is one of the successful examples. It basically means infrastructure is duplicated and separated in such a way that security is not compromised, while everything else is close to the real environment. This approach has also hidden advantage of easy surging of both sides of infrastructure, training or production, since changing the role of part of the lab means reinitialization and connecting to another part of the infrastructure, with some extra care on licensing, since academic licenses strictly forbid commercial or real-world application.

In such an approach it is important to understand possible functional organization of lab or classroom, there are basic types or configuration of computers which can be implemented as building elements. It is possible to separate machines into:

- management and control services,
- storage and support service,
- forensic services.

Forensic services are provided through general purpose forensic workstations and purpose configured workstations which are built to specific tool or task requests. General purpose forensic workstation is primarily for analysis and reporting while task-oriented is streamlined for specific tasks which usually requires specialized hardware tools, like acquisition, data recovery from damaged media, etc. The usual problem with forensic workstations is which OS to choose since forensic tools are OS dependent. With the advent of Windows 10, it is possible to implement a reliable Linux subsystem on the Windows platform, providing us with the best of both forensic platforms.

Management and control services are provided through DFL management services and communication services, mostly it is a server-oriented task.

Storage and support services are provided as support for both forensic and management in the sense of providing cooperation infrastructure, printing, scanning, data storage, backup, data scrubbing, reconfiguration, etc.

Such configurations can be further virtualized and hosted on the cloud infrastructure, like Azure or private clouds.

III. DEVELOPMENT OF CLOUD-BASED DIGITAL FORENSIC EDUCATIONAL ENVIRONMENT

The current technology aims to virtualize and employ cloud infrastructure. The idea is to simplify the business process by providing only needed services to business while infrastructure being something to rent. It can be easily summarized as a „Cloud computing is the dynamic provisioning of IT capabilities (hardware, software or services) from third parties over a network.” [18].

In the context of digital forensics, there are two issues with such an approach, legal constraints and current capabilities and design of digital forensic tools. Technical issues are solvable, it depends on the technology which is already available.

Digital forensic workflow (detailed in [1] and [6]), which contains well-defined steps of acquisition of evidence, analyses, and reporting, has to be implemented in such environment. The acquisition step means extracting digital data from devices into the forensic environment. All other steps are also executed in a forensic environment where data are secured and preserved without changes. It is important to understand that environment where forensic work is done can be fully virtual or cloud-based, without any negative implication on the quality of the forensic process. There is some possible limitation on the first glance, but they are the same as for any other forensic environment [6].

The legal issue mostly addresses the ownership and confidentiality of digital evidence [18], both with the security of DFL which cannot be completely guaranteed if you are not the owner of all facilities and physical installations.

More important for education and training are limitations or issue based on the current state of digital forensic tools. Forensic tools and practices are not well suited for virtualization or automation. There are only a few tools, mostly open source, which is fully capable of automation and parallel work in the scalable environment, a good example of such tools is Sleuthkit, and its derivatives and partly bulkextractor. Other tools, especially commercial are designed as a single user single task model, which simply does not scale up for cloud environment or virtualization. Dell did some early work on cloud preparations [8], working extremely hard to achieve this with the current versions of tools like EnCase v6, even there was a significant capability in tools itself. The next generation of commercial tools like EnCase v7 [14] and FTK v3 [13] recognizes the need for parallelism and automation moving to two different approaches, database-

centric in FTK and direct cooperation like EnCase. Still, both tools kept their initial graphic user interface dependency, where it was hard to separate case processing from case analysis steps. The FTK database centralization led to an environment of central storage and work drones using built-in support for parallelism in modern databases. This approach led to a system with a heavy footprint and price not well suited for cloud environments. A less efficient approach is from EnCase, where dedicated back-end process was used for evidence processing, while the front end GUI is used for analysis and task control. It was easier to maintain on a set of almost identical nodes, creating much more cloud-friendly environment. The other forensic vendors still keep more single machine/server approach. Mobile vendors like Cellebrite [17] and Microsytemation are moving slowly into parallelism and virtualization while still being mostly single machine oriented. This is due to their primary orientation to data extraction from mobile devices, a type of data acquisition, which is almost impossible to do within the virtual environment.

As a computer, the digital forensic workstation has a key role in digital forensics. It is an implementation of the computing platform on which various forensic tasks are done. Such a machine needs to have performance and versatilities to keep with tools and task. Traditionally from user rated reasons, a forensic workstation is a Microsoft Windows based for the law enforcement forensic tasks, while other types of forensic tasks often use Linux based machines. Since the virtual environment usually means cloning and machine duplication such workstation should be based on the configurations with the simple uniform maintenance and administration. From a training and education perspective, there is another requirement to have a scalable machine able to perform various tasks with different tools, with simple failback/restore mechanism in case of catastrophic incidents. The key element in digital forensics is a volume of evidence data to be processed, in the training/education environment evidence data volume is usually much smaller than real case evidence data, but the same principles for workstation configuration apply as in the real work.

IV. IMPLEMENTATION IN TVZ PRIVATE CLOUD

TVZ cloud infrastructure is implemented in Microsoft technology as a private cloud with resources for education and research. TVZ cloud DFL at the moment consists of a set of resources:

•20 virtual forensic workstations;

•1 virtual Foreman lab management server;

•Onedrive infrastructure for data storage;

•SharePoint infrastructure for documentation and cooperation storage (knowledge base, communication groups, etc.)

•LMS (TVZ Moodle) infrastructure for class materials

The TVZ Digital Forensics Laboratory is planned to support education (student work), research (work of TVZ staff) and forensic investigation (authorized external investigators). Up to now, the DFL was organized as part of the ICT infrastructure through the use of clouds of TVZ and the virtualization mechanisms present. The laboratory will primarily be used in teaching, performing practical exercises and theoretical part of the course in cybersecurity subjects, in accordance with the study description [15]. Laboratory organization must be such that new methods and cases can be easily implemented, and that simple transfer of knowledge method is also provided

The laboratory consists of a set of computers of various configurations, mostly virtualized on the TVZ cloud. The basics of the lab are the machines in the cloud. Workstations can be virtual and physical, depending on the requirements and capabilities, access to the lab servers is over the TVZ web portal, in the same way as access to the TVZ cloud infrastructure is provided and secured. Security, data backup, maintenance is implemented through the cloud service of TVZ and appropriate support. The lab is trying to be maximally virtual to achieve maximum independence from physical machines, and thus also achieve mobility and error resilience. All server and workstation configurations are streamlined to their tasks.

In the case of special needs such as licensing (i.e. access to licenses), the specific procedure and access mechanism are either permanent or temporary implemented. Licensees are provided from license servers inside of TVZ or out of TVZ. At the moment example is EnCase, in the future, some other tools will get licensed externally for DFL use.

The basic configuration of the system is a Microsoft Windows machine with a Linux subsystem. Each of the particular server and workstation configurations is designed for a specific task or a specific class lecture, while all are derived from the basic configuration. Detailed descriptions of how each configuration is done are kept in the knowledge base and workbooks.

Access to the lab is provided to students, teachers and to the staff who have the approval and the valid user account on TVZ.

The DFL consists of functional units:

- Workstations – for performing digital forensic tasks
- Server - provision of services and support
- Communication Infrastructure - Data Transmission, Security, etc.,

Servers are defined according to the services provided by the lab. Accordingly, they may be part of a laboratory, or external, providing a service or even special servers completely out of the TVZ infrastructure.

By functions we can define servers for:

- Laboratory management:
    - Foreman machine [12] - conducting the forensic procedure, part of the laboratory
    - Licensing – can be external
- Laboratory services:
    - Authentication of the user-part of the infrastructure

- Messaging communication/mail - part of the infrastructure
- Groupware for collaboration not yet defined - part of the infrastructure

- Data storage

The special type of servers is a license server providing license for products used. It is a not part of a lab usually on a separate machine, there are special requirements for network traffic due to licensing protocols.

Other special servers are forensic product drones, for FTK [13], EnCase [14], FidelisCybersecuirity [16] or GRR [15], machines that allow parallel work, at the moment such machines are only planned but not yet tested.

There are also network simulators - servers that enable the creation of a virtual network for traffic simulation, this type of machine is planned for advanced network forensic tasks like FidelisCybersecuirty, it is yet unclear how such functionality can be implemented in the current private cloud with available resources.

Forensic workstations are of two types:

- Physical workstations used as a portal entry point into the private TVZ cloud and for forensic data acquisition,
- The virtual - predefined virtual machine with configuration for a specific product, part of teaching class.

V. FUTURE DEVELOPMENT

Future development of the idea will follow the forensic as a service approach which was proposed by some forensic tool vendors recently. To achieve this goal some radical changes must be made in commercial forensic tool concepts with much better standardization. Open source tools like Sleuthkit and Autopsy are already capable of such implementation, but it lacks sophistication and support of the commercially available tools. The key steps are already done by forensic vendors like Access Data and Open text/Guidance software in the sense of providing their tools with parallelism in processing and some basic automation. Other vendors like NUIX are much less common and much more expensive but have a more elaborate approach to parallel processing and automation. Current development of the Python language as a widely used forensic tool also provides valuable automation/parallelism capabilities for digital forensics [9]. As it was presented in recent work about Python EnCase cooperation it is possible to [9] interact with commercial forensic tools from Python.

The key concept is embedded automation support, scripting, which must be available in the original commercial tool. It is important to notice that EnCase has for a long time internal cooperation capabilities well beyond other forensic tools on the scene. This feature provides an important step up in performance and reliability, but also a possibility to move to EnCase to cloud infrastructure. More or less similar features are available for other commercial digital forensic tools, as it is described in [9]. In the future, this will provide full "forensic as service" implementations. From training/education perspective, it will be important to keep the current state of a single workplace as a configuration, or as a type of workplace where students can learn the basics of the digital forensics.

TVZ DFL class will be updated and kept up with new tools, as the resources will be available. Results will be used in production forensic laboratory infrastructure. Lesson learned from current implementations clearly shows that such a simple structure as it is now can be used in forensic work. Even if it is not possible to go to a cloud infrastructure for DFL it is possible to clone configurations and use it as starting points. Currently, configuration developed for TVZ private cloud is used as a basic setup for purpose-built digital forensic laboratory, which is under development, and expected to be in production soon.

From the more theoretical analyses viewpoint is necessary to address a lack of control in the current setup, which requires better integration of workstations with cloud infrastructure. This is, unfortunately, a vendor-specific issue with many compatibility problems. From current experience, it is also clear that private cloud infrastructure in academia lacks reliability and support required for real heavy duty implementations.

Current DFL will be expanded with new resources and new products as new study requires, mostly for the network forensics and for the mobile forensics and incident response. It will be also expanded for other subjects in the curriculum like for the cryptography, math, etc.

VI. ANALYSIS OF QUESTIONNAIRE "PERCEPTIONS OF THE LEARNING EXPERIENCE OF ONLINE LEARNING - LEARNING IN A CLOUD - WORKING IN A VIRTUAL LAB "

Student opinion is the most important feedback on how the concept of DFL and concept of the virtual class are working and how well are accepted. The end term questionnaire both with term papers shows a positive image among students, data were collected for all enrolled 43 students. Students in Digital Forensics class on average acquired 88.33% points what gives them excellent grade. This is a subject which requires students to do 8 practical exercises in the lab trough solving tasks with EnCase and Autopsy forensic tools for checking skills, and, they had two partial exams for checking their knowledge.

Since both real lab classroom and virtual one was available for students it is possible to value usefulness of both. During winter semester of 2018/2019 in the first year of the new digital forensic study program [19], students are pleased with virtual lab concepts, mostly because of ability to work on it, in any moment during the semester. It allows them to better use their time and other resources needed for the study. Unfortunately, the lack of virtual presence for the lectures prevents additional benefits for students.

After the lectures during the first semester of specialized professional study of information security and digital forensics, the questionnaire was conducted. In total 40 respondents answered the questions, some respondents with only partial answers.

The first group of questions was related to the effectiveness of teaching in the "cloud". The response gets

TABLE I ANSWERS RELATED TO THE EFFECTIVENESS OF TEACHING IN THE CLOUD

Online learning in the online cloud - the laboratory is or can be effective	Scale 1-5 Results:
Because it offers comfort	4,38
Because it allows meeting the individual learning needs	3,79
Because it contributes to the effectiveness of communication in a group	3,15
Because it increases the sense of community with teachers and fellow students	2,82
Because it encourages greater participation and interaction of students	3,38

a numerical grade form very efficient (5) to not efficient (1), as it is presented in Table I.

The effectiveness of learning in the online cloud has been recognized in "offers comfort," and meet the individual learning needs." In contrast to this, it is possible to see the low efficiency in the "community feel with the teacher and fellow students," as well as "effective communication in the group." An assessment of "participation and interaction of students" not proved to be a measurable because the respondents differently interpreted and uniformly appraised as "something more", "same" and "slightly less" effective.

The second group of questions was related to the preference of teaching in the cloud, results are summarized in Table II.

TABLE II ANSWERS RELATED TO THE PREFERENCE OF TEACHING IN THE CLOUD

Second Group questions related to the preferred form of:	1 most prefer, 4 least preferred
a) Lectures and exercises in the classroom	2,40
b) Online courses with online laboratory	2,77
c) A combination of lectures and computer laboratory	2,03
d) A combination of lectures and online tasks with online laboratory	2,20
a) Lectures and exercises in the classroom	2,40

Respondents most favored form of teaching "a combination of lectures and computer laboratory" - although as it is visible online learning offers "comfort", which follows "a combination of lectures and online tasks with online laboratory "and the least favored" an online course with online laboratory „even less than" lectures and exercises in the classroom". Respondents recognize their need for communication with the teacher in the form of "lectures" and put it in front of "convenience".

The third group of questions allowed respondents free form responses. There were four questions, results are summarized here according to a question.

a) What do you think is the biggest benefit of online learning - working in a lab in the cloud?

The participants in unison say the biggest benefit is the ability to plan the times and places of work, there is no need to install software, flexibility, alignment of learning with other obligations.

b) What do you think is or may be the biggest drawback - in the laboratory in a cloud?

Participants identified lack of mutual communication, and especially the lack of communication and feedback from the teacher, as an additional source of information and the person who can solve the problem or issue immediately without the need for the independent search. Participants identified the lack of communication in the group as well as the occurrence of loss of motivation, commitment, as well as the monotony in an online environment. Technical problems have been recognized also, the slowness of response and time limit of the connection duration. Participants emphasized the need for precise and detailed operating instructions as well as the need for increased intensity (frequency) of the exercises.

c) How would you describe your own experiences with online learning - work in the lab in the cloud?

Participants emphasize a sense of satisfaction with the ability to work at a time when it suits them, as well as the possibility of access to all the material at any time and any place. Although satisfied with the access they point out the need for the teaching of the "live teacher", "classical education", because they lack the teacher.

d) Your comments or suggestions for improving the work in the online lab where you work this semester.

Participants indicate and emphasize the need: to simplification of the access procedure, increased computing resources for more comfortable work. Participants suggest intense exercises (in blocks), with more facilitation of the teacher and the variety of forensic tools. They ask to be given tasks on a daily basis, and the possibility for the arranged contact with the teacher during the online work. It is recognized the requirement for additional content, and for materials for those who want to know more.

VII. CONCLUSION

The work with virtual laboratory and class shows some interesting findings, student questionnaires shows that students are more comfortable with virtual lab environment but the learning outcomes were not satisfied. This situation is more related to uncertainty with related curriculums as it is noted in a recent report "The cybersecurity Workforce gap" [10] which shows that appropriate skills are not taught in most of the cybersecurity curriculums, the same situation is actually presented in the questionnaire findings.

From a practical viewpoint it is simpler to maintain virtual laboratory/class than the traditional one, even in a situation with inadequate technical support and skills. The most troublesome situation is an implementation of a commercial product which requires reliable infrastructure and adaptive configurations what private academic cloud is unable to provide reliably.

The introduction of a class using the lab in the private cloud increases comfort and students satisfaction but requires greater preparation of materials for independent students work. Although students are satisfied because they can work when it suits them best, questionnaire presents students need to communicate with each other and with the teacher what during lectures and laboratory work. This is an important issue which should be addressed in further improvements, providing kind of live interaction among participants.

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Examining Security and Usability Aspects of Knowledge-based Authentication Methods

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***Abstract* - Graphical passwords are considered to be one of the promising alternatives to conventional textual passwords. However, while offering potential theoretical improvements over their textual counterparts, it is important to evaluate how these authentication methods would fare in practice. In this study, we were interested in the user-generated passwords from the security and usability perspective. We conducted an experiment in which the participants were tasked to create and memorize three types of passwords: a textual password, a chess-based graphical password, and an association-based hybrid textual-graphical password. Two weeks after the initial registration, the users were prompted to login using their previously created passwords. By comparing the authentication methods, we showed that despite the graphical passwords' advantages, the user-created chess passwords were the weakest, and the users had the most difficulty remembering them after the two-week period. On the contrary, the association-based passwords were just as strong and memorable as the textual passwords. The conclusions drawn from this paper are therefore two-fold: firstly, alternative authentication methods should be evaluated and compared against textual passwords in real-life scenarios to determine their practical value; and secondly, association-based approaches have the potential to augment both the security and memorability of the existing and novel authentication mechanisms.**

Keywords - password security; password usability; textual passwords; graphical passwords

I. INTRODUCTION

Password literature is bloated with proposals of novel authentication methods, aiming to eventually replace or at the very least complement textual passwords. The main goal of these papers is often concentrated on showing the new method's superiority, which can introduce bias in the evaluations. In particular, the authors might be tempted to assess the method's advantages, while neglecting to focus on the other aspects, as well. Other studies may design the experiment in a way that highlights their method's strong points or choose a theoretical approach to the assessment of some aspects. Too often, a lack of empirical evaluation is replaced by descriptive argumentation of the method's advantages. Finally, very few studies ever consider textual passwords in their comparisons, despite the fact that they are ultimately the authentication method that the proposed methods are competing against.

While these new ideas are desired from an exploratory perspective, it is thus crucial to consider and evaluate their practical value. Between the memorability, security, input times, and ease of use, a potential contender for the spot of the dominant authentication method must prove itself in multiple aspects. Unless it is generally superior to textual passwords, while remaining at least as good in its weakest aspects, the new authentication scheme will not see users readily switching. It is therefore important for the studies to provide fair and comprehensive evaluations of schemes to further our understanding of what characteristics affect certain aspects. Furthermore, more studies should examine the existing authentication methods to verify and expand on the evaluations conducted in the original proposals. In our work, we endeavor to fill that gap by comparing the security and the usability of two existing authentication methods to textual passwords in a two-fold experiment. In section II, we rationalize our choice of these methods. We describe our experimental setup in section III and discuss the results in section IV. We conclude the paper with final remarks and provide some directions for future work.

II. AUTHENTICATION METHODS

The choice of the individual authentication methods to be included in the comparison was made by considering two constraints. First, we selected methods that have not yet been examined and compared. The exception to that rule are textual passwords that were included to allow for benchmark comparisons. Second, we considered methods vastly different in terms of design and use (textual, hybrid, and graphical). The chosen methods are described below.

A. Textual passwords

Traditional textual passwords have remained the most often used authentication method for the last four decades, due to their many advantages, such as the convenience of use and simple implementation. However, technological advances and users' continuous bad management practices [1] have allowed for an increase in security breaches over the last decade, prompting researchers and innovators to begin exploring possible alternatives to textual passwords.

Bonneau et al. conducted an extensive comparison of existing authentication methods, evaluating them against textual passwords in terms of security, deployability, and usability [2]. They found out that no current method outperforms the textual passwords in all three categories. In a study exploring the future of authentication, we

further elaborate on this finding, arguing that textual passwords will remain in widespread use until an overall superior authentication method is invented, and the users are motivated to make a shift to the new method [3]. Until then, it is vital to include textual passwords as a benchmark in the comparisons of novel and existing authentication methods.

B. Game Changer Password System (GCPS)

Originally proposed by McLennan et al. [4], the Game Changer Password System utilizes board games within the process of authentication. Initially, the user is presented with a panel of selected board games to choose from (similar to a movie selection screen in Netflix's interface). Upon selecting a game, an empty board is presented to the user, on which they must place the correct game pieces in the order corresponding to the user's password, as seen in Fig. 1. Even though similar game-based authentication schemes have already been proposed in the past, the main advantage of the GCPS lies in its scalability. The ability to choose between several available board games to put game pieces on allows for an exponential increase in the theoretical search space. In addition, the GCPS' graphical interface, and the users' familiarity with board games promote easier memorability, owing to the well-known Picture Superiority Effect in the memory literature [5].

The authors empirically evaluated the memorability of the GCPS in two experiments. In the first experiment, the participants were tasked to create two passwords (a chess- and a Monopoly-based one) that they thought were secure. After a delay, they were asked to re-enter their passwords again. In the second experiment, the participants created 5 different passwords, and had to re-enter their passwords a total of 24 times over the course of the next 10 weeks. For both experiments, the percentages of their password being input correctly, as well as reaction times, were measured. In their follow-up discussion of the results, the authors argue that the mean accuracies of 77% and 82% for both experiments are reasonable, considering that this is a new method. However, the experimental setup assumed creating passwords of fixed length. As it has been shown by Brumen in their follow-up analysis of the GCPS and its weaknesses, chess passwords of 4 characters in length do not provide sufficient security [6]. But if the participants were able to construct longer passwords, their accuracies would have been much lower, as well. These arguments point at the inherent problems with experimental design of the original study. Our work aims to take these points into consideration in order to re-evaluate the method under fair conditions. A further step forward is made by comparing the security and memorability of the GCPS with the other methods.

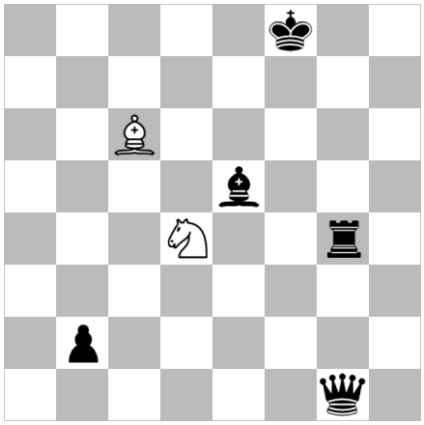

Figure 1. GCPS interface featuring a chessboard with a random, 7-character long password

C. Association Lists

The hybrid textual-graphical method Association Lists was proposed by the authors of this paper in their previous work [7]. The main idea is to employ associations between user-chosen words to boost memorability, while still maintaining a high degree of security by providing a large enough pool of available words. In the original proposal, the user is presented with three columns of ten words they have previously chosen to appear in their pool. The user's password is an indefinitely long sequence of words, with each selection made from the next column. Ideally, users would choose seemingly unrelated words to appear in the pool, and their password. That could prevent targeted guessing attacks, while keeping a high password retention due to personalized associations known only to the user.

However, there are several issues with this approach. First, the pool of available words is too small. Related to that, the users would need to create a substantially longer password to satisfy the increasingly demanding security requirements, which would in turn negatively affect the memorability. Finally, relying on the users to come up with the appropriate words for their personalized pool is not the best approach, because it hinges on the assumption that the users are security-aware and primarily motivated to protect their personal accounts. Taking these problems into account, we introduce an alteration to the original scheme. Instead of a predetermined set of words, the user is allowed to choose any word in the dictionary to appear as a given word in the password (see Fig. 2). In that sense, the proposed method can be considered somewhat similar to passphrases [8], though the system aids the user during the input by filtering and displaying a list of possible words as the user types, to decrease input time. To prevent the users from choosing predictable sequences of words, a distance algorithm should be employed in order to discard related words from the available pool. In our study, we examined the version without such restrictions, however; much like with textual passwords, and the GCPS, we were primarily interested in the strength and memorability of user-chosen passwords without any additional password requirements in place.

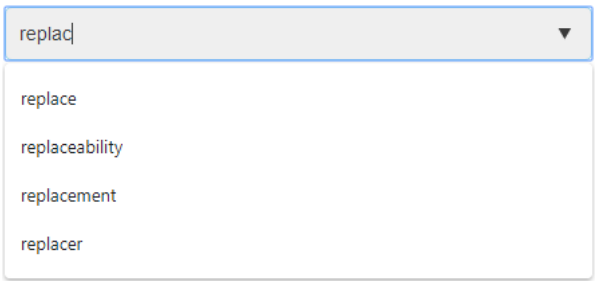

Figure 2. Word filtering and selection based on user input in Association Lists

III. RESEARCH METHODOLOGY

To examine and compare the security and usability of the three selected authentication methods, an experimental procedure was devised. We recruited a total of 58 students (36 male and 22 female) to participate in the study. All participants were between 18 and 27 years of age (mean = 20.5 years) and were undergraduate students of Computer Science or Psychology. To increase the motivation, the experiment was incorporated into the lectures concerning password security, and memory retention. The participants were presented with the experiment as an opportunity to assess their security awareness and were promised their individual results after the conclusion of the user study for future reference.

During the lectures, the students were educated about the concept of graphical passwords on the example of the GCPS, and the Association Lists. They were encouraged to ask questions about the schemes and had the chance to familiarize themselves with them by trying them out prior to the start of the experiment. For the sake of clarity, we broke down the experiment into three stages. To prevent any possible violations of internal validity, the participants were notified and briefed about each stage immediately prior to the start of it. Each stage is henceforth described separately.

In the first stage, the participants were presented with a real-life scenario in which they were required to protect their own account containing personal information. For that purpose, they were tasked to create three passwords: a textual password, a chess password in the GCPS, and an association password using Association Lists. While they were informed about the importance of secure passwords, and the ability to memorize them, they were not educated about *how* both secure and memorable passwords should be formed. With such approach, we ensured they created their passwords to the best of their own ability. During the registration phase, we measured the registration times and recorded the created passwords for all three authentication methods.

Immediately after the registration, the participants were tasked to login using their newly created passwords. Considering the participants were not aware of the second stage at the start of the experiment, the chances of them rehearsing the passwords after creation to keep them in their short-term memory were minimal. For every method, the participants had up to three attempts to login, after which their account would lock down, preventing any further attempts with the same authentication method. On the contrary, a successful attempt displayed a welcome message. Passwords and login times for all attempts were recorded. When computing the metrics, we considered the means across all attempts.

Two weeks after the registration and the initial login, the students were asked to participate in the final stage of the experiment. In this stage, the participants were tasked to login into their accounts with all three passwords that they created at the beginning of the experiment. In order to minimize the effect of any other external variables, the setup of the third stage mimicked the second stage's: three login attempts were allowed for every password, and all password attempts as well as login times were saved. Only 46 out of the initial 58 students completed the final stage and were included in the final analysis.

To estimate strength of the user-generated passwords, we used two metrics. First, we considered entropy, which is a common metric used in password research for the estimation of password strength. The advantage of the metric is that it takes both the length of the password and the character pool into account. In spite of its popularity, certain studies have pointed out the metric's weaknesses, however [9]. In particular, passwords do not follow any statistic distributions (such as languages), and guessing an entire password is not dependent on the characters that we have already guessed. For that reason, we also calculated the number of combinations for an exhaustive brute-force attack, which gave us a more accurate representation of how strong a given user-chosen password actually is.

Usability was also estimated using two metrics. Time was measured during the registration and login process to determine how long it would take the user to authenticate using a chosen method. The timer started when the user opened the login or registration screen and stopped when they pressed the submit button. Alternatively, we could measure the password input time alone, though we wanted to take the password recall time into account as well. The second metric was the number of attempts necessary for the user to input the correct password. We decided to limit the attempts to a maximum of three; if the participant was unable to input their password correctly on their final attempt, we would mark their number of attempts as four.

IV. RESULTS

To report the results in a comprehensive and organized manner, we broke the result section down into two parts, with each part focusing on one of the considered aspects: security and usability. Every aspect was initially evaluated by analyzing the corresponding metrics for every method. Then, we conducted pairwise comparisons between the authentication methods to determine whether there are statistically significant differences between them in terms of a given metric. Finally, we conducted a time analysis, in which we observed how the metric scores for every method changed over a period of time. The results of both statistical analyses are reported in Tables 1 and 2, respectively. Considering the participants had to create and re-enter all three passwords, a related samples Wilcoxon signed rank test was used for the statistical comparisons.

A. Security

The entropy of all user-generated passwords was on average higher than average password entropies estimated in some studies exploring the strength of human-generated passwords [10]. That indicates the participants followed our instructions and tried to create strong passwords based on their own understanding of password strength. A median of 74 bits for both textual and list passwords is relatively high, suggesting that the passwords were not only sufficiently long but also contained various types of characters. The average of 89 bits for lists was slightly higher than the average of 82 bits for textual passwords, and the distribution of entropy scores was more skewed towards higher scores for the list passwords. Primarily,

that is because character pool size is constant for all association list passwords, which means that entropy is entirely dependent on the password size. In other words, the entropy scores for textual passwords were potentially lower in cases when the participants did not use all types of characters (digits, lowercase, uppercase, and symbols). Comparatively, a median of 51 and a mean of 67 bits for chess passwords is much lower. Using the Wilcoxon signed rank test, we showed that the difference between the chess passwords and the other two methods is statistically significant for all three stages. Despite the fact that the GCPS had the highest maximum entropy, the majority of the participants chose passwords that were too short. The most plausible reason is that they were simply not aware of what constitutes a strong chess password. Whereas that could be amended with education, longer passwords would certainly have a negative impact on their memorability, thus putting their usefulness in question.

Fig. 3 displays the distributions of entropy scores for all three authentication methods during the registration and the two subsequent login stages. Means and medians of both logins were similar to those of registration for all methods, suggesting that the participants were attempting to input the same passwords they had created during the registration. The differences in entropy were caused by the incorrect password inputs. By comparing the entropies for each authentication method through time, we found there were practically no significant differences between either of the logins and the registration stage. The two reported significant differences, as seen in Table 2, are situational and do not suggest anything more than a few more errors during the logins. In general, the participants were able to at least remember (or guess) a similar size and characters appearing in their original password.

To examine resilience against brute-force attacks, we also considered the number of combinations necessary to complete an exhaustive key search. The distributions of combinations depicted in Fig. 4 appear on a logarithmic scale, and they are somewhat similar to the distributions of entropy in Fig. 3. Considering both metrics are measuring password strength, and rely on the length of the password, such result is to be expected. An important distinction lies in the fact that this number represents the most pessimistic cracking scenario. In other words, the user's password can *definitely* be retrieved in the number of tries equal to the number of all possible combinations. Consequently, if the average number of combinations is too low, the method can be considered unsafe.

Since arithmetic means are skewed by the exponential values, we focused on reporting and interpreting medians. Of the three considered authentication methods, the user-generated textual passwords had the highest median of 5.1×10^{25} combinations, followed by association lists with 1.5×10^{22} possible combinations. While the former had a higher average, the latter had a wider distribution, which means that some participants created passwords requiring considerably longer to be cracked. Regardless, a statistical test comparing both methods showed that there were no significant differences between the methods during any of the password input stages. On the contrary, the GCPS had significantly less combinations than both competing methods during registration and the first login. After the two-week period, the number of combinations of the input passwords did not significantly differ from that of textual and list passwords, suggesting that the participants were in general inputting longer passwords, which hints at poorer memorability discussed in the next section. Regarding security, a median of 2×10^{17} combinations for registered chess passwords can be considered inadequate protection against contemporary computers.

A temporal analysis once again showed no statistically significant differences between any of the stages for any of the three authentication methods. This finding supports our previous conclusion that the participants were able to recall similar lengths of their passwords after a two-week period. Albeit not significant, the differences were bigger after two weeks than immediately after the registration. It would therefore be sensible to repeat the experiment after a month to further investigate the memory retention.

B. *Usability*

Input times are showcased in Fig. 5. As expected, the registration time was the shortest for textual passwords, with the participants spending 35.6s on average (Mdn_T = 30.8s) to create their password. Despite being graphical methods with the participants having little experience using them, the chess and list passwords did not require much more time to be created: 38.3s and 39.3s on average (Mdn_C = 33.6s, Mdn_L = 35s) for chess and list passwords, respectively. Comparing the methods using the Wilcoxon

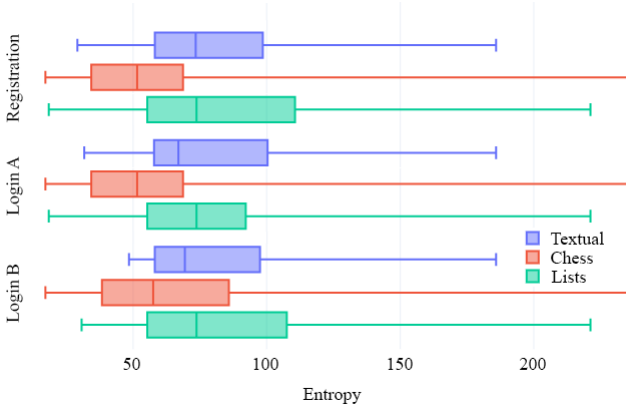

Figure 3. Entropy during registration and the logins for all three authentication methods

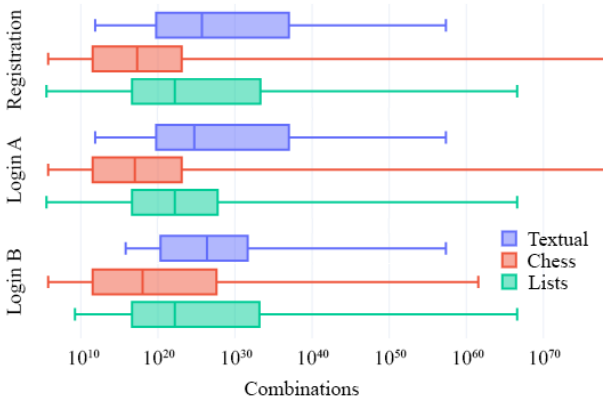

Figure 4. Number of possible password combinations during registration and the logins for all three authentication methods

TABLE I. A PAIRWISE COMPARISON OF AUTHENTICATION METHODS IN TERMS OF SECURITY AND USABILITY DURING ALL THREE STAGES

	Registration			Login A			Login B		
	T-C	**C-L**	**T-L**	**T-C**	**C-L**	**T-L**	**T-C**	**C-L**	**T-L**
Time	0.662	0.856	0.437	*0.007**	0.224	0.084	0.316	*0.01**	0.194
Combinations	*0.01**	*0.002**	0.914	*0.028**	*0.009**	0.856	0.059	0.102	0.43
Entropy	*0.001**	*0**	0.25	*0.001**	*0**	0.633	*0.027**	*0.005**	0.509
Attempt				0.52	0.061	0.284	*0.012**	*0.001**	0.168

* Statistically significant ($\alpha < 0.05$)

signed rank test found no significant differences between them. This might imply that the higher input time for graphical passwords could have been compensated by a lower time necessary to compose a new password.

Against our expectations, however, textual passwords required the most time during the first login. With 47.4s on average (Mdn_T = 43.9s), they took significantly longer than the chess method with an average login time of 32.8s (Mdn_C = 27.7s). List passwords took even less time (Mdn_L = 23.1s), though the difference was not significant due to the distribution of the login time with an average of 38.2s, which was closer to that of the textual passwords. While the shorter times for chess and list passwords might seem unusual on the first glance, they could be explained by the methods' design. It has been suggested that graphical passwords might benefit from higher memorability. Since the login time does not include only input time but recall time as well, we believe shorter times could mean that the participants were able to recall the created passwords a lot quicker. Considering it would be unlikely for input times to change to such a degree immediately after registration, such a conclusion seems appropriate.

Two weeks after the initial experiment, the login times did not change substantially. While the average login time slightly improved for textual passwords to 39.7s (Mdn_T = 37.5s), the graphical passwords' average times marginally increased to 41.2s and 34s (Mdn_C = 41.5s, Mdn_L = 31.2s) for chess and association list passwords, respectively. The slight increase for graphical passwords was expected. Since both methods were a novelty for the participants, and they had no opportunity to practice using the methods during the two-week period, their reaction times naturally increased. The same finding was reported by McLennan et al. in their GCPS proposal, in which they showed that the reaction times would decrease once again with subsequent uses of the authentication method [4].

A particularly important aspect to investigate was the methods' memorability (see Fig. 6). During the first login following the registration, the recall rate was expectedly high. The association lists had the highest recall rate of 94.64%, with an astounding 92.96% managing to login on their first try. Textual passwords followed with 87.72%, while the chess passwords had a recall rate of 84.48%, with 79.31% users successfully logging in on their first attempt. A Wilcoxon signed rank test found no significant differences between the three methods, however, suggesting that memorability is still suitably high for all three methods shortly after the password creation.

After the two-week period, however, the memorability of all three authentication methods dropped significantly. Exactly half of the users managed to remember their list passwords within three attempts (42.5% recalled them on their first attempt). 36.95% of the participants recalled the textual password, of which only 23.91% remembered it on their first attempt. Despite being a graphical authentication method, chess passwords had the lowest total recall rate of 15.21%, with only 10.87% remembering their password on their first attempt. A follow-up statistical test showed that the GCPS' memorability was significantly worse than either the textual or the list passwords'. With several chess pieces on the board, the participants found it difficult to remember the individual pieces and positions they placed them on, while also keeping track of the order. The longer the password was, the less likely it was for the participant to remember it; in practice, none of the longer chess passwords were remembered after two weeks. The same could

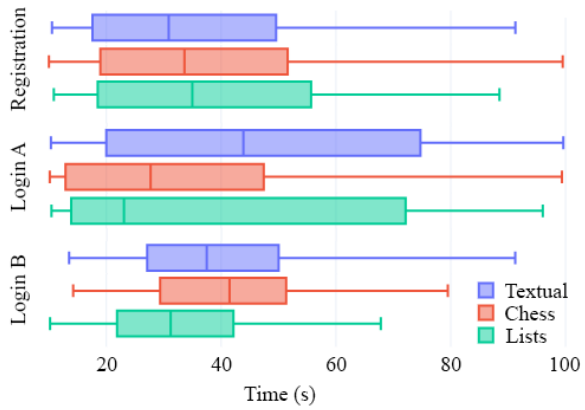

Figure 5. Password input time (in seconds) during registration and the logins for all three authentication methods

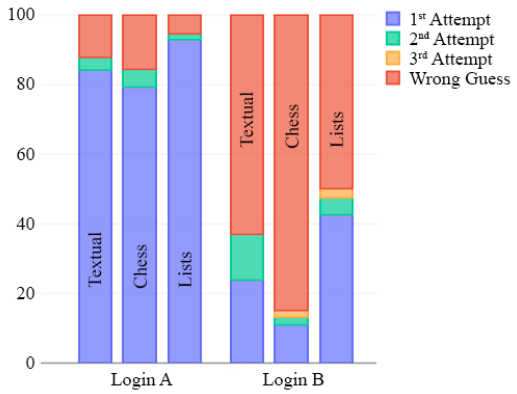

Figure 6. Password input time (in seconds) during registration and the logins for all three authentication methods

TABLE II. TEMPORAL ANALYSIS OF SECURITY AND USABILITY ASPECTS FOR THE CONSIDERED AUTHENTICATION METHODS

	Textual Passwords			**GCPS (Chess)**			**Association Lists**		
	Reg-Log$_A$	**Reg-Log$_B$**	**Log$_A$-Log$_B$**	**Reg-Log$_A$**	**Reg-Log$_B$**	**Log$_A$-Log$_B$**	**Reg-Log$_A$**	**Reg-Log$_B$**	**Log$_A$-Log$_B$**
Time	*0.019**	0.221	0.31	0.103	0.318	0.176	0.513	0.41	0.958
Combinations	0.866	0.732	0.909	0.512	0.27	0.345	0.655	0.64	0.793
Entropy	0.953	*0.047**	0.122	*0.05**	0.315	0.537	0.144	0.522	0.862
Attempt			*0**			*0**			*0**

* Statistically significant ($\alpha < 0.05$)

be claimed for textual passwords. The participants that followed our instructions and endeavored to create longer and more complex passwords, found them more difficult to remember after the two-week period. While they faced a similar problem when creating list passwords, they were generally more successful remembering them even when these passwords were a bit longer. We theorize that the associations between the selected words appearing in the password might have helped with memorability.

V. CONCLUSION

In the field of Password Security, a lot of attention has been devoted towards improving existing and developing novel authentication methods, in pursuit of a resolution to the long-lasting password security problem. However, few of these studies have employed empirical evaluations of the proposed methods, and even fewer have conducted any comparisons with other methods. In our research, we attempted to fill this gap by examining and comparing the security and usability of several password authentication schemes in a two-fold experiment. The conclusions drawn from the results have important implications for any future password evaluation studies.

An essential consideration to take in any evaluation of authentication methods should be the experimental design. In that sense, our choice of the GCPS to be included in our study was beneficial toward this conclusion. Whereas the authors had included an extensive experimental evaluation of the GCPS in their study, their obtained results have a limited usability in real-world scenarios. By compelling the participants to choose their own passwords without any limitations, we could examine both the strength and memorability of the user-chosen passwords as they would appear in the wild. We found out that without previously educating the users about what constitutes a strong chess password, we cannot expect them to create passwords of sufficient strength to withstand brute-force attacks. What is more, recall rate of these user-chosen passwords was as low as 15% after just two weeks, posing a question as to how memorable longer chess passwords would be after a certain period of time.

On the contrary, association lists proved to be a rather promising alternative to textual passwords. A close look at the differences shows that association list passwords were marginally weaker. However, they make up for that with increased memorability. While only slightly higher than the textual passwords' during the first login, the difference in recall rate increased after two weeks. It would take additional experiments to determine whether the memory retention would remain as high after a longer period of time, as well as how the memorability would be affected by further increasing the security requirements. However, rivaling textual passwords in terms of security and usability, this association-inspired method and the results of this study suggest that cognitive approaches could have the potential to extend the memorability of text-based authentication, while also maintaining a high degree of security. To draw such conclusions, we once again outline the importance of comparisons against textual passwords, which should become a necessity in any future empirical evaluations of the existing and novel methods.

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Survey on astroturfing awareness

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***Abstract* – This paper describes astroturfing as an organized effort to influence someone's thinking in order to gain benefit in various ways. Insufficient information and lack of critical thinking are good grounds for using false assumptions to influence the minds of others and their actions. This paper focuses on the survey conducted among students of the Polytechnic of Rijeka about astroturfing awareness or lack thereof. The results show that astroturfing has to be taken seriously because it is a powerful tool for manipulation and a threat to the credibility of initiatives and organizations which has a negative impact on the entire Internet community. The most effective detection techniques are development of education and critical thinking and acquaintance with astroturfing and its methods.**

Keywords* – *astroturfing; grassroots; sockpuppets; crowdturfing

I. INTRODUCTION

Astroturfing is a global phenomenon, although well known as a concept only among security experts and "Internet freaks". The word "astroturfing" is rarely mentioned, but its consequences and some forms are well described in various papers and articles. Astroturfing existed well before the Internet in relation to various political parties and initiatives, lobbying, marketing etc.

The main objective of the study was to inform the university community on the concept of astroturfing and its most common forms, as well as to measure the extent of general knowledge on this subject among student population through a survey among the students' group. The study was divided into four sections. The first part included basic information on astroturfing and its evolution in the course of time, as well as criticism and concerns it raises. The second part featured several examples of astroturfing campaigns for political, business, state and military purposes. The third part referred to the survey and its results. The last part disclosed a final review.

II. THE ASTROTURFING IDEA

In his play "Julius Caesar", William Shakespeare described how Cassius used false letters, allegedly written by people of Rome, in fact by Cassius himself, to convince Brutus to kill Caesar. This example shows astroturfing as a globally known negative phenomenon.

The term "astroturfing" was coined by a Texan senator Lloyd Bentsen in his famous statement: "A fellow from Texas can tell the difference between grassroots and AstroTurf… this is generated mail." This statement was actually Bentsen's comment on numerous letters he had allegedly received from "citizens" promoting the insurance companies' interests [10]. This example shows the common political astroturfing methodology used to oppress the campaign targets, such as persons, organizations etc. in order to affect the laws retrieval.

Astroturfing is opposite than grassroots because grassroots is not the fake campaign, but a legal alliance of the whole community to solve a collective problem. Astroturfing is fake grassroots conducted by state or other organization in order to promote a particular objective [17]. Hence highly effective, astroturfing became a powerful commercial tool used by various companies (commercial astroturfing) to affect the citizens' opinions and attitudes. The citizens became targets and casualties, but also the means of conducting further astroturfing campaigns [19].

Over time, astroturfing techniques changed and the Internet development enabled possible reach of the campaigns. It became very difficult to distinguish real grassroots campaigns and astroturfing. Widespread social networking and poor validation possibility for various claims and stories showed new possibilities for the state and military organizations. For example, some countries used their own teams with only one purpose: to decrease negative perception of the state on social networks through a large quantity of positive ones [7]. On the other hand, military organizations were not interested in opinion making in their own states, but they wanted to manipulate the other countries' citizens [3] [7]. New techniques were also developed, such as "Sockpuppets", that is fake accounts developed to enable various astroturfing activities to a certain person or organization [6]. These techniques are difficult to trace and very convincing because of the anonymity the Internet provides. Furthermore, posts can be sent by automatized programmes (bots) instead of real people. Furthermore, Internet surroundings caused the appearance of paid organized astroturfing ("crowdturfing"), where companies astroturf upon client's request, making it difficult to detect this because real persons are being used [20].

III. CASE STUDY

A. Political Astroturfing

The usual method of political astroturfing consists of sending a large number of letters to journalists or politicians to show bigger support to law or initiative than there actually is. For example, after the terrorist attack on

September 11th, 2001 in the United States of America, the state began to control its citizens on a large scale, which caused great public discontent. In order to simplify the control procedures, President George W. Bush passed the USA Patriot Act [18]. To ensure the necessary backing, he created a false grassroots movement using Republican website GOPTeamLeader.com as a new followers' recruitment center. The website was primarily used to recruit new team leaders expected to recruit a large number of followers and, therefore, help to lobby by contacting media and various politicians in the form of spontaneous patriotism and support President Bush's initiatives. They were awarded the President's signed photographs. A year later, team leaders were enabled to use website resources to make the President's messages far-flung by using pre-formatted texts and topics. The users could have sent up to 6 or more letters simultaneously. The vast number of those letters to senators and editors enabled easier passing of the controversial laws because it looked like Bush had much larger support than it actually was the case. Several years later, the website got a CapWiz tool, an online advocacy software which allowed users to send advocacy messages and alerts on a large scale, which enabled George W. Bush to manipulate the public opinion to a large extent. The tool enabled users to send hundreds of e-mail messages to media, senators, and congressmen to express fake support for the President's politics [5].

B. Commercial Astroturfing

The tobacco industry has also used astroturfing techniques several times as a marketing tool [16]. Philip Morris hired a PR company Burson-Marsteller to create a campaign meant to affect the legislator and to diminish the awareness of smoking adversity. The PR company formed the Advocacy Communications Team that founded National Smokers Alliance using Philip Morris's funding. It enabled the Alliance to form a group of 300,000 members using advertisement, telemarketing, and similar expensive techniques [16]. Also, young activists recruited new members in the local bars and bowling alleys. The activists were paid by a new member they recruited. The members were sending letters of protest to legislators criticizing laws which banned smoking. Smoking was regarded as a human right and a sign of personal freedom. That particular campaign was not a grassroots movement, but professionally guided astroturfing. The vice president of Burson-Marsteller was leading the Alliance together with other Burson-Marsteller executives.

In 2010, the Alliance of Australian Retailers launched a PR campaign as an answer to the new cigarettes package legislation [4]. They claimed that the business activities of local shops will greatly suffer because of the new legislation. The documents which leaked revealed that various tobacco companies had donated a large amount of money for the campaign. The campaign ended unsuccessfully, but slowed down the passing of the new legislation.

C. State Astroturfing

State astroturfing began in China in 2004. The state hired a group of Internet commenters to promote its opinions as their own and paid them 88 dollars per month and 50 cents per post. The country started using astroturfing campaign to strengthen positive attitude towards the state and the government. The rise in criticism was followed by a rise of astroturfing [2].

It is estimated that after 2008, there have been 200,000 – 300,000 people involved in astroturfing attempts. The members are recruited among students and government offices and regularly trained [7]. Consequently, an American news portal [1] detected a lot of positive Chinese government propaganda on their own pages.

D. Military Astroturfing

Military astroturfing is very secretive – it includes sophisticated person-oriented software. The American Airforce ordered a software able to manage false user identities, so-called "sockpuppets" [15]. One person should be able to manage at least 10 carefully made false identities with false personal history and all other details. The false identities must not be detected by any sophisticated enemy and have to be from various countries. IP addresses used were to be changed on a daily basis, but every identity might get a static IP address which can be easily changed. Software had to enable false identities to be displayed at certain locations in the USA or abroad. The access to software had to be secure and enabled from any government facility [15]. It is known that the US Government signed a 2.76 million dollars contract with company Ntrepid for software development, which was meant to promote pro-American attitude abroad under the control of CentCom which controls American operations in the Middle East [15].

Furthermore, such software was used in the Earnest Voice operation, American astroturfing campaign outside America spreading pro-American attitude on social networks. Sockpuppets were used to artificially support locals whose attitudes suit American government [3].

IV. THE SURVEY

With the aim to establish the extent of general knowledge of astroturfing among student population, a survey was carried out between June 15th and 29th , 2018. Since the majority of the student population take part in social networking, the survey has been carried in 3 different Facebook groups of the Polytechnic of Rijeka (altogether 237 members). The respondents in first 2 groups (203 members) were the students of Professional Study of Informatics (Secord and Third Year of Study), and only 20 of them (9.85%) filled in the survey form. The fact suggests a mild disinterest in the topic. The third group (34 members) consisted of Specialist Graduate Professional Study of Information Systems students. They showed greater interest – 12 of them (35.29%) filled in the survey. Although the pattern in the study is relatively small (N = 32), it can be considered representative due to its structure. The pattern structure is shown in Table I. The pattern consists the students of various age, academic year and field of study. Most of the accepted respondents (96.88%) are aged 21 – 27. Most of them (62.5%) attend Professional Study of Informatics (50% the third academic year).

TABLE I. THE PATTERN STRUCTURE

	The Pattern Structure (N = 32)		*N*	*%*
Age	21		3	**9.37%**
	22		6	**18.75%**
	23		7	**21.88%**
	24		6	**18.75%**
	25		5	**15.63%**
	26		2	**6.25%**
	27		2	**6.25%**
	43		1	**3.12%**
Course of Study	Professional Study of Informatics		20	**62.50%**
	Specialist Graduate Professional Study of Information Systems		12	**37.50%**
Year of Study	Professional study of informatics	Second Year	4	**12.50%**
		Third Year	16	**50.00%**
	Specialist Graduate Professional Study of Information Systems	First Year	11	**34.38%**
		Second Year	1	**3.12%**

Only a small number of students (3.12% of the pattern) attend the second academic year. A total of 37.5% of the respondents attend Specialist Graduate Professional Study of Information Systems.

A. Survey Structure

In order not to reveal the respondents' personal data, the survey was anonymous. The first parts of the blank form included basic questions regarding the respondents (their age, academic year and field of the study). The second part consisted of questions regarding astroturfing and it was divided into two lines, depending on the respondent's answer to the first question. The second line of questions was intended to establish the level of the respondent's knowledge of astroturfing.

TABLE II. SURVEY QUESTION

	The Pattern Structure (N = 32)	*N*	*%*
Are you familiar with the term astroturfing	Yes	4	12.50%
	No	28	87.50%

B. Survey Results

In order to precisely identify the awareness of astroturfing danger and outspread, it was necessary to evaluate the respondents' knowledge about the topic.

The respondents were asked whether they are familiar with the term astroturfing or not (Table II.). Based on the response to that question, the respondents where divided into two survey groups (N1 and N2). The first survey group included respondents who were familiar with the term astroturfing (4 of 32), and the second survey group included respondents who were not (28 of 32 respondents, i.e. 87.5%). This shows that the majority of students know nothing about the concept. Since there is no proper research on the topic in Croatia, and the only information available comes from several articles [11], the answer to this particular question is probably the respondents' personal opinion on widespread conspiracy theories contamination.

The remaining survey questions and answers are presented in Table III and Table IV. In the first survey group (N1=4), 3 of them (75%) also answered "Yes" to the second question "Do you think that astroturfing is commonplace in everyday life?" (Table III.). Only 1 respondent (25%) answered "No". A total of 3 (75%) of the informed respondents think that there were astroturfing attempts to affect their opinion and 1 of them thinks he/she has never encountered any astroturfing attempt. All of the 3 affected respondents are more aware of political astroturfing, and less of astroturfing at the state level. Furthermore, all of the 3 informed respondents think that people in their surroundings are not immune of the astroturfing attempts, but half of them considers they are immune. That shows a great level of self-esteem of these respondents, but it is their utterly personal opinion. One might suppose that the respondents are able to recognize some astroturfing attempts, but it is doubtful to what extent. Since each individual forms his/her opinion in interaction with their surroundings, depending on the information available, it is hard to obtain objective and trustworthy information.

A total of 3 of 4 respondents (75%) from the first group think that astroturfing might be suppressed by better-problem oriented education. Only 1 respondent thinks that education is not the way to solve this problem. All 4 of the informed respondents claim that Croatia has no protective legislation against astroturfing attempts. Furthermore, 3 of 4 respondents think that the European Union has some protective legislation, but they did not provide an example of any legislation. As an interesting notion, one respondent from the second group (not familiar with the concept) mentioned GDPR (General Data Protection Regulation) as European astroturfing legislation. All members of the first group are convinced there is no astroturfing protection software.

The answers of the second survey group (N2 = 28), that is not familiar with astroturfing, are presented in Table IV. The second question was whether they think that state or other organizations try to indirectly affect their opinion: as much as 21 respondents (75%) answered "Yes", while only 7 of them (25%) answered "No". Those who answered "Yes" were asked whether they recognized any influencing attempt.

TABLE III. RESPONDENTS WHO ARE FAMILIAR WITH ASTROTURFING

		N1 (N=4)	*%*
Do you think that astroturfing is commonplace in everyday life?	Yes No	3 1	**75.00%** **25.00%**
Have you ever experienced an attempt to influence your opinion through astroturfing?	Yes No	3 1	**75.00%** **25.00%**
		N(N = 3)	**%**
By whom:[a]	Countries Political parties Big corporations Grassroot Movements Other	1 3 2 2 0	**33.00%** **100.00%** **66.67%** **66.67%** **0.00%**
Do you think people around you are resistant to such a kind of attempt to influence their thinking?	Yes No	0 4	**0.00%** **100.00%**
Do you think you are resistant to attempts to influence your mind?	Yes No	2 2	**50.00%** **50.00%**
Do you think that such an attempt to influence you or others can be prevented by better education about the problem?	Yes No	3 1	**75.00%** **25.00%**
Do you think there is legislation in Croatia to protect you from this attempt to influence you?	Yes No	0 4	**0.00%** **100.00%**
Do you think that the European Union has legislation to protect you from such an attempt to influence you?	Yes No	3 1	**75.00%** **25.00%**
		N (N = 3)	%
Are you familiar with any legistlation?[b]	Yes No	0 3	**0.00%** **100.00%**
Do you think there is a software to protect you from such an attempt to influence you?	Yes No	0 4	**0.00%** **100.00%**

a. The respondents could both choose more than one answer and write their own answers.

b. This question only applies to respondents who have answered "Yes" to the question whether they believe there are regulations in Croatia or the European Union, so that% is counted on that base.

As much as 15 respondents answered "Yes", 13 of them recognized the attempt made by political parties, 10 by big companies and 8 of them identified attempts made by the state or civil sector. One respondent added the newspapers-made attempt.

Regardless of the answer to the previous question, the respondents were asked if they considered that people in their surroundings are immune to astroturfing attempts. The majority of 16 respondents answered "No".

When asked if they considered themselves immune, only 1 respondent answered "Yes". This result shows the lower self-esteem in the group regarding the first group results.

All of the respondents were asked whether they think that better education might solve the astroturfing problem. The majority of them (19 out of totally 21) answered "Yes". That answer is significantly different when comparing the group results to those of the first group.

Regarding the protection legislation in Croatia, 18 respondents thought there wasn't any.

Regarding the European Union legislation, 10 respondents thought there is such legislation, 1 of them offered GDPR as an answer, and 11 respondents thought there wasn't any.

Regarding protective software, 7 respondents thought that such software might exist, but they were not able to provide any examples. A total of 14 respondents thought there was no such software.

C. Results Interpretation

Although most of the respondents are aware of the attempts to affect their opinion and attitude, the majority of them do not know the astroturfing concept and are not aware of the frequency of these attempts. Awareness of the astroturfing danger is much larger abroad, but there are certain articles in Croatia [11] which describe the danger of astroturfing.

Most of the respondents are aware of political parties' astroturfing which is in line with common recognizing of political astroturfing as the most widespread and the oldest one.

TABLE IV. RESPONDENTS WHO ARE NOT FAMILIAR WITH ASTROTURFING

		N2 (N=28)	*%*
Do you think that states or other organizations want to influence your opinion / attitude in an indirect way (e.g. by posting on social networks with bogus accounts or false initiatives)?	Yes No	21 7	**75.00%** **25.00%**
Did you recognize an attempt to influence your opinion or attitude?	Yes No	15 6	**71.43%** **28.57%**
		N (N = 15)	**%**
By whom:[a]	Countries Political parties Big corporations Grassroot Movements Other Press	8 13 10 8 1	**53.33%** **86.67%** **66.67%** **53.33%** **6.67%**
Do you think people around you are resistant to such a kind of attempt to influence their thinking?	Yes No	5 16	**23.81%** **76.19%**
Do you think you are resistant to attempts to influence your mind?	Yes No	15 6	**71.43%** **28.57%**
Do you think that such an attempt to influence you or others can be prevented by better education about the problem?	Yes No	19 2	**90.48%** **9.52%**
Do you think there is legislation in Croatia to protect you from this attempt to influence you	Yes No	3 18	**14.29%** **85.71%**
Do you think that the European Union has legislation to protect you from such an attempt to influence you?	Yes No	10 11	**47.62%** **52.38%**
		N (N=10)	%
Are you familiar with any legislation?[b]	Yes No	1 9	**10.00%** **90.00%**
Do you think there is a software to protect you from such an attempt to influence you?	Yes No	7 14	**33.33%** **66.67%**
		N (N = 7)	**%**
Are you familiar with some examples of software? [c]	Yes No	0 7	**0.00%** **100.00%**

a. The respondents could choose more than one answer and write their own answers.

b. This question only applies to respondents who answered the question whether they believe there are regulations in Croatia or the European Union, so that % was also counted.

c. The question relates only to respondents who answered "Yes" to the question whether they think that there is software so that % was also counted.

It is commonly known that political parties encourage their youth organizations to "like" the posts and articles of

their political party members, as well as the articles which are in line with the political party attitude.

It is known that, youth organizations aside, Croatia has professional astroturfers who open new Facebook pages and groups and influence Facebook members to "like" or "dislike" various articles [11]. To avoid legal consequences, they are discreetly discrediting the political opponents making the false posts. Opening such pages and groups and their administration has become a profitable business. Sockpuppets' articles are not illegal since the administrator avoids the elements that might be considered calumny [11].

The majority of respondents considered themselves more immune to astroturfing attempts in comparison to their surroundings. It is commonly known as "superiority illusion" or "Lake Wobegon effect"[21]. People usually underestimate others and have a high opinion of themselves. A survey on Stanford University shows that 87% of students think better of themselves than their colleagues [22]. In general, the lack of objective information is making the students' attempts to defend themselves from sophisticated astroturfing campaign less successful.

The majority of the respondents agree that astroturfing influence can be prevented through better education. The main problem is insufficient research and expertise on

astroturfing, so the main source is various newspaper articles that might be the astroturfing attempts, too.

The students think that there is no proper anti-astroturfing legislation in Croatia, but they are not aware that Croatia has some legislation for particular cases of astroturfing. For example, in 2007, the Consumers' Protection Act was passed [8] according to which the malpractice can be punished. In 2009, another law, on false advertising, was also passed [9]. As mentioned before, the Criminal Act recognizes the calumny concept. Croatian laws are not appropriate for the fight against astroturfing, except for some commercial astroturfing examples. Croatia, as an EU Member State, has to apply the European Union's Unfair Commercial Practices Directive [13].

The majority of the respondents think that the European Union legislation solutions are better than Croatian, but it is not so overwhelming as it should be to protect against astroturfing attempts, especially not those made by great state actors as the USA or Russia (that is a great problem today). GDPR was not made as a protective tool against astroturfing, although it may help detect some attempts when using stolen personal data. The complexity of astroturfing praxis disables the legislators to pass the laws which could regulate astroturfing comprehensively [14].

Software as a protective tool was not considered by students, although scientists from Indiana University developed software which could detect astroturfing on Twitter [12].

V. CONCLUSION

Astroturfing is an effective and complex "special war tool" based on a false presentation of an astroturfing campaign as a legitimate grassroots movement. It emulates grassroots in order to achieve someone's particular aims. Therefore, astroturfing cannot be ethical.

Manipulating others' opinions and attitudes is as old as the humanity itself. The techniques changed during the periods of time, becoming more complex and expensive. It is hard even to detect contemporary campaigns. Today, astroturfing campaigns need precise planning, sophisticated thinking on how to avoid legal consequences and data leaks as well as complex organizational structure. Otherwise, the target attacked can detect the attempt and it can easily fail.

Internet development enabled astroturfers to easily reach billions of people. The complexity of the astroturfing techniques and a variety of different media disable the efforts to make effective protective software. One software has been developed for Twitter.

It is expected that the problem of astroturfing is going to become more complex than it is today, but also various defense techniques, including legislation, software, and education are going to be developed as well. Critical thinking is an effective defense against astroturfing which every individual should be able to develop.

The majority of students' pattern are well aware of astroturfing as an imminent danger, although not acquainted with the word "astroturfing" itself.

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Neural Networks for File Fragment Classification

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***Abstract* - File fragment classification is an important step in file forensics in which filetypes are assumed based on their available content fragments. Methods typically used for this task utilize machine learning techniques on features like byte frequency distributions and fragment entropy measures. In this paper, a contribution to this field is made through exploration of novel approaches to the problem including feedforward artificial neural networks and convolution networks. Feedforward neural networks were trained with byte histograms and with byte-pair histograms, while convolution neural networks were trained with blocks consisting of 512 bytes of data obtained from the *GovDocs1* dataset. The results suggest convolution neural networks are not as promising for this problem as feedforward artificial neural networks, and feedforward artificial neural networks showing great results.**

Keywords – file fragment classification; file type detection; artificial neural network; convolutional neural network; feed forward neural network; file type forensics

I. INTRODUCTION

Digital forensics involves many steps and procedures, with file discovery and recovery being one of the most important ones. Files can contain important information and clues both in their content and metadata, thus making their extraction crucial for successful forensics.

There are various methods for recovery of deleted files. The task can generally be split in two different approaches, depending on the availability of the file system index. In cases where either the file system index is available, or it is possible to reconstruct it, usual approaches use that information to reconstruct the blocks of the deleted file [1]. In contrast, there are occasions where it is not possible to obtain such information, making the task significantly harder. It might be possible to detect the beginning of a file by searching for magic numbers, and the end by looking for signatures, depending on the filetype. That information can easily be tampered and is therefore unreliable. Additional problems occur due to fragmentation, making it impossible to detect all the file fragments and piece them together. Several existing methods have been proposed and tested to help with that issue, all of them trying to determine the filetype based on just a part of the file. The usual approaches consist of taking hand engineered features that are further utilized by a machine learning model such as k-NN [2], k-means [2], decision trees [2], support vector machines (SVM) [3], [2], [4] and neural networks [2], [5], [6].

In this paper, we explore automated feature extraction methods based on unigram and bigram byte frequencies as well as convolution using whole blocks of 512 bytes. Section II covers a concise overview of related work. Section III introduces the data representation and preprocessing, as well as a detailed description of used artificial neural network (ANN) architectures. The experimental setup and results are presented in section IV, followed by a conclusion and future work discussion in section V.

II. RELATED WORK

With file type classification being an essential part of forensics analysis, there are numerous methods proposed for achieving it. Basic approaches are based on magic numbers and file headers and signatures. Through the years more advanced approaches have been proposed.

A simple linear classifier based on hand-engineered features is proposed in [7]. The model is proven to work but suffers from high false positive rates even for smaller numbers of different file types. Various other machine learning approaches have been tested in [2], such as SVM, k-NN, k-means, decision trees and neural networks. The primary focus of that research is set to improve the classification speed. They also introduced the possibility of using sampled file blocks instead of hand-engineered features. The main differences in our paper are the focus on classification results, and the block sampling process. In [2] it is proposed to use the first block of a file as it often includes magic numbers. Even though that can significantly boost the accuracy, we decided not to use that information as it can be easily modified and can't help in case of file fragmentation.

Multiple researches approach the problem by collecting unigram and other N-gram features, such as is done in [3] and [4]. Contrary to those approaches using SVM for classification, we are using neural networks. Additional differentiation from [4] appears in the classification step as they are using multiple blocks to boost classification accuracy, but we are training our models without the knowledge of all the blocks of a file, but just a single fragment.

There is research using convolution neural networks (CNN) in [6]. The authors converted 1D byte blocks into 16x16 2D grayscale images and used that as input for CNNs used for image classification. Even though the results are promising, the described approach adds nonexistent correlation to some byte pairs, as bytes 1 and 17 for example now become closely related. To overcome

that issue, we propose a CNN using 1D convolution on the original byte block.

III. PROPOSED APPROACH

A. Data representation and preprocessing

GovDocs1 [8] is a publicly available dataset commonly used for training and testing file type classification models. The dataset contains 986278 files, with 213 different file types. With some files occurring more than 100000 times, while some of them being represented less than 10 times, there is a huge disbalance in classes. Dating back to 2009, the dataset contains only a small number of new file extensions that are common nowadays, such as the Office Open XML (introduced in December 2006).

To mitigate the disbalance between file types, 18 extensions have been selected based on their frequency in the dataset and usage, as displayed in Table I. A new dataset is created to further reduce the disbalance by random sampling 25000 blocks for every file type, creating a well-balanced set of 25000 samples per class. This approach is favored since it is highly similar or same as in other similar work (for example [3]), thereby enabling classification results comparison. The average file size is 495.45kB, which equals approximately 1000 blocks per file, thus having enough different blocks for even the least common file types. While sampling, the first block of every file is ignored as it can contain magic numbers or other file specific information which could lead to overfitting.

Rather than hand engineering the features that would represent the data used for training the machine learning models for filetype classification, we use two simple automated approaches for file fragment representation.

First, being raw byte-arrays of size 512B randomly sampled directly from memory blocks are fed into a convolutional neural network, which is meant to identify distinct patterns in these byte-arrays related to different classes, similar as in the task of image classification. The general difference is in the spatial dimension of the sought patterns and the convolution itself, image being in 2D and byte-arrays being in 1D, thus corresponding convolution is applied.

Second approach we use are byte frequencies represented in the form of unigram and bigram frequencies. Those values are then used in a feedforward artificial neural network, described in more detail in section III.B. Unigrams are represented as the number of times each byte appears in the current block. There are 256 different byte values, resulting in 256 different unigrams, thus having the feature vector be 256 units long. As there are 512 bytes in the sampled block, the sum of all the unigram features is also 512 for every block. When calculating bigram features, the feature vector must count all different bigram occurrences, resulting in a feature vector of 65536 elements. As there are only 511 bigrams in a block, the feature vector will be sparse. Trying to reduce the feature vector, multiple feature selection methods have been tested, such as variance threshold, false positive rate (FPR), false discovery rate (FDR) and family-wise error rate (FWE). The authors' experiments showed that only variance threshold is applicable, as other tested methods resulted in low reduction rates even with extreme parameter values. With threshold set to 0.2611, variance threshold reduced the input vector to 1043, while still containing important information, as seen in the results in section IV.

TABLE I SELECTED FILE TYPES AND FILE COUNT

Extension	Number of files	Extension	Number of files
csv	18717	ppt	51292
doc	76605	pptx	220
docx	164	ps	20630
gif	36302	rtf	1067
gz	14021	swf	3473
html	202440	txt	88856
jpg	109283	xls	62876
pdf	231106	xlsx	39
png	4125	xml	32186

B. Used models

As mentioned before, we have tried out two different approaches for presented task, convolutional neural network (CNN) and simple feedforward artificial neural network (FFANN). The later turned out to yield significantly better results.

FFANNs consist of the number of layers of their computational units called neurons, which are arranged in a way that the output of each neuron of a certain layer is connected to the input of each neuron in the following layer. In addition, neuron applies an activation function, which ensures a degree of nonlinearity in the model. The number of layers, as well as the number of neurons in each layer, is variable depending on the learning capacity needed for a given task. However, the first, input layer and the last, output layer are fixed in sizes, which depends on the data dimensions and the number of classes, so only the sizes of hidden layers can be arbitrary. Furthermore, choosing a specific activation function can also make a difference. Therefore, various architectures were examined, from rather small three-layered nets to more complex nets with six or seven larger layers. The size of the architecture unexpectedly turned out to bring minor, if none improvements, while significantly increasing time complexity. For this reason, only 2 hidden layers were used in the models tested and evaluated in the section IV. As for the activation functions, RELU, leaky RELU, tanh, SELU and sigmoid function were tested, out of which RELU appeared to be the best, and the least time-consuming choice.

CNNs, on the other side, have connections between layers on a local scale, which means that each neuron of one layer is connected to a certain number of adjacent neurons of the succeeding layer, ending as well with an activation function, most commonly RELU. This number, called the kernel size, determines the size of each neuron's receptive field of that particular layer, through which a distinctive pattern is sought. Layers which are connected to their successors in described way are called convolutional layers and they usually have additional dimension, referred as the number of channels, which allows them to search for multiple different patterns through the same receptive field. Typically, CNNs consist of convolutional layers and

pooling layers in alternating order. Pooling layer combines the outputs of neuron clusters into a single neuron, usually taking the maximum or the average value in a cluster, which reduces the spatial dimension of a data stream through network and lowers the computational costs. Most importantly, it effectively increases the size of the receptive field in the following convolutional layers. The size of the cluster is called pooling stride. The number of channels stays intact through pooling layers, but through each convolutional layer it commonly grows. In the end, output of the network still needs to match the number of classes. This is accomplished by simply adding one or two fully-connected layers, described above, of appropriate size. The last pooling layer is therefore flattened out as to fit the shape of the following layer. The authors have experimented with different variations of described architecture and the one found to be the most successful is introduced in the chapter IV.

IV. RESULTS

Multiple architectures of the models described in section III.B. are trained using the appropriate dataset and measuring macro-average F1 score for the chosen 18 classes. All the models are tested on 10 independent test sets, all of them being subsets of the *GovDocs1* dataset [8].

Amongst convolutional neural networks, best results are achieved with an architecture containing 3 convolution layers of sizes 64, 128 and 512 with kernel size 5. The flattened pooling layer is followed by a fully connected layer of 512 neurons, followed by another fully connected layer of 18 neurons for the output. The model achieved macro-average F1 score of 0.6155, which is slightly better than the results reported in [3], leading to the conclusion that convolution is capable of finding meaningful patterns. As seen in the confusion matrix in Figure 1, the model has high accuracy for text-based files, such as *csv*, *ps*, *rtf* and *xml*, as they contain patterns such as *ps* commands or *xml* tags. Worse performance is measured on archive files such as *gz* and *pptx* for example, where the file is often mistaken for a picture. Differentiating those classes is difficult as it can be possible that a block from a *pptx* file actually contains an image and is therefore indistinguishable from the image filetype. Feedforward artificial neural networks show remarkable results. Multiple architectures achieve

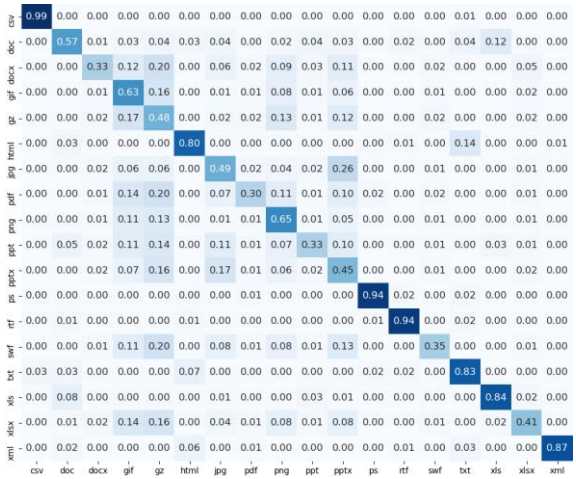

Figure 1 Confusion matrix for convolutional neural network

TABLE II MACRO-AVERAGE F1 SCORES FOR DIFFERENT FULLY CONNECTED ARTIFICIAL NEURAL NETWORK ARCHITECTURES

Architecture	F1 Score
256x2048x18	0.8036
256x1024x512x18	0.8067
256x750x1500x18	0.8092
256x800x500x200x18	0.8105
256x1500x750x18	0.8136
1043x512x18	0.7993
1043x1024x512x18	0.8021
1043x1500x750x18	0.8053
1043x1024x18	0.8086
1043x2048x18	0.8138

similar results, as shown in Table II, leading to a conclusion that the score is limited by the task, rather than the network architecture. Using unigrams as input, a macro-average F1 score of 0.8135 is achieved with a network containing the 256 neuron input layer, two hidden layers of 1500 and 750 neurons and an output layer of 18 neurons. As displayed in Figure 2, the model has better accuracies while still having problems with archive file-types as discussed previously.

Using selected bigrams as input, the results stayed nearly the same as with unigrams, as seen in Table II. The highest macro-average F1 score is 0.8138 while using just a single hidden layer with 2048 neurons. The corresponding confusion matrix is given in Figure 3.

Given the aforementioned results, there are notable differences in performance across the models. As displayed in Figure 4, convolutional neural networks perform worse than their fully connected counterparts. That is further tested using nonparametric Kruskal-Wallis test with 5% significance level, with null hypothesis being that the mean performance of all classifiers is the same. With resulting p-value of 6.1402×10^{-5} we can reject the null hypothesis in favor of the alternative that the macro-F1 score is different across the tested models. The difference is further tested using a permutation test with null hypothesis that the model using unigrams performs equally to the one using bigrams. That hypothesis however could not be rejected with a 5% significance level.

Comparisons are also made between different architectures using the same data representation. Figure 5 displays the macro-average F1 scores neural networks

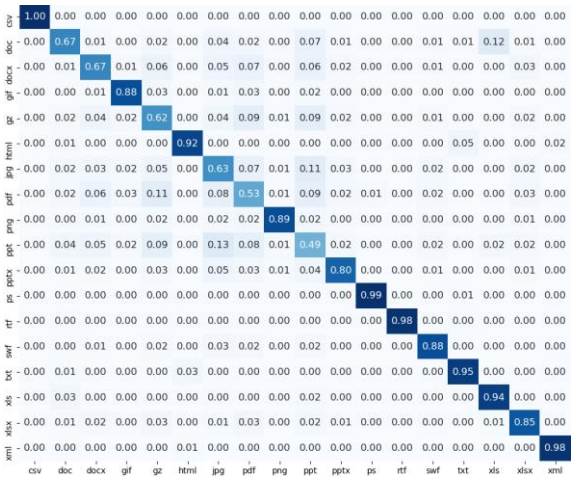

Figure 2 Confusion matrix for feedforward artificial neural network using unigrams

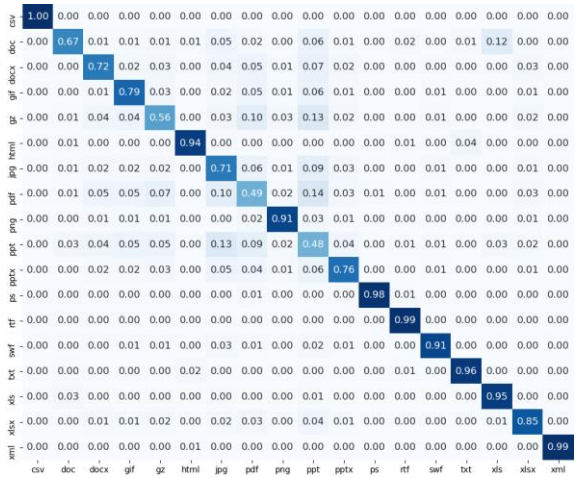

Figure 3 Confusion matrix for feedforward artificial neural network using bigrams

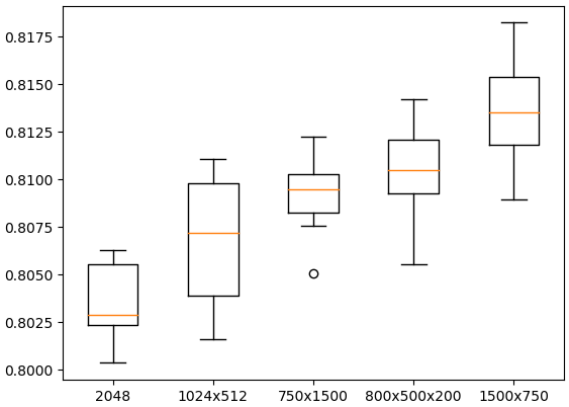

Figure 5 Boxplot displaying the macro-average F1 score of different architectures using unigrams (only the sizes of the hidden layers are displayed)

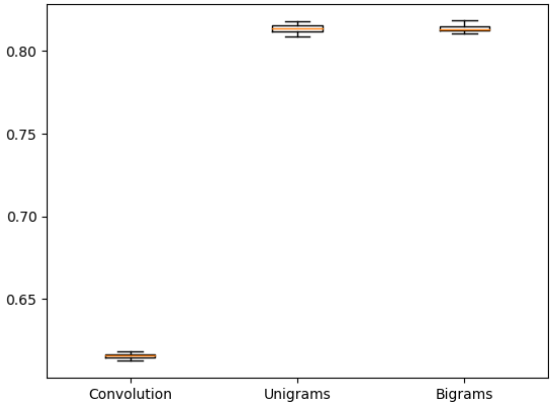

Figure 4 Boxplot displaying the macro-average F1 score of different models

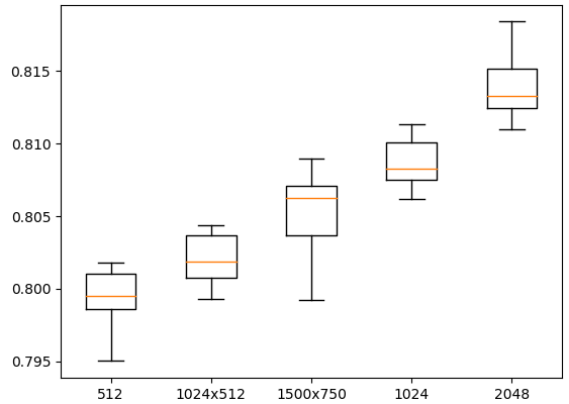

Figure 6 Boxplot displaying the macro-average F1 score of different architectures using bigrams (only the sizes of the hidden layers are displayed)

using unigram feature representation, for the models given in Table 2. Even though the absolute difference between the models is not as big as the one between convolution and unigrams, there still exists statistically significant differences in model performances. Testing the null hypothesis that the F1 scores are the same for all 5 architectures with Kruskal-Wallis test results in a p-value of 2.1389×10^{-6}, leading to the rejection of the hypothesis in favor for the alternative that there exists difference between models. Additional analysis using permutation test show that with a 5% significance level, the model with two hidden layers with 1500 and 750 neurons performs better than the rest.

Similar results are obtained for feedforward neural networks using bigrams for feature representation. As seen in Table 2 and Figure 6, the difference between models is comparable to the one in Figure 5. With a p-value of 2.0546×10^{-8} the hypothesis that the models perform the same is rejected and permutation test shows that the architecture of just a single hidden layer with 2048 neurons outperforms the others.

Comparing the confusion matrices in Figure 2 and Figure 3, it is visible that although the two models are performing the same based on the macro-average F1 score, they do not make the same mistakes. Based on that conclusion, a new model is proposed, namely an ensemble of all the used classifiers. Convolution network is left out of the assemble as it increased the execution time significantly, while providing no statistically significant difference. The final output of the classifier is computed based on the output of each individual classifier, weighted by the classifier confidence in its output. The classifier outperformed others with a macro-average F1 score of

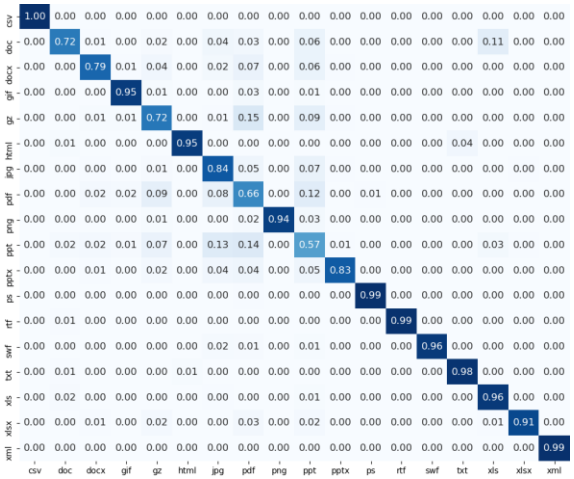

Figure 7 Confusion matrix for ensemble

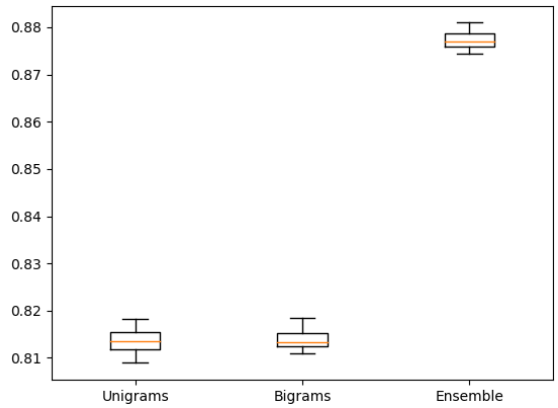

Figure 8 Boxplot displaying the macro-average F1 score for base models and ensamble

0.8772. The results can also be seen in the confusion matrix in Figure 7, where it is visible that the number of misclassified items is much lower, while still existing on some specific classes.

In comparison to the best unigram and bigram model it is clearly seen on Figure 8 that the ensemble outperforms both. That claim is tested using Kruskal-Wallis test with 5% significance level, where the null hypothesis that all three models are the same is rejected with a p-value of 6.1402×10^{-5}, leading to the conclusion that ensembles really do perform the best for the given task.

V. CONCLUSION

Presented ANNs, individually and in the ensemble, yield quite satisfactory results, especially in comparison to other methods in the field. This is to say that a simple fully-connected network has enough capacity to approximate a complex mapping such as binary file representations to its filetypes.

ACKNOWLEDGMENT

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UnProVET: Using Explicit Constraint Propagation to Construct Attack Graphs

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***Abstract*—One of the important problems in network security consists in the construction and analysis of attack graphs which represent all possible attacks a malefactor can carry out within a specific computer network. In this paper we describe the software system for constructing such attack graphs. The system is based on the constraint propagation mechanisms which are very close to that employed by the algorithms for solving Constraint Satisfaction Problem (CSP) and its variants. Unlike several other known software systems for attack graph generation it employs explicit constraint propagation implemented using special data structures. The computational experiments show that the system has good performance and outperforms the competition in certain scenarios.**

I. Introduction

Attack graphs are the special labeled graphs used to represent the development of attacks in computer networks. They are an important object of the study in both theoretical and practical areas of computer security. There are multiple ways of representing how the attacks develop in the network using special graphs. The first representations of this kind were very ineffective [1]. In [2] there was described the first class of attack graphs, for which the time required to generate them grows as a polynom on the number of hosts in a corresponding computer network. After [2] there have been published a number of papers which proposed the classes of attack graphs with steadily declining complexity of their generation. We would like to specifically point out the papers [3], [4], where there have been proposed the class of attack graphs with practical effectiveness of their construction lying between $O(n^2)$ and $O(n^3)$. These papers are based on the idea to synthesize an attack graph during solving the logical programming problem: essentially, the attack graph is the output of some Prolog program. The main disadvantage of the attack graphs from [3], [4] is that they have loops, which significantly hinder correct interpretation of attacks. Also, in order to outline the set of shortest attacks in a graph with loops one has to perform a lot of laborious computations. To the best of our knowledge, today the most compact attack graphs are the ones constructed by the approach described in [5], [6], [7]. However, the corresponding graphs too contain loops. As it is mentioned in the review [8], the `NetSPA` system later was included into the commercial tool which is not available for public use. Therefore, we could not compare our results with that of `NetSPA`. Note, that a promising trend in attack graph generation is captured in e.g. [9], where it was proposed to use distributed computing for this purpose. The current implementation of our tool is a single-threaded program, but in the nearest future we plan to consider the parallelization of the algorithms we employ. An additional information on the research related to attack graphs and their generation can be found in the review [10].

In [11], [12] we proposed a new class of attack graphs which are generated as a result of a discrete dynamical process of automaton type. The resulting attack graphs do not contain loops and the development of each attack has strict time hierarchy. The complexity of constructing such attack graph is $O(n^2)$. The procedure that finds the shortest attacks in a network has the same complexity. Also in [11], [12] we described the propositional encoding technique for the algorithms that construct graphs of this class. The result of such encoding is a Boolean formula in Conjunctive Normal Form (CNF). This formula can be used to solve various combinatorial problems aimed at figuring out the security properties of a considered network, for example, to distribute patches that deactivate some vulnerabilities on specific hosts. This formula can be used to construct an attack graph by iteratively applying the Unit Propagation rule to it.

In this paper we present the new variant of the software system used in [11], [12], which employs explicit constraint propagation to generate attack graphs. The new version works directly with data structures containing the information about a network without the transition to Boolean expressions. This approach is justified in the case when one wants to construct an attack graph fast, and there is no need to solve any related combinatorial problems. We show that the speed of attack graphs generation achieved by this new procedure significantly exceeds that of the generation via Boolean constraint propagation.

Let us give a brief outline of our paper. In the next section we give the main notation and results used as a basis for the following constructions. In particular, the section contains a short description of the UnProVET system. In Section 3 we describe the new variant of UnProVET in which the constraint propagation is implemented without derivation mechanisms from Boolean logic. The fourth section contains the results of computational experiments on comparison of UnProVET with similar systems.

II. Basic notation and Background

Below let us consider the process of attack development in a computer network as a discrete dynamical process of

automaton type. In our formal description we use the notation system introduced in [11], [12].

Hereinafter, we use an undirected labeled graph $G = (V, E, L_V)$ as a model of computer network, where $V \to L_V$ is the mapping that defines the vertices' labels: each label contains some information about a vertex. The set V, $|V| = n$ is associated with a set of *hosts* of a computer network, and each edge $e = (a, b), e \in E$ interprets the physical connection between hosts $a, b \in V$. A *neighborhood* of an arbitrary vertex $v \in V$ is the set of vertices adjacent to v. Assume that there are two specifically outlined vertices in V: v_M and v_T. Here v_M is the vertex which represents the host of a malefactor. The goal of a malefactor is to obtain control over host v_T.

An important assumption is that there is defined a mapping $V \to L_V$ which associates with an arbitrary vertex $v \in V$ some information (label). In particular, with each host $v \in V$ there is linked a binary word l_v. Every coordinate of l_v shows whether or not a host v has a particular vulnerability. We refer to l_v as *vector of vulnerabilities*. Informally, the vulnerabilities are the conditions which make it possible for the malefactor attacking v to escalate its access rights on v. Let us denote by U the list of all possible vulnerabilities that can appear on network hosts. Then for an arbitrary v the vector l_v will contain $|U|$ numbers from $\{0, 1\}$, the 1-coordinates signifying that the corresponding vulnerabilities from U are present at v.

In the context of the model employed in [11], [12] we assume that the only active subject in a network is the malefactor. Its actions take place at discrete time moments and consist in escalating malefactor's privileges on hosts available to the malefactor at this time moment. In [11], [12] there have been considered the following access levels:

1) Access level $user_0$ of host v' to host v'' means that v' can read $l_{v''}$, i.e. v' (which is either v_M or a host on which M has high access rights) can physically connect to v''.
2) Access level $user$ of host v' to host v'' means that v' can perform elementary attacks on v''.
3) Access level $root$ of host v' to host v'' means that v' gains the access level $user_0$ to all hosts from the neighborhood of v'' in graph G.

Informally, the elementary attack mentioned in point 2 is the atomic action of a malefactor which consists in exploitation of one or several vulnerabilities of a considered host.

The introduced gradation of access levels makes it possible to consider the development of attacks in computer network as a dynamic process taking place at discrete time moments. Below we go in a little bit more detail regarding the way the development of attacks was represented in [12]. The corresponding conditions on execution of elementary attacks were formulated as close to the ones in [3] as possible. The successful execution of any attack (including elementary attacks) is the escalation of current access rights of M to the next possible level in the gradation above. The attack on a network is deemed to be successful if at some time moment M manages to get $root$ access to host v_T.

Thus, assume that at $t = 0$ the malefactor can access only the hosts with which it is physically connected, i.e. is in the relation $connect$ with them. Then at time moment $t = 1$ the access level of M to these hosts is elevated to $user_0$. If the host to which M has access rights $user_0$ possesses the *remote_exploit* vulnerability then at the next time moment M escalates its access rights to this host to $user$. If M has $user$ rights on some host on which there exists the *local_exploit* vulnerability then M can get the $root$ access to the corresponding host at the next time moment. Finally, if M has the $root$ access to host h at time moment t, then at $t + 1$ it is assumed to be in the $connect$ relation with all hosts from the neighborhood $N(h)$.

In [11], [12] it was shown that the process of development of an attack in computer network corresponds to the State Transition Graph (STG) Γ_G of a discrete dynamical system (DDS) which we denote as Δ_G. The graph of attacks on network G essentially is a special representation of Γ_G. Also in these papers it was shown that under the monotonicity assumption over the discrete automaton mapping represented by graph Γ_G, the DDS Δ_G has a single stationary point and does not have cycles of length > 1. Thus it is easy to make the conclusion that the attack graph A_G constructed from Γ_G is a directed graph without loops (unlike the graphs generated by the MULVAL system [3]). The complexity of constructing A_G for G (under standard assumptions for computer security) is $O(n^2)$, where n is the number of hosts in network G.

III. Attack Graph Generation as the Constraint Propagation Process

In [12] we presented the UNPROVET (Unit Propagation Escalation Vulnerability Tool) system for generating attack graphs. In this system an algorithm that constructs A_G based on Γ_G is encoded into a Boolean formula C_G in a Conjunctive Normal Form (CNF). For this purpose the tool employs the standard symbolic execution mechanisms described for example in [13]. CNF C_G can be used to solve various combinatorial problems related to A_G. For example, it can be the patching problem: to patch a relatively small number of vulnerabilities on some network hosts in such a way that all previously possible attacks on target host become impossible. The information about the network which does not change with time, and also the initial state of the malefactor are represented via the unit clauses which are conjunctively added to C_G. Then the tool applies to an obtained CNF the simplest Boolean Constraint Propagation rule called the Unit Propagation Rule [14], [15]. The result of its iterative use is the derivation of the values for all variables in C_G. These values are then used to effectively construct an attack graph A_G. In the present paper we describe the variant of UNPROVET in which the constraint propagation is implemented directly over data structures used in the transition from G to Γ_G and A_G without constructing CNF C_G.

Below we give examples to key notions mentioned above. The example of a graph G representing a computer network is given on Figure 1.

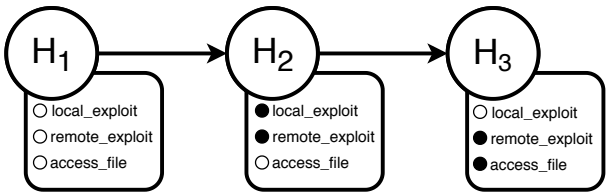

Fig. 1. The example of the network graph with three hosts and their vulnerabilities.

Let us comment on Figure 1. It shows the network with three hosts (H_1, H_2, H_3). There are three kinds of vulnerabilities: *local_exploit*, *remote_exploit*, *access_file*. The *remote_exploit* vulnerability allows the malefactor to elevate its access rights from $user_0$ to $user$. The *local_exploit* vulnerability makes it possible to improve it from $user$ to $root$. Finally, the *access_file* vulnerability gives the malefactor access to file system and thus to use malicious software. Hereinafter we assume that by exploiting it the malefactor launches some trojan.

The exploitation of one vulnerability is called an elementary attack. In the context of the approach used in [11], [12] with each separate realization of elementary attack we associate two discrete time moments: t and $t+1$. In more detail, we assume that at t the conditions on this elementary attack are satisfied (we refer to them as *preconditions*), and at moment $t+1$ we observe the result of this attack (*postcondition*). The elementary attacks most often considered in practice can be split into the following two classes (here we follow [3]):

- *NetAccess* corresponds to determining if there is physical interconnection between hosts. It is responsible for obtaining the access rights $user_0$.
- *ExecCode* corresponds to successful execution of malicious software on an attacked host. It is responsible for escalation of access rights from $user_0$ to $user$ and from $user$ to $root$.

In Tables I and II these attacks are represented by pairs (precondition, postcondition).

Attack name	multi-hopAccess	directNetworkAccess
Preconditions	$root^S$ $connect_S^T$	$root^M$ $connect_M^T$
Postcondition	$user_0^T$	$user_0^T$

TABLE I
ATTACKS FROM $NetAccess$ CLASS

Attack name	remoteExploit	localExploit	trojanInstall
Preconditions	$user_0^T$ *remote_exploit*^{T}	$user^T$ *local_exploit*^{T}	$user^T$ *access_file*^{T}
Postcondition	$user^T$	$root^T$	$root^T$

TABLE II
ATTACKS FROM $ExecCode$ CLASS

Here by S (source) and T (target) we denote the host from which M starts the attack and the attacked host. The access level of a malefactor on a particular host is denoted by superscript (for example, $user^T$ means that M has $user$ rights on host T).

The condition $connect_K^L$ is a predicate which takes the value of $True$ if and only if hosts K and L are connected by an edge in G (i.e. there is direct physical connection between these two hosts).

Thus, in order to perform the *remoteExploit* attack on host T the malefactor must gain $user_0$ on this host at the preceding time moments. To do this M has to get $root$ access to one of the hosts physically connected to T. Also, T must have the *remote_exploit* vulnerability.

An arbitrary state of a DDS Δ_G defined by network G is (in accordance with [11]) a binary matrix of size $3 \times n$: the element (i, j) of this matrix is equal to 1 if and only if at the corresponding time moment the malefactor M has access level number j to the host number i, $i \in \{1, \ldots, n\}$, where $j \in \{1, 2, 3\}$, $1 = user_0$, $2 = user$, $3 = root$.

As it was noted above, the DDS Δ_G does not have cycles of length ≥ 2 and has exactly one stationary point. An arbitrary transition from t to $t+1$ corresponds to changing some components in the state matrix from 0 to 1. Taking into account the standard for computer security assumption on the monotonicity of malefactor's actions (i.e. the results of elementary attacks on preceding steps can not be cancelled later), it is easy to see that the number of different states of Δ_G does not exceed $3n$. All possible transitions between states of Δ_G (i.e. the State Transition Graph, STG Γ_G) can be represented by a table. The Table III specifies the STG for the network from Figure 1.

Time moment t	DDS state Δ_G	Elementary attack corresponding to transition $t \to t+1$
0	1 1 1 0 0 0 0 0 0	
1	1 1 1 1 0 0 0 0 0	DIRECTNETWORKACCESS(H_2)
2	1 1 1 1 1 0 0 0 0	REMOTEEXPLOIT(H_2)
3	1 1 1 1 1 1 0 0 0	LOCALEXPLOIT(H_2)
5	1 1 1 1 1 1 1 0 0	MULTI-HOPACCESS(H_2,H_3)
5	1 1 1 1 1 1 1 1 0	REMOTEEXPLOIT(H_2)
6	1 1 1 1 1 1 1 1 1	TROJANINSTALL(H_3)

TABLE III
ALL POSSIBLE TRANSITIONS BETWEEN STATES OF DDS Δ_G FOR THE NETWORK FROM FIGURE 1.

Comments to Table III. From the table it follows that Δ_G

for the network from Figure 1 has 6 states. The initial state corresponds to the situation when M controls only its own host H_1. The final state represents the situation when M launches a trojan on host H_3. After this point there are no possible actions in the system (so it is a stationary point).

IV. The UnProVET system

The UnProVET software system was designed to solve a variety of problems related to attack graph generation. It was implemented in C++. Similar to MulVAL, the UnProVET system takes as an input an .xml file which contains the description of a network, of vulnerabilities on the hosts, of *and*- and *or*-attacks. After the file is loaded the user can use the graphical interface to edit scenarios, e.g. add or remove facts, modify, add or delete attacks, etc. After this the tool can be used to generate an attack graph. This can be done using two distinctive approaches: the first involves reducing the problem of attack graph generation to the Boolean satisfiability problem (SAT) [16] and using SAT solvers to generate them [12]. The second approach implies direct constraint propagation via the corresponding C++ implementation. The attack graph can be visualized using Graphviz [17]. The result is similar to the one presented at Figure 2.

As it was mentioned above, the UnProVET system essentially performs the transition from Γ_G to an attack graph in its traditional sense. In particular it uses as its basis the format for attack graphs used by the MulVAL system [3]. Such attack graphs contain vertices of three kinds:

- The rectangular vertices in attack graph show the information related to a state of a network, which can not change with time. For example, such information can be about the physical connection between two hosts or the list of installed programs on each host. Let us join all such information into the set to which we refer as set of facts and denote by F.
- The oval vertices represent elementary attacks. The vertices from which the arcs go into oval vertex mean the preconditions of this attack. The vertex to which the edge goes from the oval vertex interprets the postcondition of an elementary attack. Let us denote the set of elementary attacks as A and call it the set of "and"-attacks, since their realization requires that all preconditions are present.
- The diamond-shaped vertices interpret the postconditions of elementary attacks. At each time moment the malefactor can theoretically perform several elementary attacks from a single class, which result in the same gain (i.e. several elementary attacks have the same graph vertex as postcondition). Let us denote the set of diamond-shaped vertices by O and refer to it as the set of "or"-attacks, since their realization implies that at least one of related individual "and"-attacks is realized.
- The arcs of graph A_G represent the transitions between time moments. Denote the set of arcs as E.

Thus the attack graph A_G is the quadruplet of sets $A_G = (F, O, A, E)$. It is a directed acyclic graph the vertices of which can formally be divided into Q layers, where Q is the number of distinctive states in Δ_G. Thus, each layer corresponds to a particular time moment.

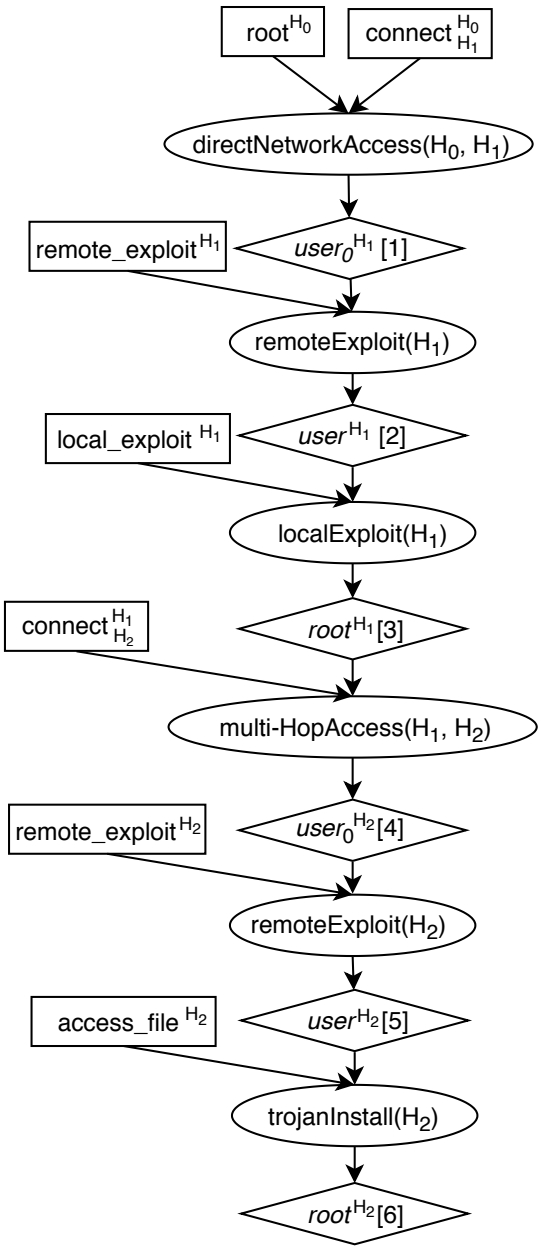

Fig. 2. The example of attack graph for the network from Figure 1

Initially in UnProVET all elementary steps that take place in DDS Δ_G from $t = 0$ and until the system enters the stationary point were encoded into Boolean formulas which in turn were joined into a general formula C_F in Conjunctive Normal Form. With each fact there was associated some literal. All literals were conjunctively added to C_G. Then the Unit Propagation rule [14], [15] was iteratively applied to the obtained CNF $\tilde{C}_G$. This resulted in derivation of values for all variables from $\tilde{C}_F$ and thus provided the information about all possible attacks in network G. This information can be effectively transformed into attack graph A_G.

Let us briefly describe another possible approach to construction of A_G based on graph Γ_G (assuming that it is defined by a table similar to Table III). In the context of this approach the constraint propagation procedure is realized directly over the data structures containing the information about graphs G and Γ_G. In [12] it was shown that the knowledge of facts (i.e. vulnerabilities, interconnections between hosts, etc.) is sufficient for constructing an attack graph. However, it is possible to do it without Unit Propagation rule. Thus, in this paper we implemented direct constraint propagation over the data. It means that essentially the system starts from the initial state (of a DDS, see e.g. Table III) and constructs the next state by applying all possible transformation rules (i.e. elementary attacks) to a present state. The program stops its work after the two consecutive states are equal (i.e. the system enters a stationary point). Essentially, the SAT variant from [12] and the direct implementation perform the exact same work but by different means.

V. Computational Experiments

In the computational experiments we compare UNPROVET with the well known MULVAL tool. In particular, we measure the time of attack graph generation by MULVAL with that of two implementations in UNPROVET: the one employing derivation in Boolean logic and the one that uses explicit constraint propagation directly over available data.

In the experiments we used the networks generated according to the following algorithm. To represent networks we use adjacency matrices. For a given network size N, the adjacency matrix is initially filled with all zeroes. Then starting from vertex number 1 and up to vertex N first the algorithm randomly chooses the number of edges k_i that will go from vertex v_i randomly from $(3; \frac{N-i}{8})$. If $\frac{N-i}{8} < 1$ then $k_i = 0$. Then the k_i edges are generated between v_i and the vertices randomly chosen from $\{v_{i+1}, \ldots, v_N\}$. Once the network structure is fixed, 75% vertices are randomly chosen and assigned some vulnerability that can theoretically be exploited. The malefactor is always associated with vertex v_1. The goal for all systems is to construct the attack graph representing all possible attacks on a network.

The experiments were performed on one core of Intel Core i7-8700 processor with 16 Gb RAM. The results are presented in Table IV. For each graph dimension 10 networks were generated, thus the data in the Table IV is averaged for 10 tests. The time is presented in seconds.

Dimension	MULVAL	UNPROVET UP	UNPROVET direct
500	3.03	1.16	1.07
1000	9.16	3.2	2.79
2000	68.18	10.6	8.77
5000	1534.51	46.22	35.57

TABLE IV
TIME OF ATTACK GRAPH GENERATION FOR UNPROVET AND MULVAL (IN SECONDS).

The "UNPROVET UP" column corresponds to the variant when the Unit Propagation rule is applied to the corresponding Boolean formulas to generate attack graphs while "UNPROVET direct" shows the result for the proposed direct scheme of constraint propagation. It is clear that in the considered experiments the attack graph generation speed of UNPROVET is considerably higher than that for MULVAL. Note that the direct propagation is always better than its implementation via Boolean logic, but the difference in runtime is always within 30%.

VI. Conclusions and Future Work

In the present paper we described the UNPROVET software system designed for constructing graphs representing possible attacks on computer networks. The novel functionality of UNPROVET which uses explicit constraint propagation directly over C++ data structures shows significantly better performance in attack graphs construction compared to the approach employing the reduction to SAT and using Unit Propagation rule. We also show that UNPROVET works faster than the well known MULVAL system for attack graphs generation.

In the nearest future we plan to extend the functional capabilities of UNPROVET towards being able to solve problems of distributing patches aimed at blocking possible attacks. For this purpose we plan to use the state-of-the-art SAT solvers.

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The importance of integration of information security management systems (ISMS) to the organization's Enterprise Information Systems (EIS)

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***Abstract* - The interconnected information systems and networks drive the organizations into a critical situation that determines the need for explicit measures for information protection. The "culture of security" becomes a very important part of the business competition and security policy is a crucial component of business management. The organizations generate, use, store and transmit a huge amount of information which is vital to their functioning and prosperity. It is necessary the information be kept confidential when required, to be available when and where needed and protected from modification and loss of integrity. On this paper, I would like to explain the importance and the impact that information security management system may have on the general enterprise information system. This paper explains the processes that must be taken to integrate the ISMS to EIS, how this integration will help the organizations to protect their data and how this integration will affect on the growth of the business value and trust to the consumers.**

Keywords* - *information security, enterprise information system, integration, data protection, business value

I. INTRODUCTION

Almost all Business processes in organizations are transformed by information technologies. These include both the core processes, such as manufacturing, purchasing or distribution, as well as supporting processes, such as working time management or payroll. In addition to this, confidential information is available in almost every organization and information's, such as employee data or secret construction plans now are relying on the IT infrastructure, respectively on the data information protection services and which are managed by IT systems engineers. Ensuring safe and reliable IT operations are also governed by numerous regulations and laws [1]. Current threats, complex spy programs and data theft, such as Sony, Yahoo, Visa, Deutsche Telekom etc. demonstrated that IT risks have become a corporate risk. In order to prevent deliberate outflow of business-critical information, it is not only required concrete technical measures, but it is necessary to build a package of technical, organizational, physical, procedural and personnel measures and to consider them consistently and on holistically approach. [2] To address the many aspects of such holistic protection of business-relevant information and activities and to ensure the information security of an organization efficiently and effectively managed, the support of a software system for the management of Information Security Management is a need.

The diversity of opinions and factors influencing the process of IT adaption to information security needs is emphasized in many papers [3]. The literature has identified a number of factors affecting this process and most of them have listed factors such as senior management, government, IT consultants, organizational behavior, and so on [4]. Organizations are often affected by the models and standards that are implemented on information security within the same industry, but however not all the models and standards are implemented in the same way. For small organizations that operate with a small staff and which distribute information with key staff only, the implementation of information security does not seem to be a necessary option. However, companies where information is distributed to more people simultaneously, it is impossible to manage them without a proper system, thus, presenting the problem of data vulnerability. The third group of organizations is on where the main product is information [5].

Information Security Management System is defined by ISO 27001 as a set of policies and procedures for systematically managing an organization's sensitive data [6]. The goal of an ISMS is to minimize risk and ensure business continuity by pro-actively limiting the impact of a security breach.

Organizations have different approaches when deciding to implement an information security system. Some organizations see information security systems as a competitive edge in the market that can provide them with greater credibility in their client relationship, as well as an increase of credibility in their organization and products. Another group of organizations implements information security systems only when they see that their competitors are operating in the same way. The

views create cultural diversity within organizations of the same industry and no doubt enables them to improve.

The objective of security policy is to protect the organization's sensitive and critical information in the best manner. In this way, the organization achieves at least two important results: reducing the risk and damage to its business interests and reputation due to harm to own sensitive information or partner's organization information and increasing the confidence in business partners an opportunity for outsourcing activities [7].

II. THE IMPORTANCE OF INFORMATION SECURITY

Information, support processes, systems, and networks are important business assets. Defining, achieving, maintaining, and improving the security of information is essential to maintain a competitive edge, cash flow, profitability, legal compliance and trade image.

Their organizations and systems and networks face security threats from a wide range of areas including computer fraud, espionage, sabotage, vandalism, fires or flooding. Causes of malware such as malicious code of programming, computer piracy and Denial of Service Attacks (DoS) have become more common, more ambitious and more sophisticated. Information security is important for both types of public and private sector organizations and it serves to protect critical infrastructures.

In both sectors, information security will function as an incentive, eg. to achieve e-governance or e-business and to avoid or reduce the risks involved. Liaison between public and private networks and the sharing of information sources increases the difficulty of achieving access control.

The tendency to use distributed IT systems has also weakened the effectiveness of centralized and specialized control Many information systems have not been designed to be safe. Security that can be achieved by technical means is limited and should be supported by appropriate management and procedures. Identifying which security control should be active requires careful planning and attention in every detail. Information security management requires participation by all employees in the organization. Participation of shareholders, suppliers, third parties, customers or other external parties may be required. Advice from specialists or organizations outside the main organization has often proved to be necessary.

The threat of external hackers and malicious attackers of information systems are still a major issue for information security and widely reported in the current events and highlighted in practicing managers' publications, for example. However, many researchers now believe the biggest threat to information security remains internal. This is outlined in several cases in which employees stole data while still working for their company, yet most employee security breaches occur accidentally or unintentionally.

Information security is important and decisive from the protection of organizational assets' view. Information is an asset and like any other asset of an organization it has its value. According to [5], [6] information security refers to the processes and methodologies which are designed and implemented to protect print, electronic, or any other form of confidential, private and sensitive information or data from unauthorized access, use, misuse, disclosure, destruction, modification, or disruption. Information security is important and decisive from the protection of organizational assets' view. Information is an asset and like any other asset of an organization it has its value.

The existing and new businesses have to face with the fact that information security risks may have a negative impact on the process of business continuity, public image, the relationship between organizations, financial loss, affect relationships with clients, partners, and may create problems with legal authorities in case of discrepancies with the law. Information, support processes, systems, and networks are important business assets. Defining, achieving, maintaining, and improving the security of information is essential to maintain a competitive edge, cash flow, profitability, legal compliance, and trade image [10]. Organizations, systems, and networks face security threats from a wide range of areas including computer fraud, espionage, sabotage, vandalism, fires or flooding. Causes of malwares such as malicious code of programming, computer piracy and Denial of Service attacks (DoS) have become more common, more ambitious and more sophisticated. Information security is important for both types of public and private sector organizations, and it serves to protect critical infrastructures. In both sectors, information security will function as an incentive to avoid or reduce the risks involved. [11] The relation between public and private networks and the sharing of information sources increases the difficulty of achieving access control. The tendency to use distributed IT systems has also weakened the effectiveness of centralized and specialized control. Many information systems have not been designed to be safe. Security that can be achieved by technical means is limited and should be supported by appropriate management and procedures. Identifying which security control should be active requires careful planning and attention in every detail. Information security management requires participation by all employees in the organization.

III. THE IMPORTANCE OF ISMS INTEGRATION

Even though cyber-attacks are primarily reported as threatening IT systems, it should not be forgotten that the information must be protected regardless of the medium.

The organizational setup and embedding of an ISMS in the overall organization is a fundamental success factor for your ISMS project.

Our research found that there are three essential points that should be considered when setting up and integration the ISMS:

1. **Derivation from Business Strategy:** You increase the meaningfulness and appreciation of the ISMS when it is heavily wired to the

business strategy of your organization. A good understanding of business strategy will help you better understand what information assets are essential to your business. This can be incorporated into the design of the information security strategy. In addition, the demonstration of the business understanding helps you in the constant dialogue with organizational units, since you have a common basis for discussion.

2. **High management commitment:** The acquired understanding of the business strategy will pay off at the latest to increase the management commitment. Present the top management with the ISMS as a business case. Explain how the ISMS mitigates significant business risks, creates competitive advantages and nonetheless creates new value. [12] Ideally, the ISMS may even increase your organization's revenue and revenue (for example, if you are an IT service provider and your customers consider an effective ISMS as an added value. Details for the design of a business case for ISMS we have also put together for you. Even after setting up the ISMS, continuous dialogue with top management is important to ensure long-term survival. It is the responsibility of the management to make changes to the ISMS (eg. new or changed policies) [13]. Nevertheless, as an IS manager, you are responsible for providing essential information to management as needed. We recommend a combination of regular reporting (eg quarterly) and ad hoc reporting in case of significant changes or incidents.
3. **Dialogue with organizational units:** The interfaces of the ISMS with the specialist departments and asset (information value) owners first enable the ISMS to be filled with life. In most cases, the departments or their managers have the organizational responsibility for information assets and are therefore responsible for their protection. So you also know the meaning of the information values and are your contact for risk management. [14] If you have created an open dialogue with the organizational units, the continuous risk management will achieve much higher quality. The typical problem of "hushing up" risks can be addressed very well by you.

The success of your ISMS can be influenced very early by the correct touchdown. When setting up the ISMS, business-oriented integration into the organization is crucial.

IV. CONLUSION

With the aim of always being alert to Security, Fire and Automation issues, not only facing current threats but also monitoring technological developments, it is necessary to have Information Security Management System integrated into the organization structure, so that organization can read its existing security plans based on current requirements.

The right choice of ISMS and integrated management of an infrastructure of an organization can support decision-making, both at regular and daily level and in the strategic area at the administration level.

In combination with the possibility of an integrated management system, there is direct information about authorized maintenance personnel in case of any information security data breach [15].

Based on research, to accomplish the mission, the Integration of Systems should serve three (3) main areas:

- Consolidation of "dispersed" sources of an organization's security data in order to maximize the existing infrastructure, along with new investments in physical infrastructure.
- Provide the appropriate procedures that enable the transformation of the data collected into useful information at the lowest possible cost. To this end, Integration of Security Systems should be equipped with a high degree of automation and sufficient builder intelligence in order to efficiently manage a large number of buildings from a central office with resources of limited, assisted by some local guards. As an example, we mention the automated correlation of an alarm event from a recorded video.
- Supporting integrated management systems for the maximum extent possible actions by the structures and users of the facility. For example, through a unified platform, the right people with the right information will be informed via appropriate communication tools and in a timely manner, and then it is mandatory to support communication and cooperation between users, different operators and addressing each step alarm event management or access control, until final issues resolution and outcome evaluation.

In addition, with the common control platform and the gradual establishment of compatible systems, it generates enough infrastructure for common policies and security practices in all organizations, helping to implement future actions that are designed and certified by improved procedures.

Lastly, this is achieved through the homogeneity/interchangeability of the centralized management tool and architecture that supports backup centers at both local and regional level (backup/servers and redundant databases) and at the level of decentralized (disaster recovery sites).

With the evolution of technology and the gradual support of open communication protocols - the interaction of equipment from different manufacturers, the choice of a suitable integrated management program increases the desired efficiency, thereby improving investment reliability over time.

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Development of a New International *Behavioral-Cognitive Internet Security Questionnaire*: Preliminary Results from Croatian and German samples

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***Abstract* - This study is based on previous results obtained with the validated Users' Information Security Awareness Questionnaire (UISAQ) and its main critiques concerning length and international usage. The aim was to develop a new international short version of the UISAQ, Behavioral-cognitive internet security questionnaire (BCISQ, Velki & Šolić, 2018). Authors gathered information on risky behavior and security awareness among 250 Croatian students and 225 German adults using the same instrument translated to German. The BCISQ consisted of 2 subscales with a total of 10 items. Model fit for both groups (Croatian and German) was tested using the Software program R. For both groups, the analyses did not confirm a two-factor structure. Due to large covariances between the measurement errors of the last two questions on the cognitive scale it is recommended to split this scale into two separate subscales, risk and importance. The resulting three-factor model shows a good fit for the Croatian (CFI=0.97, TLI=0.96, RMSEA=0.04, SRMR=0.04, χ^2=46.61) and the German sample (CFI=0.93, TLI=0.90, RMSEA=0.05, SRMR=0.05, χ^2=51.44). Future studies should try to further develop the third subscale (risk) of the BCISQ as well as to test the BCISQ in other cultures and languages.**

Key words – information security, international questionnaire, risky online behavior

I. INTRODUCTION

Today, in the digital age, information security and data privacy emerge as important issues in different areas of human life (e.g. security with online bank accounts, medical documentations, students' e-transcript and other online private data). While there is more and better security software available (antivirus, spam-filters, encryption, etc.), the user still remains the weakest link in online security [1]. The first scientific studies on this matter mostly focused only on examining password usage and password quality and strength [2-7]. But the problem regarding password security represents only a small portion of human online risky behavior. Further studies have used different methodological approaches to examine security awareness, to test the relationship between information security awareness and information security threats, to examine the extent of social engineering or to give recommendations for safer internet use [8-15], but still did not cover the whole range of human online behavior.

A. Development of information security questionnaires

In order to examine a wide range of users' potentially risky behavior when using different information and communication systems, it was necessary to develop a very general, but reliable and validated questionnaire which measures information systems users' awareness on security matters. The first validated scientific measurement instrument on this issue was the Users' Information Security Awareness Questionnaire (UISAQ), which was developed five years ago in Croatia [16,17] and later the same authors used this new instrument in order to do systematic research on information security awareness on a Croatian population [18,19]. The UISAQ consists of two parts: the first part measures users' potentially risky behavior, and the second part measures the level of user's information security knowledge and awareness. The questionnaire has 6 sub-areas that measure: usual risky behavior, personal computer maintenance, borrowing access data, knowledge and awareness, security in communications, secured data and backup quality. Later, only few other scientists have developed similar instruments. Turkish scientists developed their Four Measurements Scales [20] measuring risky behavior, conservative behavior, exposure to offence and risk perception. Australian scientists [21] have followed with the Human Aspects of Information Security Questionnaire (HAIS-Q). The HAIS-Q measures seven focus areas: password management, email use, internet use, social media use, mobile devices, information handling and incident reporting. Each focus area is further divided into three specific sub-areas, knowledge, attitude and behavior, resulting in 21 areas of interest.

The main critiques of the developed and validated instruments primarily concerned their length. The UISAQ consists of 33 items, the HAIS-Q of 63 items, and the Four Measurements Scales even has 89 items. Questionnaires that take a long time to complete can be inconvenient for academic and non-academic studies, because the participants could not keep their interest in so

many questions, sometimes giving false answers without even reading the questions. Especially for the public sector and the governments it would be useful to have a short, reliable and validated instrument that can quickly assess the problem of security awareness and provide data that can be generalized and compared between different populations. Another issue of the UISAQ was that it was only available in Croatian language, making international usage and comparison of data impossible.

B. Study aim

The aim of this study was to develop a new international short questionnaire, based on the previous version of the UISAQ [16,17] in order to provide an international validated instrument that could gather reliable data in a short time. For the new questionnaire, the most reliable items were selected from the UISAQ. Firstly, the selected items were translated into English and tested. After initial testing, the 10 most reliable items were tested again in English and after that translated into German. Model fit for both versions of the questionnaire (English and German) was tested using the packages lavaan [22] and lavaanGUI [23] in R [24].

II. METHOD

A. Participants

The participants in this study were Croatian students (N=250) from the J.J. Strossmayer University of Osijek. 45.6% of the participants were male and 54.4% female. The average age of the student participants was 20.58 +/- 1.39 (arithmetic mean +/- SD). In addition, 225 young adult Germans participated in the study, with a proportion of 25.7% of men and 74.3% of women. The average age of young adult participants was 27.48 +/- 12.20 (arithmetic mean +/- SD).

B. Procedure

During the winter semester Croatian students were asked to voluntarily provide some general demographic information (age and gender) online and to fill out the new *Behavioral-cognitive internet security questionnaire* (BCISQ, Velki & Šolić, 2018) in the English language. Later during the semester, German participants were recruited online to answer the same questionnaire, which had been translated into German.

C. Instruments

For the purpose of this research the authors created a new international instrument *Behavioral-cognitive internet security questionnaire* (BCISQ, Velki & Šolić, 2018) in English and German, which is based on previous research on the development of different versions of the UISAQ [16-19]. The first part of the BCISQ consisted of 4 items measuring computer users' potentially risky behavior (Behavior scale, Cronbach $\alpha_{(\text{English version})} = 0.71$; Cronbach $\alpha_{(\text{German version})} = 0.62$)). The second part of the questionnaire consisted of 6 questions measuring the level of users' information security awareness (Cognitive scale, Cronbach $\alpha_{(\text{English version})} = 0.72$; Cronbach $\alpha_{(\text{German version})} = 0.63$).

III. RESULTS

For the development of the BCISQ suitable items to assess (1) potentially risky behavior and (2) information security awareness (i.e. judgments of risk and importance of some potentially risky online behavior) were selected from different version of the UISAQ [16-19].

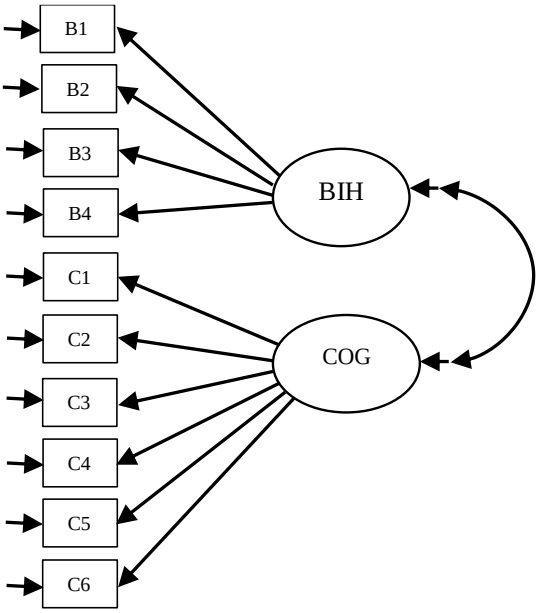

Figure 1. Theoretical model for both versions of the BCISQ (English and German)

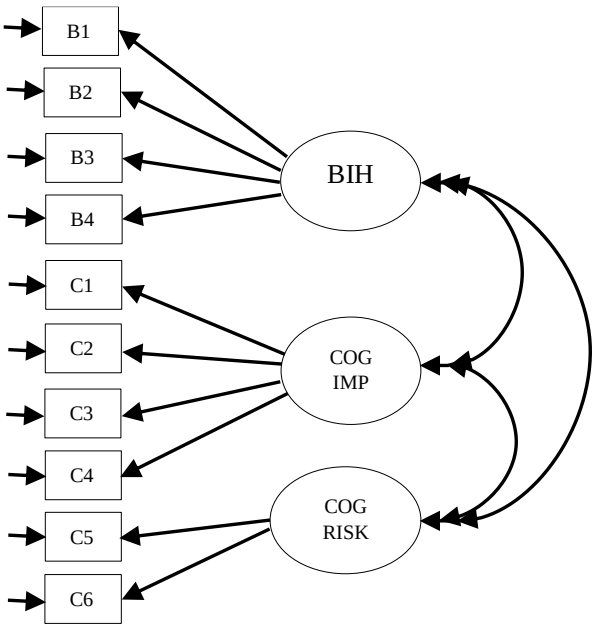

Figure 2. Final model for both versions of the BCISQ (English and German)

TABLE I. MODEL FIT INDICES FOR THEORETICAL AND FINAL MODEL WITH REFERENT VALUES[1]

Model fit indices	Theoretical Croatian model (df=34)	Theoretical German model (df=34)	Final Croatian model (df=32)	Final German model (df=32)	Reference values	
					Good fit	Adequate fit
χ^2	164.18/34 = 4.82	102.16/34 = 3	46.61/32 = 1.45 (n.s.)	51.44/32 = 1.61	p > 0.01 (n.s.)	χ^2 / df ≤ 2
CFI	0.76	0.75	0.97	0.93	≥ 0.95	≥ 0.90
TLI	0.68	0.66	0.96	0.90	≥ 0.95	≥ 0.90
RMSEA	0.12	0.09	0.04	0.05	≤ 0.06	≤ 0.08
SRMR	0.07	0.08	0.04	0.05	≤ 0.08	≤ 0.10

1. http://davidakenny.net/cm/fit.hm

The model fit for both groups (Croatian and German) was first tested for the theoretical models (Figure 1). For both, the Croatian and the German models, the results did not show adequate model fit (Table 1).

Additional analysis showed high covariances between the measurement errors of the last two questions of the cognitive scale (r = 0.67 for the Croatian sample and r = 0.47 for the German sample; modification index for the error covariance in the Croatian sample = 110.54; modification index for the error covariance in the German sample = 39.51). Therefore, the cognitive subscale, which measures security awareness, was split into two subscales: risk and importance.

The final model, consisting of 3 scales (Behavior, Cognitive Risk and Cognitive Importance) was tested for both groups (Figure 2). Results showed a good model fit of both models, which confirmed a good construction of the new instrument. The model fit was slightly better for the Croatian than the German sample.

For both theoretical scales, differences between the Croatian and German samples were tested using ANOVA. On both scales, there were statistically significant differences (Table 2). Croatian students had a slightly higher security awareness and less risky online behavior. These differences could be a result of cultural, language and age differences between those two groups but also due to the inadequate model fit of the theoretical model and the necessity of developing a new one.

TABLE II. Mean comparison between the Croatian and the German samples using ANOVA

Analysis results		N	Mean	SD	F
B scale - online risky behavior	Croatian	250	4.74	0.41	57.04**
	German	225	4.41	0.56	
	Total	475	4.58	0.51	
C scale - security awareness	Croatian	250	3.68	0.72	119.78**
	German	225	2.99	0.64	
	Total	475	3.35	0.76	

** p < 0.01

IV. CONCLUSION

The newly developed international instrument, i.e. a modified version of the *Behavioral-cognitive internet security questionnaire with 3 subscales,* showed good potential for future study purpose. It can be used as an international instrument to gather reliable data in a short time.

The model fit for the Croatian sample (English version of the questionnaire) was better than in the German sample. In addition, Croatian students showed less risky online behavior and better information security awareness. Maybe these results could be explained due to language differences. In Croatia, the majority of information systems that people work with every day are in the English language and most young people have a better understanding of specific information security terms in English. Nevertheless, in Germany most operating systems and programs do actually have a German version. It is not clear are the obtained differences result of language or cultural differences between Croatian and German students. It can be concluded that the English language should be used as a basis for international usage and future data comparison.

Both models (with Croatian and German samples) point at the same problematic area. The original cognitive scale should be split into two separate subscales, one that would examine the cognitive importance of information security and another that would examine the cognitive risk of information security.

Future studies should try to develop a third subscale (risk) of the BCISQ because only two items do not suffice to represent a whole subscale. Furthermore, it would be interesting to develop a behavior scale that represents a simulation of real online behavior in potentially risky situations. In addition, the BCISQ should be tested in other cultures and age groups in order to confirm its reliability. It is also recommended to apply longitudinal designs in future studies to test the stability and consistency of the BCISQ.

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Investigating file use and knowledge with Windows 10 artifacts

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***Abstract* - Windows 10 operating system is the most widely used operating system today that contains many programs and mechanisms for managing computer hardware and software. Looking from a digital forensics point of view these produce valuable records of user activities. In a forensic world, such records are known as Windows artifact which can be described as a system generated records of the user activities that have forensic value. Gaining a deep understanding of how these records are created and what information they contain can help the examiner to acquire valuable data that can be used as evidence and support other evidence. The artifacts can be a great way to focus on relevant data and reduce the need for full examination of constantly increasing data storage that examiners encounter. Through this paper, the focus will be on analyzing different, fewer know artifacts, that aren't supported by mainstream forensic tools because they vary between versions of Windows, resulting in the need for manual analysis. Their deep understanding is necessary to avoid misinterpreting their content which can result in wrong conclusions. Additionally, the paper presents the results of testing Windows 10 artifacts and open-source tools used in the testing process.**

Keywords - Windows 10; artifacts; digital forensics

I. INTRODUCTION

Digital forensic examiners in Windows operating system investigations use forensic tools that parse Windows artifacts automatically. These artifacts often differ between versions of Windows system. Sometimes forensic tools won't be able to parse this valuable information automatically. Through this paper, the value of manually analyzing Windows artifacts will be shown, as well as how they can be used to separate potentially relevant data for investigation. The focus will be on useful information, for file use and knowledge, that can be found in specific artifacts and how their deep understanding is needed to avoid misinterpreting the findings.

The paper is organized as follows. Section 2 and 3 give a brief overview of digital forensic and Windows 10 operating system. Section 4 describes specific Windows artifacts and their value in forensic investigations, while section 5 combines before explained artifacts in investigation of file use and knowledge use-case. Section 6 concludes the paper.

II. DIGITAL FORENSICS

Digital forensic, also known as digital forensics science is a branch of forensic science encompassing the recovery and investigation of material found in digital devices, often in relation to computer crime. The history of digital forensics goes back to late 1980s and early 1990s as a result of the adaptation of personal computers by a wide range of people, industry, and appearance of digital crime. The growth of digital crime caused law enforcement agencies to begin establishing specialized groups to handle technical aspects of investigations [1].

Because of the fast and rapid spread of electronic devices, today it's hard to imagine a crime that doesn't involve digital evidence. Criminals are using technology to facilitate their offenses and avoid apprehension, creating new challenges for law enforcement agents and forensics examiners [2]. As technology and electronic devices advanced through years, so did digital forensic which can today be separated in few core branches; computer forensics, mobile forensics, network forensics, and cloud forensics, that are related to the type of digital devices involved in digital crime. The digital forensic process starts after a crime is committed and noticed; typically process includes preparation, identification of potential evidence, seizure and acquisition, analysis and report or presentation of findings.

III. WINDOWS 10 OPERATING SYSTEM

An operating system is a collection of software that manages computer resources and provides services for computer programs.

From 1985 till 2019 Microsoft developed 26 versions of the Windows operating system. Each version of the operating system brought changes to the user interface and equally, most of them had a different way of storing data that is of forensic value to the examiner. Microsoft stopped mainstream support for all Windows systems except for Windows Server 2016, 2019 and latest, Windows 10 [3]. Windows 10 is a series of personal computer operating systems which was released in July of 2015; Windows 10 receives new builds on an ongoing basis at no additional cost to users. Now, the latest build of this operating system is 1809; labeled YYMM where YY represents the year and MM represents the month of release [4]. Windows 10 introduced many new features like the timeline, focus assist, nearby sharing, new parental control, touch input, face login and many more

TABLE 1. WINDOWS OPERATING SYSTEM SHARE BY VERSION

Month	Windows 7	Windows 10
June 2018	**17.98%**	15.38%
July 2018	**18.66%**	16.56%
August 2018	**16.46%**	15.44%
September 2018	**17.53%**	16.06%
October 2018	**16.63%**	15.92%
November 2018	**16.08%**	15.77%
December 2018	15.09%	**16.04%**

[5]. As shown in the Table 1, in December 2018 Windows 10 overthrow Windows 7 as most widely used Windows system which means that digital forensic examiners will most likely encounter mentioned operating system; however, even after the end of official support by Microsoft, examiners will likely encounter older versions which require understanding of differences between system version.

IV. WINDOWS 10 ARTIFACTS

From a digital forensic examiner view, Windows artifacts are evidential records that are automatically generated and saved by the Windows operating system as a result of user interaction with the computer. Each version of Windows operating system contains many different artifacts that differ between each version. Some of the artifacts are found in all versions while some versions on first look don't support specific artifacts, although they can still be present because of the need for backward compatibility or future use. Often a problem for mainstream forensics tools are changes in data format and location of artifacts that happen between versions, demanding the need for vendors to often update their tools which in some cases is not acceptable and need for manual analysis is required.

From the large list of Windows artifacts available in Windows 10 operating system, the focus will be on manual analysis of Shimcache, Prefetch, Shellbag, $UsnJrnl, System Resource Usage Monitor (SRUM) and UserAssist artifacts with open-source tools.

A. Shimcache

This cache (also known as AppCompatCache) is a component of the Application Compatibility Database which is used to identify application compatibility issues and track executables on Windows system. This artifact contains the name and file path of executables on the system. Poor understanding of this artifact can be misleading as records of executables don't confirm that they were actually executed, rather, it means that specific executables were recognized by the system. In records, the examiner can find associated "last modified" date and time value; however, this value represents modified time of the file; e.g. for NTFS, this is the last modified time of the file as stored in the $STANDARD_INFORMATION attribute. Furthermore, new entries are recorded at the moment of system shut down with the most recent entries placed on top of the list. This artifact records up to 1024 entries and only files with specific extensions are logged (e.g. ".bat", ".exe", ".dll"). Passing maximum 1024 entries will result in the old entries being overwritten by the new ones. The location of above-mentioned information is recorded in Windows registry [1] under registry key "HKLM\SYSTEM\CurrentControlSet\Control\SessionManager\AppCompatCache\AppCompatCache". The file that contains mentioned registry key is "SYSTEM" registry file located at "C:\Windows\System32\config" folder.

There are many tools for parsing Shimcache data, commercial and open-source, and analysis for the purpose of this paper has been done with Eric Zimmerman's AppCompatCacheParser (v1.4) tool [6]. When the tool is run through command prompt and required attributes are specified, it will parse "SYSTEM" hive's registry key AppCompatCache and all records will be exported in comma-separated values (CSV) file. The CSV file will contain the cache entry position for each entry, full path to the file and last modified time (modification time applies to that of the file) in Coordinated Universal Time (UTC) as shown in Table 2. Additionally, executed flag in Windows 10 (1809) is not present and they all have the value of "NA".

Microsoft changed the data format of Shimcache through versions of Windows system resulting in the need for detailed testing and adjustment of forensic tools. Reference [7] is Application Compatibility Cache Key's knowledge base which contains known information about this artifact and how it has been changed through different versions of Windows system. This artifact is great for determining executables and malicious behavior that was present on the system, even if they were deleted. Furthermore, it also shows directories where executables were located which can help examiner detect purposely buried folders.

B. Prefetch

Prefetch feature has been introduced with Windows XP operating system and it's still present in Windows 10; it enables Windows to load portions of frequently used programs when the computer first boots up, enabling them to load faster.

Windows prefetch, in the first 10 seconds of program

TABLE 1. SHIMCACHE ENTRIESPARSED APP COMPAT CACHE RECORDS

Cache Entry Position	Path to the file	Last Modified Time (UTC)	Executed
0	.\VeraCrypt.exe	17.1.2019 10:34:58	NA
1	.\FTK Imager.exe	20.10.2017 15:08:38	NA
2	.\firefox.exe	17.1.2019 9:50:14	NA
3	.\ZoomIt.exe	18.6.2013 13:12:34	NA
4	\Bandizip.exe	2.10.2018 11:11:49	NA
5	iexplore.exe	15.9.2018 17:39:41	NA

[1] The Windows Registry is a hierarchical database that stores low-level settings for the Microsoft Windows operating system.

execution, records name of application, date and time of executions, run count and path to executable file. Time and date information is collected on the first run of a specific application and on every next run the "last run time" is updated. Extension of prefetch file is ".pf" and the name format of the file is "<*AppName*>.EXE-XXXXXXXX.pf" where "XXXXXXXX" represents the hash value of executable's location path. The system can contain multiple prefetch files of an identical program because of different locations of executables, resulting in prefetch file with same application name but different hash value. Forensics examiners can encounter system without prefetch artifacts for two reasons; user manually turned off prefetching in Windows Registry or sometimes system has prefetching disabled because of the Solid-State Drive (SSD). Prefetch files are located at "C:\Windows\Prefetch" and their parameters are set up in Windows Registry key "HKLM\SYSTEM\CurrentControlSet\Control\SessionManager\MemoryManagement\PrefetchParameters".
Windows 10 introduced changes of prefetch format and in which way the file is stored on disk; it uses compression to store prefetch files, and signature is "MAM." or in hexadecimal "4D 41 4D 04". The most important change is that prefetch now stores up to eight "Last run" times.

Testing has been completed with Eric's PECmd (v1.2.0.2) tool which parses prefetch artifacts [8]. As result this command prompt (CMD) tool export a CSV file that contains the full path of processed prefetch file, its created, modified and accessed time, executable name and path's hash, version of operating system, run count, run dates and times for up to last eight executions, as shown in Table 3. Examiner can use prefetch to determine how many times the program was run from a specific location, even if the program is deleted. Additionally, it can contain evidence of wiping tools and in case of malware execution examiner can determine first/last run times and location of malware executable.

C. Shellbag

Microsoft Windows uses a set of Registry keys known as "Shellbags" to maintain the size, views, icon, and position of a folder when using Windows Explorer [9]. It tracks and stores how different windows appear to the user when they view it; to give constant experience between reboots of the system. From forensic examiner point of view, it's a great artifact for quick profiling of the system and determining which folders did user access. It records information as folder position, size, icons, associated date and time in a moment of change. Shellbag data is user-driven and it also tracks local network and external directories. Data will remain within Registry key even after a folder is deleted or Universal Serial Bus (USB) flash drive is detached, and it's user account specific. Shellbag data is recorded in NTUSER.DAT and UsrClass.dat files; NTUSER.DAT file is located at "C:\Users\<*User*>" and UsrClass.dat at "C:\Users\<*User*>\AppData\Local\Microsoft\Windows".

TABLE 2. PARSED PREFETCH DATA

C:\Windows\Prefetch\HXD.EXE-3AAB4DBE.pf	
Source Created (UTC)	24.1.2019 11:06:52
Run Date & Time (UTC)	24.1.2019 12:08:28 24.1.2019 12:08:24 24.1.2019 12:03:59 24.1.2019 11:35:28 24.1.2019 11:24:23
Run Count	5
Version	Windows 10
Hash	3AAB4DBE

TABLE 3. SHELLBAGS BEHAVIOR

Entry Creation (Desktop)	
Activity	Shellbags recorded
Creation of a folder	NO
Right click on a folder	YES
Opening a folder	YES
Copy & Cut function	YES
Rename (double click on name)	NO
Rename (right click - rename)	YES
Deletion of a folder	YES
Selecting a folder	NO
Additional Entry Creation (folder structure)	
Activity	Shellbags recorded
Creation of a folder	YES
Selecting a folder	YES
Renaming of a folder	YES
Entry Creation (CMD)	
Activity	Shellbags recorded
Creating a folder	NO
Deletion of a folder	NO
Renaming of a folder	NO

On Windows 10 (1809) system, after loading the NTUSER.DAT file in NirSoft's ShellBagsView (v1.21) tool [10], no Shellbags records were present; however, loading the UsrClass.dat file showed all Shellbags records. Shellbags data is stored and updated on various user's activities, and it also depends on whether the user is manipulating folders directly on desktop or folder structure. Table 4 shows when Shellbags data is recorded in a moment of different user's activities.

D. Update Sequence Number Journal ($UsnJrnl)

UsnJrnl is a feature of the New Technology File System (NTFS) which maintains the record of changes made to the volume [11]. When enabled, the system records all changes made to files and directories on volume in the UsnJrnl; creation, deletion, modification, overwrite, compression, etc. This artifact is a great source of timeline information for malware and incidence response investigations, time stomping and anti-forensics activities. From Windows Vista and onwards the UsnJrnl is enabled by default. It's composed of "$Max" and "$J" data streams located in hidden system file at "C:\$Extend\$UsnJrnl". Data stream "$Max" contains

metadata of change log while "$J" contains actual change log records including Update Sequence Number (USN) and Master File Table (MFT) reference number [12]. The USN information is also stored in $STANDARD_INFORMATION attribute of the MFT record. Additionally, the MFT header contains $Logfile Sequence Number (LSN) [13]. The Blueangel's NTFS Log Tracker uses a combination of $J, $LogFile and $MFT files to display more valuable information [14]. NTFS Log Tracker extract UsnJrnl timestamp, USN, file name, event flags, source info, and file attribute. It also records the full path of the file, extracted from MFT, if selected. List of possible event flags, file attributes and source info can be found in official Microsoft documentation [15], [16].

E. System Resource Usage Monitor (SRUM)

SRUM (also known as SRUDB.dat) feature has been presented in Windows 8 operating system that tracks application resource usage, services, windows apps, energy usage, networks connections, and data usage by maintaining the database of historical activity. The file is an Extensible Storage Engine (ESE) database that has multiple database tables as shown in Table 5 [17]. This artifact records names and paths of every application that executes on the system. Its records user's Security Identifier[2] (SID) that executed the program. Furthermore, it records the names of all networks on which system has been connected, length of connection and how many bites were written to or read from the hard drive by the specific application. Its records application battery usage and Central Processing Unit (CPU) usage [18]. This artifact can help the examiner to determine which user launched a specific process, data upload and download, it keeps data of programs that were deleted, installed, uninstalled, run from external media, etc. The entries are written to the file (date and time) every hour and on shutdown, meaning that examiner won't get the exact time when the application has been run but when operating system recorded it. The data is temporarily saved in Windows Registry at Registry key "/HKLM\SOFTWARE\Microsoft\WindowsNT\-CurrentVersion\SRUM\Extension" and then it's periodically transferred in the SRUDB.dat database at "C:\Windows\System32\sru\SRUDB.dat. For the purpose of this paper, analysis of the SRUM data has been done with Nirsoft's ESEDatabaseView (v1.62) utility that reads and displays the data stored in the ESE database [19]. Opening an SRUDB.dat file in the above-mentioned utility will show all present tables with their Globally Unique Identifier (GUID). To get valuable data from the ESE database, the forensic examiner needs to have a good understanding of how SRUM tables are connected among each other. For example, checking the Application Resource Usage table won't contain application name and user SID, but it will contain "AppID" and "UserID" columns. These IDs can also be found in "SruDbIdMapTable" table under the column "IdIndex" and the corresponding column "IdBlob" contains actual data like application name with path and user SIDs, depending on the value of "IdType", in format of 16-bit Unicode Transformation Format (UTF-16) encoded string [16]. ESEDatabaseView utility has the functionality to detect UTF-16 strings in binary data that will convert "IdBlob" content in the readable format. However, the mentioned functionality won't show user's SID in the readable format. SIDs are identified with "IdType" value 3 and they need to be manually converted to usual string format as they are composed of multiple components as shown in Table 6 [20]. Converting SIDs components can be done with Microsoft Calculator in programmer mode. Once when the examiner has the user's SID and application name, the timeline of specific user activities can be determined.

TABLE 4. IMPORTANT SRUMDB.DAT TABLES

Table GUID	SRUM Extension
{973F5D5C-1D90-4944-BE8E-24B94231A174}	Network Data Usage Monitor
{D10CA2FE-6FCF-4F6D-848E-B2E99266FA89}	Application Resource Usage Provider
{DD6636C4-8929-4683-974E-22C046A43763}	Network Connectivity Usage Monitor
{D10CA2FE-6FCF-4F6D-848E-B2E99266FA86}	Push Notifications (WPN) Provider

[2] Security Identifier is a number used to identify user, group, and computer accounts in Windows.

F. UserAssist

UserAssist is a Registry key that records the use of applications by the user. Based on the records of this Registry key, Windows Explorer displays frequently used programs on the left side of the Start menu in the Windows XP system. It's quite similar to the before mentioned Prefetch artifact with the biggest difference that it's user-specific, unlike Prefetch. To be added in UserAssist, applications need to be launched over a shortcut, link file, explorer, etc. Programs run through CMD won't be recorded. UserAssist is located in NTUSER.DAT file at "C:\Users\<users>" folder and the specific Registry key that store UserAssist data is located at "HKEY_CURRENT_USER\Software\Microsoft\Windows\CurrentVersion\Explorer\UserAssist". The UserAssist

TABLE 5. RAW HEX SID COMPONENTS

Raw Hexadecimal SID example	
0105000000000005150000007C8906DF25E4B91C52E245D7E9030000	
SID's component	Format and Value
SID identifier	**S**
Version of SID	0x01 = **1**
Number of dashes (minus 2)	0x00 00 00 00 00 05 (48-bit number in big-endian format) = **5**
Identifier authority	0x15 00 00 00 (32-bit number in little-endian format) = **21**
Domain or local computer identifier	0x7C 89 06 DF - 25 E4 B9 1C - 52 E2 45 D7 (32-bit in little-endian) = **3741747580-481944613-3611681362**
Relative ID (RID)	0xE9 03 00 00 (32-bit in little-endian) = **1001**
Converted SID	S-1-5-21-3741747580-481944613-3611681362-1001

Registry key contains multiple sub-keys represented with GUIDs as shown in Table 7 [21], [22]. The values of this Registry key are ROT 13 ciphered, meaning that examiner will need to use tools that can decipher them [23]. The UserAssist contains the program's path, run counter, last run time, focus counter and focus time. This artifact is great for determining the frequency of program execution, the time of the last program launch, deletion of a program, how long a user has interacted with a given program and many more user behaviors. It's a great source of information on servers and computers which have Prefetch disabled. Testing of this artifact has been done with Didier Stevens's UserAssist (v2.6.0) tool that can decipher and parse this artifact on a live system or by importing NTUSER.DAT file [24]. To successfully open *.DAT file, the tool must be run with administrator privileges and sometimes the loading of *.DAT file can fail; the tool has the option to load *.reg files which have been loaded successfully on each try. The UserAssist utility displays Registry key, the index number of entries, run counter, system last run time and last run time in UTC, focus counter and focus time. Executed program's path can sometimes include folder GUIDs; a few examples are shown in Table 7.

From testing, it has been concluded that UserAssist data is recorded immediately and that focus counter represents how many times specific run program's window was selected by the user while focus time represents total time, in milliseconds, that user had the window selected. The UserAssist as many artifacts have few exceptions that require good understanding. For an example, UserAssist won't increase run count if the program is run on startup or as a scheduled task; however, the entry will be recorded with focus counter and time. Furthermore, it's possible, because of above-mentioned exceptions that run counter will have a value of "0".

V. COMBINING THE ARTIFACTS

Examiner should always try to combine multiple artifacts; their combining will result in a better understanding of user activity and they will mutually support each other.

TABLE 7. USERASSIST SUB-KEY AND KNOWN FOLDER GUIDS

Sub-keys GUIDs	Description
{CEBFF5CD-ACE2-4F4F-9178-9926F41749EA}	Executable file execution
{F4E57C4B-2036-45F0-A9AB-443BCFE33D9F}	Shortcut file execution
Known folder's GUIDs	Description
{0139D44E-6AFE-49F2-8690-3DAFCAE6FFB8}	Common programs
{1AC14E77-02E7-4E5D-B744-2EB1AE5198B7}	System
{7C5A40EF-A0FB-4BFC-874A-C0F2E0B9FA8E}	Program files x86
{6D809377-6AF0-444B-8957-A3773F02200E}	Program files x64
{9E3995AB-1F9C-4F13-B827-48B24B6C7174}	User pinned
{A77F5D77-2E2B-44C3-A6A2-ABA601054A51}	Programs
{F38BF404-1D43-42F2-9305-67DE0B28FC23}	Windows

An example below is showing how artifacts can be combined and used to investigate use file and knowledge. For this purpose, a small use case has been created where it's suspected that a user was in possession of confidential document; however, files and wiping tools were not found on suspects system on initial check. To determine if that is the case, a combination of the before mentioned artifacts have been used.

With checking Shimcache data examiner can determine if there has been the presence of non-standard executables on the system. By looking at extracted Shimcache records it can be determined that the wiping tool "Eraser" installation file was present as well as a record of the executable file of the mentioned wiping tool as shown in Table 8. With Shimcache records examiner can confirm that user had executable files of wiping tool present on the system and there is a possibility that the program has been run. To determine if wiping program has been run examiner can look in Prefetch, UserAssist, SRUM and UsnJrnl records. In the Prefetch folder, two Eraser Prefetch files have been created by the operating system. As Prefetch files are created on the first run of a program, the examiner can confirm that the wiping tool has been run and when. The created time of file run counter and last run times gives examiner more insights on usage of the wiping tool as shown in Table 9. To support these findings examiner can as mentioned before, look at SRUM records. The first step is determining "IdIndex" of Eraser wiping tool in table "SruDbIdMapTable" of SRUM database, and then the matching "IdIndex" number must be found in application resource usage table under "AppId". Corresponding "UserID" can be found in column right of it, and then examiner can identify users SID in table "SruDbIdMapTable". When above mentioned SRUM data is connected examiner can once again confirm that specific wiping tool has been run and by which SID; as SID number is unique for each user, the user that run program can be identified as shown in Table 10.

The third artifact that can confirm that the wiping tool was run is the UserAssist. With it, examiner can find records of launched programs by a specific user. Additionally, the examiner can also determine last run time, path to executable file, run count and how long the

TABLE 8. SHIMCACHE RECORDS

Entry Position	Path	Modified Time UTC
2	C:\Program Files\Eraser\Eraser.exe	28.8.2016 0:50:44
5	C:\Users\Admin\Desktop\Eraser 6.2.0.2979.exe	13.4.2018 13:09:43

TABLE 9. PREFETCH RECORDS

File Name	Created Time	Run Counter	Last Run Time
ERASER 6.2.0.2979.EXE-D37D8F97.pf	5.2.2019. 11:56:42	2	5.2.2019. 12:02:14, 5.2.2019. 11:56:35
ERASER.EXE-CE61944A.pf	5.2.2019. 11:57:44	1	5.2.2019. 11:57:34

TABLE 10. SRUM RECORDS

SruDbIdMapTable		
IdType	IdIndex	IdBlob
0	1098	.\Eraser.exe
0	1154	.\Eraser 6.2.0.2979.exe
3	334	0105000000000000515000000 7C8906DF25E4B91C52E245 D7E9030000
Application Resource Usage table		
TimeStamp	AppId	UserId
05.02.2019 12:04:00	1098	334
05.02.2019 12:04:00	1154	334

TABLE 11. USERASSIST RECORDS

Name	Counter	Last	Focus Counter
.\Eraser 6.2.0.2979.exe	2	5.2.2019 12:02:14	11735
.\Eraser.exe	1	5.2.2019 11:57:33	251891

wiping tool was in focus of screen; as shown in Table 11.

UsnJrnl tracks all changes that are made to files and directories on the volume which an examiner can use to determine the activity on the system. In this case, UsnJrnl contains a record of confidential file's link creation and WordPad program prefetch file being changed. Record also shows that confidential file has been renamed and when Eraser files and its Prefetch file were created. Furthermore, there are records of constant file renaming with random characters, ending with deletion of the confidential file which confirms wiping of confidential data.

With all collected information examiner can confirm the presence of confidential data and wiping program for hiding evidence.

VI. CONCLUSION

Mentioned Windows artifacts have a great value in forensic investigations, especially when it comes to understanding file use and knowledge; it's crucial for an examiner to understand how, when and for what purpose specific files and programs have been used. These systems generated records offer examiner a way to do quick profiling of user activities and reduce the time of analysis, but their deep understanding is required. Furthermore, the artifacts often change between versions of the Windows operating system and manual analysis of the artifacts sometimes can't be avoided.

To acquire a better understanding of Windows artifacts examiners should always analyze changes, test artifacts behavior, and their forensic tools so that they can avoid misinterpreting valuable data.

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Information Security in Principles and Provisions of the EU Data Protection Law

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ABSTRACT - Information security practices are a staple compliance mechanism ensuring the lawful processing and protection of personal data in the new European legal framework of Data Protection. Both the General Data Protection Regulation and the Regulation 2018/1725 on the protection of natural persons regarding the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data contain recognizable principles of and provisions regarding information security methods and practices. The purpose of this paper is to analyse the new EU data protection framework from the perspective of regulation of information security requirements, especially from the perspective of the data controllers and processors and their obligations to ensure conditions for lawful and secure processing of personal data and comply with potential data subject requests.

Key words: information security, GDPR, data protection, personal data

I. INTRODUCTION

Regulation 2016/679 of the European Parliament and of the Council on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, otherwise known as the General Data Protection Regulation is not just a fundemental stepping stone in development of the European personal data protection legislation and an instrument that enlivens the status of personal data protection as a fundamental right as recognized by the Article 8 of the Charter of Fundamental Rights of the European Union, it is also a groundbraking document in regulation of information security, probably equally important as the contemporary Network and Information Security Directive. [1]

As a Regulation directly applicable in Member State, it mandates a systematic application of best information security practices in a number of interesting ways, and in a moment defined by information security risks coming from ever widening array of sources and actors characterized by different motives, methodology and level of sophistication.

Yearly reports by relevant regulatory and governmental institutions in the field such as those done by the European Network and Information Security Agency (ENISA) and EUROPOL depict continuing rise in the number and complexity of detected attacks on information systems and data.[2]

Furthermore, established research describes an increase in massive, low-skilled attacks committed by perpetrators without advanced knowledge and understanding of information systems, often described as script-kiddies (*skiddies*).[3] Previously, in 2017, an EU Commission President Juncker repeated a finding that over 80% of European enterprises have suffered at least one case of information system attacks and that the volume of attacks has increased at rate almost 40% compared to the year before. [4]

Personal data has become a valuable commodity. Collection of massive amounts of personal data fuels modern information age economy. Through extensive and often sensitive profiling, data subjects and their personal data are objectified, often traded and exchanged even by the most scrupulous of actors in the data economy, let alone those who view personal data as raw industrial resource somehow disconnected from the lives and concerns of data subjects the data was harvested from.[5]

Since most of personal data collection, processing and storing is done through information systems an appropriate level of security of those systems is required to ensure the security of personal data. Some authors suggest recognizing data protection managament systems as a a paradigm of managing and ensuring security of processing of personal data. [6]

Where the data collected and processed is of sensitive nature, such as personal data containing or revealing racial or ethnic origin of data subjects, their political opinions, their religious or philosophical beliefs, trade union membership, or where data controllers process genetic data or biometric data for the purpose of uniquely identifying a natural person, data concerning health or data concerning a natural person's sex life or sexual orientation, the controllers are obligated to implement higher security measures and ensure a higher level of security to lessen the chance of a personal data breach.

This need to ensure a higher level of information security is not specific to handling special categories of personal data. In the information society economy and in the current threat environment, a higher level of information security is required to foster ongoing development of information society services. The European Commission and the lawmakers of Member States have repeatedly tried to regulate this requirement and improve the state of information security. Notwithstanding the Network and Information Security Directive and the national

transposition measures, the General Data Protection Regulation is the most recent example how information security principles and practices are making its way into law. Of course, one can argue that a normative approach alone will not be sufficient. However, an efficient and universally accepted legal and administrative regulation concerning information security is a requisite for transnational cooperation and a condition required to ensure that all actors participating in personal data processing and other information society services develop and enforce adequate security measures in order to prevent future personal data breaches.

The Regulation ultimately enforces these measures with potentially crippling fines, as well as establishing a framework for collective action against data controllers responsible for the breach of personal data, regardless of the source and perpetrators of the incident. This form of objective, strict liability only partially amenable through observing due dilligence on the behalf of the controller creates a significant burden, so there is a lot of incentive for data controllers to improve the security of processing.

The purpose of this paper is to discuss principles of information security and their application in the provisions of the General Data Protection Regulation and how they affect everyday practice of data protection and use of personal data.

II. INFORMATION SECURITY PRINCIPLES IN THE GENERAL DATA PROTECTION REGULATION

Even though the Regulation itself mentions the term „information security“ only once, it is nonetheless abundantly clear that recognized information security practices present a framework of ensuring accountability in personal data processing. [7]

In general, the provisions of the Regulation that concern information security strive to achieve several key objectives in order to facilitate data controllers accountability, a key principle of personal data processing that demands that the data processor be able to prove compliance with principles of personal data processing as stipulated by the General Data Protection Regulation.

In practice, as data controllers are liable for personal data breaches - breaches of security that lead to the accidental or unlawful destruction, loss, alteration, unauthorised disclosure of personal data, unauthorized access to personal data, or other unathorized transmition, storage or processing of personal data – data controllers need to make sure they have proper security controls in place to be able to prove accountability.

This demands proper security controls with regard to access and identity management, ensuring that only employees that need access to personal data to conduct required processing operations actually have access, and that they have the lowest possible level of access that allows normal operation. Employees that handle personal data should receive adequate privacy training and additionaly adequate organisational measures such as non disclosure and confidentiality provisions need to be made part of employee contracts.

While not mandated by the Regulation, encryption and pseudonymization are specifically mentioned in the context of risk management and incident response, especially concerning the cases of obligation to notify data subjects that a breach has occured.

Data controllers also have an obligation to prepare for potential incidents and data breaches. Controllers have to be able to identify that a breach has taken place, do what needs to be done to contain it, recover personal data, resume operations and report the incident to supervisory bodies.

The Regulation defines the relations between data controllers and data processors in a more detailed fashion. The new provisions demand compliance from processors and subprocessors and give data controllers tools to ensure that their business partners are contractually obliged to comply with the Regulation's standards.

While many of these obligations existed in the previous legal framework, the Regulation was developed on the foundations of Article 29 Working Party opinions and guidelines and contains enforceable and concrete provisions.

Starting with the Article 5, the Regulation systematically introduces information security principles and practices as a compliance mechanism to ensure secure processing and protection of data subject rights. The Article states that personal data shall be processed in a manner that ensures appropriate security of the personal data. According to Article 5, this manner of processing includes both protection against unauthorised or unlawful processing of personal data as well as additionally protecting against accidental loss, destruction or damage. Data controllers, data processors and others are required to achieve this using appropriate technical or organisational measures, a principle of *integrity and confidentiality* – well known components of the so called CIA triad of information security – confidentiality, integrity and availability. [8]

III. INFORMATION SECURITY AND DATA CONTROLLER OBLIGATIONS

In Chapter IV of the Regulation, Article 24 lays out responsibilities of the data controller. The data controller can be any legal person or natural person, public authority, agency or other body which, alone or jointly with others, determines the purposes and means of the processing of personal data. [9]

The article states that controllers shall implement appropriate technical and organisational measures to ensure and to be able to demonstrate that processing is performed safely and securely in accordance with the Regulation. The controllers are required to take into account the nature, scope, context and purposes of processing as well as the risks of varying likelihood and severity for the rights and freedoms of natural persons whose data is being processed. Article 24 mandates implementation of appropriate data protection policies and regular review and update of technical and organisational measures where necessary. These provisions are accompanied by several recitals that establish the liability of the data controller for the safety and security of processing conducted by him or on his behalf, an obligation to implement appropriate and effective measures and ability to demonstrate that he is performing processing in compliance with the Regulation.[10]

Recital 75 of the Regulation states that risk to the rights and freedoms of natural persons coming from personal data processing may potentially lead to various consequences such as physical, material or non-material damage,

discrimination, identity theft, fraud, financial loss, damage to reputation, breach of professional secrecy etc. The recital also explicitely mentions situations where data subjects might be unable to exercise their rights and freedoms, control their data or when data processed might reveal sensitive data.

Additional situations mentioned by Recital 75 where processing activities pose recognized risk to the rights and freedoms of natural persons are those that concern analysing individual's performance at work, his economic situation, health, personal preferences or interests, location or movements of individuals in order to create or use personal profiles. It also underlines situations where data processed is the personal data of vulnerable natural persons, in particular of children, are processed or where processing involves a large amount of personal data and affects a large number of data subjects as those that pose risk.

The following Recital 76 refers to the obligation of the data controller to determine and assess the likelyhood and severity of the risk to the rights and freedoms of data subjects by taking into consideration criteria such as nature, scope, context and purposes of the processing.

Finally, Article 25 stipulates the obligation of the data controller to implement technical and organisation measures such as pseudonymisation, designed to implement data protection principles such as data minimisation and integrate them into its processing operations. When data controllers develop new applications, services and products based on processing of personal data, the controllers should develop them with data processing principles in mind from the start. The controller should also process only personal data necessary for specific purpose of processing, with regard to the amount of data, extent of processing, period of their storage and accessibility, ensuring what the Regulation calls data protection by design and by default.

IV. DATA PROCESSOR OBLIGATIONS

Another key issue the Regulation addresses is the relationship between data controllers and processors. This relationship in the past was subject to criticism concerning the ability of the controller to realistically enforce data protection measures and obligations on organisations doing the processing work on his behalf.

This is why Regulation Article 28 now explicitely regulates the relationship between data controllers and data processors. Data processor can be a natural or legal person, a public authority, an agency or any other body which processes personal data on behalf of the controller.

The processor receives personal data provided by the data controller and acts according to specific instructions issued by the controller. Generally, the Article 28 forbids the controller to use the services of processors who are unable or unwilling to supply sufficient guarantees to implement appropriate technical and organisational measures and function according to the security standards and data protection principles demanded by the Regulation. Failure to comply to these provisions could put data controllers at risk of large administrative fines as well as civil lawsuits.

At the same time, Article 28 regulates the obligation for data controllers to contractually or otherwise stipulate that processor acts only on documented instructions only, employs persons under adequate confidentiality regime by means of a contract or statutory obligation etc. The processor is required to implement all appropriate technical and organisational measures, can not engage subprocessors without ensuring their adherence to same level of security, assists the controller in complying with provisions of the Regulation and at the choice of the controller is obliged to return or delete all personal data belonging to the data controller.

V. INCIDENT MANAGEMENT AND REPORTING

Section 2 of the Chapter IV of the GDPR contains a number of provisions dealing directly with obligations of the controller with respect to information security, starting with the measures ensuring security of processing, notification of personal data breach to supervisory authority, communication of the personal data breach to the data subject and continuing into Section 3 and provisions regarding data protection impact assessment.

The Article 32 of the Regulation introduces an obligation for the data controllers to consider the nature, scope, context and purposes of processing, the likelihood and severity of risks the processing may pose to the rights and freedoms of data subjects and with all that in mind consider the state of the art and the costs of the appropriate technical and organisational measures.

The Regulation follows to specifically name pseudonimysation, encryption, efforts to ensure ongoing confidentiality, integrity, availability and resilience of processing systems and services, ability to restore systems and data to a state of availability etc. Finally, the Regulation expects that data controllers will implement adequate processes to regularly test, assess and evaluate effectiveness of technical and organisational measures meant to ensure the security of processing.

It is apparent that the Regulation now introduces a requirement for data controllers to notify national supervisory bodies should a personal data breach occur – a similar requirement that has for some time existed in the legislation regulating electronic communications and financial services both in EU legislation and in national legislation.[11]

While some of the data protection authorities have previously encouraged controllers to report breaches, the 1995 Data Protection Directive 95/46/EC which was mostly transposed into national legal systems of Member States by 1998 and adopted by all new Member States in the following decades did not contain such requirement. The General Data Protection Regulation in Article 34 now mandates controllers to notify the supervisory authority unless the breach is unlikely to result in a risk to the rights and freedoms of individuals, and also to communicate a breach to the individual if it is likely to result in a high risk to their rights and freedoms. This puts forth certain obligations to controllers, namely to choose and apply adequate technical and organisational measures in relation to a required level of security of processing, which in turn is proportionate to the potential risks to rights and freedoms of data subjects whose data is being processed. The question of qualification of high risk

The controllers need these technical and organisational measures to detect potential breaches and prevent them, to discover ongoing security incidents to be able to report them and act in the interest of data subjects and to resume normal operation as soon as possible. The broad obligations set in

Articles 32 and 33 of the Regulation have been investigated and commented upon in the Article 29 Data Protection Working Party Guidelines on Personal Data Breach Notification under Regulation 2016/679 (GDPR) whose latest revised and adopted document was made available in early 2018. [12]

The central issue in complying with the provisions of Article 33 of the GDPR is the definition and meaning of the term data breach itself. Guidelines establish that a data breach is a type of security incident where a breach of personal data occurs and leads to any of a number of events and results such as accidental or unlawful - destruction of personal data, loss of personal data, alteration, disclosure, access to personal data, transmission, storage or some other accidental or unlawful kind of processing.

A previous WP29 Opinion 03/2014 provides a categorization of personal data breaches following well known security principles of confidentiality, availability and integrity. An integrity breach would involve alteration of personal data, confidentiality breach an unauthorized disclosure or access to personal data and an availability breach would correspond to accidental or unlawful destruction or loss of personal data.[13]

A matter raised in the Guidelines concerns criteria to establish wether a an availability breach has taken place. They offer examples of a loss of availability where an intentional deletion or deletion by accident occurs, where in the case of use of encrypted data a decryption key has been lost or where ability to restore data from backup is lost and is not possible to restore access to backedup data. Another given example of a loss of availability is when a significant disruption to the normal service occurs due to factors such as cyber attacks (i.e., denial of service attacks, malware attacks etc.) or infrastructure events such as power failure.

Regarding the obligation of data controllers to report temporary loss of availability as a data breach, Regulation Article 32, Guidelines explain that controllers should assess the likelihood and severity of impact on the rights and freedoms of natural persons as a result of the disruption in availability of their data and notify the supervisory authority unless the temporary breach is of such nature that it is unlikely to result in a risk to individuals' rights and freedoms.

With that in mind, the Regulation in Article 33 lays down the obligation of data controllers to notify the supervisory authority that a personal data breach has taken place. The Article regulates that the controller has an obligation to notify the authority no later than 72 hours after becoming aware of the personal data breach unless the data breach is unlikely to result in a risk to rights and freedoms of natural persons. Data processors are mandated to notify their data controllers immediately without delay after becoming aware of the data breach.

The Article 33 goes on to describe what a notification of personal breach to supervisory authority will consist of, mandating that data controllers:

- Describe the nature of the personal data breach including categories and number of data subjects potentially affected and personal data records concerned;
- Communicate the name and contact details of the data protection officer or other contact poitn where mroe information can be obtained
- Describe the likely consequences of the personal data breach etc.

The Article also stipulates that data controllers have to document any personal data breaches and relevant data, effects of the breach and whatever action they have undertaken to remedy and resume normal operation in order to verify compliance with the Regulation.

VI. NOTIFICATION OF DATA SUBJECTS

The provisions of the paragraph 1 and 2 of the Article represent an important compliance mechanism. Complying with these provisions basically demands that data controllers implement an information security policy, possibly invest in some sort of information security management system and educate their employees on the fundemental tenets of information security.

In that regard, information security standards such as ISO 27000 family of standards contain useful controls that cover relations with suppliers, issues of physical security, use of cryptography, management of assets, implementation of information security policies and human resources as well as handling incident response obligations.

Especially sensitive is the requirement regulated by the Article 34 that regulates the obligation to communicate that a data breach has taken place to the data subject. Should a personal data breach be likely to result in a high risk to the rights and freedoms of natural persons, the controller has to communicate the personal data breach to the data subject without undue delay. The contents of this communication mirror the provisions of Article 33, with addition of being described in clear and plain language understandable to the data subject. Guidelines offer criteria to distinguish risk and high risk, and assessment should take into account factors such as the type of the data breach, nature, sensitivity and volume of personal data, ease of identification of individuals, severity of potential consequences, special characteristics of the individual and the data controller, number of affected individuals etc. On the basis of the Personal Data Breach Severity Assessment Methodology developed by the European Network Information Security Agency, a free personal data breach notification tool was developed to help controllers report personal data breaches to competent authorities and assess the severity of the breach. [14]

However, should conditions exist such as use of appropriate technical and organisational measures that render personal data unintelligible to non-authorized users, or measures undertaken that prevent high risks to freedoms and rights of data subjects from materializing, data controllers would not be in obligation to notify data subjects. This provision creates an incentive for data controllers to implement these measures into their systems in order to lessen their potential liability.

These obligations form Article 34 will likely result in several outcomes. What has already happened is that the number of complaints, especially against Big Data companies and leading Internet platforms is on the rise, resulting in increased regulatory oversight and legal proceedings. According to the European Commission data, over 95 thousand complaints have been introduced between 25th of May 2018 and 28 of January 2019. [15]

The other outcome is favourable to information security industry, which is recording growth, development of new

tools and services aimed at connecting existing information security resources, standards and services for use in assuring data protection compliance.

With new provisions regarding collective legal actions in mind, it is obvious there is an increasing likelyhood of potentially crippling lawsuits to go along with already very strict administrative fines, justifying the spur in spending and investment into data protection compliance not just from major internet platforms and Big Data market players.

VII. DEVELOPMENT, COMPETENCE AND ROLE OF DATA PROTECTION OFFICERS

Data Protection Officer as an institute of data protection law first appeared in the West German *Bundesdatenschutzgesetz* in 1977, and subsequently in data protection regulation of several other European countries even before the adoption of Data Protection Directive in 1995. Not many countries however opted to regulate the data protection officer position and function. [16]. In Regulation 45/2001 designation of the DPO became mandatory for EU bodies and institutions.

There were and are various reasons for implementing a DPO as an institute of data protection law. Data protection legal framework is becoming increasingly complex in light of the technological an sociological changes due to the ongoing information revolution. To comply with these provisions, data controllers need specialized knowledge and skills. Secondly, the development of the applicable legal framework is demanding. National supervisory bodies, European data protection board (formerly the Article 29 Working Party) publish an increasing number of opinions and guidelines that direct and form the practice of data protection in the EU. Thirdly, the common digital single market represents a challenge with respect to handling data subject requests possibly coming from different Member States and cooperating with their national supervisory bodies. All these tasks expect a level of expertise many controllers simply cannot have within the ranks of their employees.

These reasons have contributed to the expanded and more elaborate regulation regarding data protection officers in the GDPR. Section 4 of the Chapter IV of the GDPR regulates the obligation to designate data protection officers, their position and their tasks in Articles 37 to 39.

In contrast to older practice of quantitative criteria for the obligation to designate data protection officers, such as when data controller employs twenty or more employees as was regulated in the former Croatian Personal Data Protection Act, the Regulation adopts qualitative criteria taking into account the status of the data controller, the purpose and scope of processing and wether large scale of special categories of personal data and personal data relating to criminal convictions are being processed.[17]. The Regulation explicitely provides for the possibility of having an outsourced data protection officer on the basis of a service agreement.[18]

The Regulation also elaborates on the expected competences and expertise of the data protection officer, stipulating that the data protection officer will be designated on the basis of professional qualities and expert knowledge of data protection law and practices, and the ability to fulfil the tasks of the data protection officer regulated in the Article 39: inform and advise the controller or processor and the employees on their obligations, monitor compliance with the Regulation, cooperate with the data protection supervisory authority and act as a contact point on issues relating to processing etc.

There are many parallels between data protection officers and information security advisers and chief information security officers that have sporadically been regulated in national legal system of Member States [19]. Regarding information security policies, both categories of experts have a role developing and managing the policies, even if the information security experts take on a more technical role and manage the tehnical implementation. Where DPOs help develop privacy policies and website notices, policies on use of social media, employee policies and codes of conduct, the information security advisers monitor implementation and adherence to security standards and requirements, access control and monitoring etc.

Both of these functions participate in managing the relations with service and product vendors, especially concerning their safeguards, security policies and procedures, previous incidents and data breaches and potential sharing of sensitive information. Normally, when present in an organisation, they usually coordinate management and response to data breaches and coordinate employee training.

VIII. DATA PROTECTION IN EU INSTITUTIONS

A few years after the adoption of the Data Protection Directive and following its transposition into national legal systems of Member States, EU adopted an acompanying Regulation (EC) No 45/2001 that provides natural persons with legally enforceable rights, specifies the data processing obligations of controllers within the Community institutions and bodies, and creates an independent supervisory authority, the European Data Protection Supervisor.

The EDPS is a supervisory body intended to oversee data protection in EU institutions and is responsible for monitoring the processing of personal data by the Union institutions and bodies. The EDPS monitors activities that use personal data of anyone who works with the EU, contractors and beneficiaries of various grants, even the visitors of EU institutions and bodies, and also consults DPOs of EU institutions, gives out advice in opinions, comments and decisions, raises awareness, conducts data protection audits to verify compliance etc.

Since the GDPR introduced new, more elaborate data protection rules for the dana controllers in the EU, it was necessary to develop the legal framework applicable to EU institutions that would provide EU citizens with the same level of security and assurance that they can enjoy when dealing with other data controllers under the General Data Protection Regulation. The EU law makers recognized importance of a coordinated and equivalent approach to personal data protection to align as far as possible the data protection rules for Union institutions, bodies, offices and agencies with the data protection rules adopted for the public sector in the Member States. This is why a second Regulation, the Regulation 2018/1725 concerning protection of natural persons with regard to the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data, and

repealing Regulation (EC) No 45/2001 and Decision No 1247/2002/EC was enacted in 2018.

These two Regulations follow the same principles, and they should be, from the perspective of judicature of the Court of Justice of the EU be treated as a common and equivalent legal framework.

Concerning relevant information security provisions, Article 4 of the Regulation 2018/1725 mirrors the Article 5 of the GDPR, maintaining that one of the general principles of processing of personal data shall be to ensure appropriate security of the personal data, including protection against unauthorised or unlawful processing and against accidental loss, destruction or damage, using appropriate technical or organisational measures ('integrity and confidentiality').

The Regulation continues to copy provisions of the GDPR concerning obligations of data controllers (Article 24 of the GDPR into Article 26), data protection by design and by default (Article 25 of the GDPR into Article 27), regulating the relations between the data controller and the processor (Article 28 of the GDPR into Article 29), maintaining records of processing activities (Article 30 of the GDPR into Article 31).

Likewise, provisions of the Article 32 of the GDPR on security of processing are mirrored in Article 33 of the Regulation 2018/1725 with a minor difference in paragraphs 3 and 4, which have switched place so that Article 33 of the Regulation 2018/1725 puts the obligation of the controller and the processor to take steps to ensure that any natural person acting under the authority of the controller or the processor who has access to personal data does not process them except on instructions from the controller, unless required to do so by Union law, before the provision concerning adherence to an approved code of conduct.

The newer Regulation does however include a new section 3 in the Chapter IV. The new section is labeled *Confidentiality of electronic communications* and consists of three new articles regulating confidentiality of communication, protection of information processed by users' terminal equipment and contained in the directories of users.

Article 36 regulates that Union institutions and bodies shall ensure the confidentiality of electronic communications, in particular by securing their electronic communications networks.

Article 37 relates to protection of information transmitted to, stored in, processed and collected from users' terminal equipment and regulates that Union institutions and bodies have an obligation to protect such information collected from users accessing publicly available websites and mobile applications. Recital 54 of the Regulation further explains this point in reference that Union institutions and bodies, with respect to Article 7 of the Charter of Fundamental Rights of the European Union should protect such communications and related informationas Article 7 regulates that everyone has the right to respect for private and family life, home and communications.

Finally, Article 38 concerns the directories of users maintained by the institutions and bodies of the EU, and regulates that access to personal data contained in these directories and directories themselves has to be limited to what is strictly necessary for the specific function of the directory.

Section VI of the Chapter IV in Articles 43 to 46 contains adapted regulations concerning the status, position and tasks of data protection officers in the institutions and bodies of the EU.

There are several key differences between the GDPR and the Regulation 2018/1725 in this regard. For one, the newer Regulation reduces the possibility of an externalized data protection officer acting on the basis of a service agreement, which was one of the more interesting features of the Article 37 of the GDPR.

While still possible, the use of externalized DPO is now secondary choice. Paragraph 4 of the Article 43 states that the data protection officer shall be a staff member of the Union institution or body, and that Union institutions and bodies *may* designate a data protection officer on the basis of a service contract only when taking into account their size and if their organisational structure and size prevents them from designating a data protection officer, presumably because conditions of designating a person with adequate professional qualities, expert knowledge of data protection law and practices and the ability to fulfil DPO tasks are not met.

IX. CONCLUSION

In twenty four years since the EU adopted the Data Protection Directive in 1995, there has been a substantial amount of regulatory and practical progress both in the field of personal data protection and in regulation of information security. Especially in the recent years, in the judicature of national courts, the EU Court of Justice[20] and in the proceedings involving national supervisory bodies the rising number of cases have affirmed the status of personal data protection as a fundamental right.[21]

Information revolution and development of information society on the back of rapid technological development have sped up the adoption of relevant regulation much beyond the usual speed of legislative development. This in turn has created a substantial pressure on data controllers to invest in compliance in a field that was almost ignored just a decade ago.

Regulatory and practical issues of personal data compliance and information security compliance are, from the perspective of current European legal framework, intrinsically connected. The personal data protection framework has obviously, from the fundamental principles of processing such as the integrity and confidentiality principle through regulation of technical and organisational protection measures, incident reporting responsibilities and the designation and tasks of data protection officers adopted practices similar to those that have evolved in information security practice in roughly the same time period. This is a natural consequence of the fact that personal data is data processed and stored mostly in information systems, and security of information systems is vital for security of personal data. It also underlines a need for further research and development of safer information systems, applications and practices.

The efforts of the EU lawmakers, within the wider initiative to create the unified legal framework for the European digital single market have largely succeeded in the field of data protection. For different reasons, notably the fact that Member States' legal systems often consider information security an aspect of national security, the development of the common European legal framework in the field of information security has not been as succesful.

Hopefully, some of those solutions will eventually be applied to future EU common regulation of information security.

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Fair Exchange and Anonymous E-Commerce by Deploying Clone-Resistant Tokens

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***Abstract*—The majority of E-commerce transactions reveal private information such as customer's identity, order contents and payment information during the transaction. Other personal information such as health conditions, religion, and even ethnicity may be also deduced. Even when deploying electronic cryptocurrencies such as Bitcoin, anonymity cannot be fully guaranteed. Also, many anonymous payment schemes suffer from possible double spending circumstances. E-commerce privacy is basically a difficult problem as it involves parties with concurring interests. Three major e-commerce requirements are highly difficult to resolve: anonymous purchase, anonymous delivery and anonymous payment. This work presents a possible e-commerce system addressing all three anonymity requirements for electronic-items business on open networks. The system offers anonymous entities authentication mechanisms up to completing a fair anonymous e-commerce transaction. The system is based on deploying a physically clone-resistant hardware token for each relevant involved party. The tokens are made clone-resistant by accommodating a Secret Unknown Cipher (SUC) in each hardware-token as a digital PUF-like identity. A set of novel generic system-setups for units, protocols and e-commerce schemes is introduced. The proposed anonymization is basically attained by virtually-replacing relevant e-commerce entities by low-cost, unique and clone-resistant tokens/units using SUCs. The units act as trustable anonymous, authenticated and non-replaceable entities monitored by their acting users.**

***Keywords*—Anonymous e-commerce, e-payment, Fair Exchange, Anonymity, Secret Unknown Cipher, Physical Unclonable Functions.**

I. INTRODUCTION

E-commerce has become a viable solution for online shopping. It provides consumers with an easy way to buy items from merchants located all over the world. The purchase of digital items requires often an electronic payment (e-payment); the main concerns in any e-payment system are security and privacy of participants and the transaction's attributes. Nowadays, cryptocurrencies are increasingly used as anonymous or pseudo-anonymous e-payment systems, they either use proof of operation, such as in Bitcoin [1], or proof of stake, such as in BitcoinDark, to verify transactions and add new blocks to the blockchain which is used as a public ledger accessible to everyone. Bitcoin was introduced in [1] as a peer-to-peer electronic cryptocurrency system. Bitcoin makes intensive use of cryptographic functions to transfer crypto money from one user to another without revealing its identity. Since transactions are associated with users' public addresses, users are encouraged to create as many public addresses as possible to make it difficult to link the transactions and hence increase users' privacy [1][2].

Blockchain may solve both tampering and double spending issues in many cryptocurrencies. In Bitcoin, the difficulty of the proof of work is auto-adjusted every two weeks targeting 10 minutes block generation, this allows fast double spending when Bitcoin is used in fast payment actions [3]. In cryptocurrencies, users are anonymous and don't trust each other. However, Blockchain doesn't consider the notion of fairness [4]. Fair exchange allows two participants to exchange digital items fairly, such that delivery may not happen without payment and vice versa.

In this paper, we propose a new e-commerce system where each participant has its unique physical clone-resistant unit. Physical Unclonable Functions (PUFs) [5][6] have been proposed during the last decade to provide an intrinsic identity of electronic devices. Due to their analog nature, PUFs behavior is inconsistent by aging and under different environmental and operational conditions. This makes the use of the so called "fuzzy extractor" or helper data algorithm besides each PUF instance necessary resulting with the increase in hardware complexity in terms area and time.

Recently, Adi proposes to create digital clone-resistant units nominated later as Secret Unknown Cipher (SUC). SUC fulfil the same PUF tasks, however in digital form. SUCs are therefore consistent during the whole lifecycle of the digital system [7][8]. The proposed SUC allows counteracting the drawbacks of PUFs and creating robust clone-resistant identities. In [8], Mars et al. propose a SUC design based on Random Stream Cipher (RSC-SUC) deploying a class of T-functions as key stream generator with few random optimal involutive S-Boxes. In [9], a SUC creation process based on random block ciphers was proposed, it is deploying random optimal S-Boxes as a source of secret randomness in the SUC design in addition to the secret key. In [10], a SUC design template based on combining well-selected NLFSRs having low complexity feedback functions was proposed. Compared to the SUC designs in [8] and [9], NLFSRs can be distributed over all the FPGA area. Generic authentication protocols of SUC based on random block ciphers were proposed in [11] while [10] proposes authentication protocols of SUC based on random stream ciphers.

Contribution. The contribution of this paper is firstly, a new procedure is introduced for anonymous e-commerce transactions where each unit has its own clone-resistant hardware token based on digital physical clone-resistant functions. Secondly, we propose a strong and fair exchange

protocol based on online trusted third party. Finally, we propose a novel use of One-Time-Coin generator through Automated Teller Machine (OTC ATM) adapted to the SUC structure to allow the exchange of OTCs with money anonymously.

The remainder of this paper is organized as follows. Section 2 describes the state of the art of anonymity and fair exchange in e-commerce and e-payment. In section 3, the anonymous e-commerce system architecture together with the commercial hardware setup and delivery are described. Section 4 presents the proposed new fair exchange protocol with its payment management concept**.** Finally, section 5 concludes the paper results.

II. RELATED WORK

E-commerce transactions reveal usually private information of customers whose identities are disclosed during the payment process. Additional private information such as their health condition, religion, and ethnicity can be also deduced. Many e-commerce schemes have been proposed to provide user privacy protection and fairness. According to [13], the e-commerce privacy is mainly based on the following properties:

- *Customer Anonymity:* No unauthorized third party, including the Trusted Authority (TA), may acquire any identifiable information (name, address or Internet address) of an individual or customer participating in an e-commerce activity.
- *Transaction Unlinkability:* No single entity (third parties, online payment systems, etc.) should be able to link one or more shopping activities or transactions to a unique (personally identifiable) user.

In [14], a privacy preserving e-commerce protocol has been proposed. It allows unlinking online transactions from customer identities; hence the customer privacy will be preserved. Furthermore, Rial [15] categorized privacy preserving protocols as follows:

- Private purchase protocols: The protocol reveals to the service provider the identities of the users but hides from the service provider which items the users purchase. This type of protocols can only be used to purchase digital products since the delivery process can reveal the purchased items. The communication between the users and the service provider employs an authenticated channel.
- Anonymous purchase protocols: The protocol hides from the service provider the identity of the users. However, the service provider learns which items are purchased by the users. Communication between users and a service provider should be done through anonymized channels.
- Private Billing: The protocol reveals to the service provider the identity of users but hides from the service provider the consumption readings of the meter. Communication between users and service provider employs an authenticated channel.
- Anonymous Billing: The protocol hides from the service provider the identity of the users but it reveals the consumption measurements.

Our proposed anonymous e-commerce scheme based on clone resistant units with fair exchange protocol ensures customer anonymity with anonymous purchase and anonymous billing. Furthermore, the Trusted Third Party (TTP) cannot learn which items were purchased but it reveals the spending of each user for every transaction.

In traditional transactions, the customer and the merchant meet face-to-face and hence they can fairly exchange money and goods. For online transactions, fairness is unpredictable since one of the two parties can cheat the other. i.e. the customer may not receive the goods after payment or the merchant may not receive the payment after providing the goods to the customer. Fair exchange protocols ensure that, at the end of the transaction, both service provider receives the payment and the user receives the product. Otherwise none of parties would get anything. Fair exchange protocols are classified into:

- Gradual exchange protocols [16]: the two parties exchange secret data bit by bit. In normal cases, no participant has an unfair advantage over the other participant. However, it can be seen that one of the participants may get more secret data bits than the other and terminate the exchange procedure. In addition to that, this protocol requires a lot of communications during the same transaction and hence it is inefficient.
- Trusted Third Party (TTP) protocols: they involve a TTP that guarantees fairness of the transactions. TTPs may have online and offline type. In online TTP [17], whenever the two participants intend to communicate, they send their data to the TTP which checks for correctness. If it is the case, the TTP validates the transaction and the two participants get their right data, if not both parties get nothing. In offline TTP [18][19][20][21], the TTP is only involved in case of dispute.

In [22], Pagnia et al. provide a formal definition of the strong fair exchange problem and proved that it may not be reached without a trusted third party. In this paper, fairness in our proposed e-commerce system is based on the electronic commerce server that is the TTP itself.

III. E-COMMERCE BUSINESS MODEL

Traditional commerce is based on physically exchanging items between users fairly. In e-commerce, the identity of a user cannot be verified directly by the other users in an online transaction. Thus, there is a need for a TTP to realize secure and fair exchange between users. In traditional e-commerce, users are forced to reveal their identities to the TTP, which would violate anonymity and privacy of users. To ensure e-commerce participants anonymity, we propose to deploy anonymous Commercial Hardware Token (CHT) based on a SUC where the TTP will be able to verify each anonymous CHT based on its SUC. However, participants identities will not be revealed. Furthermore, the proposed anonymous e-commerce is selling e-goods where the participants are not obliged to provide a delivery address that may disclose their identity.

A. E-commerce Model

This section describes the business model of the proposed physically anonymous e-commerce. The proposed e-commerce concept involves an Electronic Commerce Server

(ECS) which is considered as a TTP, the merchants providing e-goods, the consumers willing to get anonymously e-goods and the One Time Coin generator that can be an Automated Teller Machine (OTC ATM). The OTC ATM is able to generate one-time coins and sell them to the users. Fig. 1 describes the proposed business model. It proceeds as follows:

- **Step 1:** the customer orders a digital item anonymously from a merchant.
- **Step 2:** the merchant delivers anonymously the encrypted digital item with a secret key known only to the merchant and the ECS.
- **Step 3:** the customer orders a One Time Coin (OTC) from the OTC ATM. The ordered OTC should have a value equivalent of the ordered digital product from the merchant.
- **Step 4:** The customer sends the encrypted OTC to the merchant.
- **Step 5.a:** the merchant sends a proof to the ECS that he/she sends the encrypted digital product to the customer and confirms to the ECS that he/she gets paid for the digital product.
- **Step 5.b:** the customer confirms to the ECS that he/she got the encrypted digital product from the merchant and that he/she paid the merchant for it.
- **Step 6:** the ECS verifies that both the merchant and the customer are providing identical data with no conflict. If it is not the case, it rejects and aborts.
- **Step 7:** the ECS sends the OTC to the OTC ATM that verifies that the provided OTC is not spent before; this protect against double spending. Steps 6 and 7 ensure a fair exchange between the merchant and the customer such that even both parties get the other's item or none does.
- **Step 8.a:** The ECS provides the merchant with the decryption key of the OTC.
- **Step 8.b:** The ECS provides the merchant with the decryption key of the digital product.
- **Step 9:** the merchant provides the OTC to the OTC ATM and gets the equivalent money of the digital product even in cash or the OTC ATM transfers it to an anonymous merchant account.

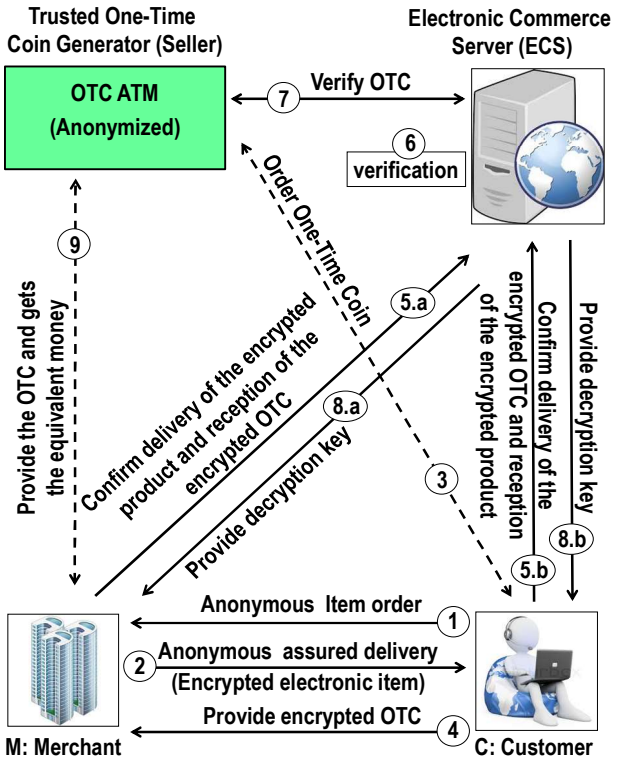

Fig. 1. E-commerce Business Model

B. SUC-based Commercial Hardware Token

The Commercial Hardware Token (CHT) based on SUC constitutes the heart of the proposed fair exchange physically anonymous e-commerce. Each CHT embeds its SUC as physical clone-resistant unit. SUCs have been proposed to overcome some of the PUFs drawbacks especially their inconsistency [7] [8].

Definition. Secret Unknown Cipher is a randomly internally single-event-generated unknown cipher such that: it is unpredictable, tamper-proof and non-removable. Neither users nor manufacturer have influence or access to its creation process. Even the manufacturer should not be able to back trace the creation process and deduce the created random cipher.

Fig. 2 describes the conceptual scenario for embedding a SUC in a CHT device that includes a System on Chip (SoC) FPGA. The CHT personalization process proceeds as follows:

- **Step 1:** The Trusted Authority (TA) uploads a software package as a smart cipher designer called "GENIE".
- **Step 2:** The GENIE is then ordered to create a non-predictable cipher (SUC) with the help of the True Random Number Generator (TRNG) located within the SoC to assure randomized, unpredictable and unknown results. The GENIE stores the created SUC permanently at unknown location/s within the FPGA fabric and makes it usable only for encrypting and decrypting data.
- **Step 3:** The GENIE is then kicked-out (that is, deleted as a program and ordered to leave the device forever). The end result is a usable cipher which nobody knows. Notice that the created ciphers are basically different, even when having an unknown individual structure and unknown locations for each individual device.
- **Step 4:** In the enrollment process, the TA (or any other TA') challenges each SUC_u by a set of *t*-cleartext patterns $\{X\} = (X_{u,0} \dots X_{u,t-1})$ to generate the corresponding t-ciphertext set $\{Y\} = (Y_{u,0} \dots Y_{u,t-1})$ where $Y_i = SUC_u(X_i)$. Then, the TA stores the *t*-cleartext/ciphertext pairs $\{X\}/\{Y\}$ in the corresponding device records as: Units Individual Records (UIR) labeled by the serial number of the device SN_u. The $\{X\}/\{Y\}$ pairs are to be used later by the TA/TA' to identify and

authenticate devices. Notice that multiple TA's can operate completely independently for their own individual application by using the same SUC.

SUC concept is comparable to the conventional PUFs, with the advantage that it is collision-free. As a bijective cipher SUC offers higher entropy compared with a conventional PUF, which is equivalent to a collision-prone hash function. Invertibility is an advantageous property that was deployed in [23] to build a strict chain of trust for a secured vehicular software update protocol which is much more complex in traditional PUFs.

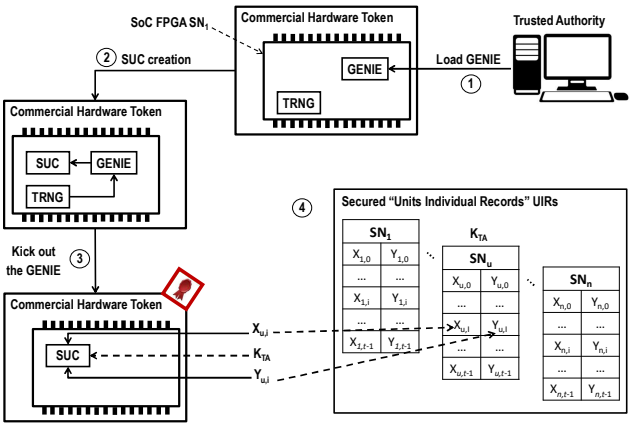

Fig. 2. Concept for CHTs personalization

C. Commercial Hardware Token (CHT) Setup and Delivery

Fig. 3 describes the main personalization process of the CHTs by the ECS and the delivery to the users:

- **Step 1:** The CHTs manufacturer is responsible for producing CHTs. They are fabricated such that each CHT embeds an SUC ensuring its uniqueness and unclonablity or at least clone-resistance.
- **Step 2:** The ECS gets N CHTs from the CHTs manufacturer.
- **Step 3:** The ECS challenges each CHT, for instance CHT having serial number SN_M, with a set of t-challenges $X_{M,i}$ ($0 \le i \le t-1$) and gets the corresponding responses $Y_{M,i}$ and stores them in the corresponding area on the ECS UIR defined by SN_M.
- **Step 4:** The ECS delivers the certified CHTs to the CHT-shops.
- **Step 5:** Merchants and consumers can buy CHTs without revealing their identities to the shop.

D. The System Threat Model

The proposed e-commerce scheme assumes the following:

- *ECS is a trusted third party:* It is assumed that the trusted third party will not misbehave or collude with one of the transacting parties.
- *CHTs are clone-resistant or Unclonable:* SUC is designed to be resistant against mathematical cloning. It is also resistant to physical cloning by deploying countermeasures against side channel attacks. This results with secure CHTs, such that even the manufacturer will not be able to clone them.

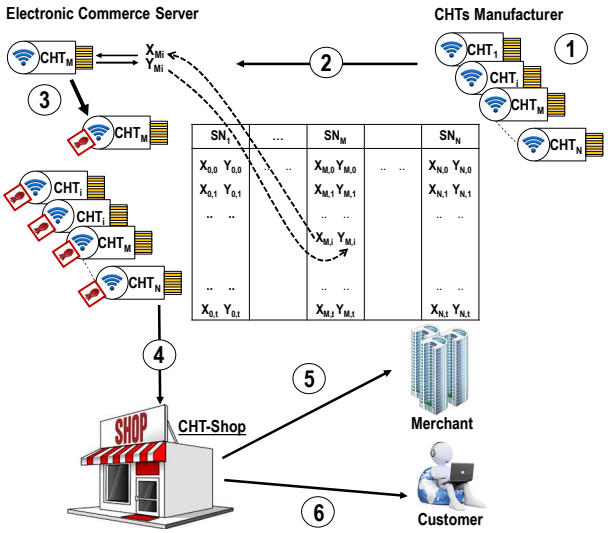

Fig. 3. CHTs setup and delivery

- *Merchant is not considered honest:* The merchant can try to cheat or provide counterfeit services.
- *The consumer may try to cheat:* After receiving the e-good, the consumer could claim the inverse and try not to pay the merchant.

IV. Fair Exchange and Anonymous E-Commerce based on CHTs

Anonymity constitutes an appealing requisite in e-commerce. Anonymous e-commerce aims to protect the identity of the actors in the e-commerce scheme especially the consumers. Cryptocurrencies such as Bitcoin provide pseudo-anonymity because they are based on a public ledger blockchain making all the users transactions visible to the public [1], [2]. To improve privacy in Bitcoin, users should use different public addresses for different transactions, this makes it difficult to link users's transactions.

In our proposed scheme, each participant (ECS, Merchant and Customer) has a CHT. When a service is required by a consumer from a merchant, the ECS lets the customer and the merchant trust each other with a simple intervention by the ECS. For this purpose, the generic mutual authentication protocol in [11] can be used. A secret shared key (Z) between the consumer and the merchant is generated at the end of this protocol. The key Z will be used in the fair exchange protocol, this would allow both parties to communicate securely such that no other third party even the ECS will not be able to eavesdrop the communication and get what digital items they are exchanging.

The ECS acts like an escrow agent where it ensures fairness at the end of the exchange, but it does not have any access to the shared services between the consumer and the merchant in normal case. After completion of the exchange, if there is a dispute between the merchant and the consumer, the ECS gets the shared secret key and verifies which participant was not honest.

A. Fair Exchange Protocol

Fair exchange protocol ensures that the exchange of digital items between the merchant and the customer is fair, so at the end of the exchange, either both the merchant and

customer get the other's item or neither of them does. Fig. 4 describes the proposed fair exchange protocol involving the ECS as trusted third party. The ECS acts as an escrow agent, where the customer and the merchant rely on it to ensure fairness when finishing the exchange of the digital item. The fair exchange protocol proceeds as follows:

- **Step 1:** the customer C, identified by its serial number SN_C, asks for a service P_t from the merchant M identified by its serial number SN_M.
- **Step 2.a:** Merchant M requests one response $Y_{M,j}$ from the ECS. The ECS sends $E_{X_{M,j}}(Y_{M,j}) \| Y_{M,j}$ to M which computes $X_{M,j} = SUC_M^{-1}(Y_{M,j})$. M will use $X_{M,j}$ as encryption key.
- **Step 3:** Merchant M encrypts the service P_t by using the key $X_{M,j}$ and sends it to the customer as $Y_1 = E_{X_{M,j}}(P_t)$.
- **Step 4.a:** the customer receives the encrypted service Y_i and confirms that to the ECS by encrypting it using the session key Z and sends it concatenated with the encrypted: service value V_C, the required product P_t and the coin to be used to pay the service OTC_t as $E_Z(Y_1) \| E_{X_{C,i}}(V_C, OTC_t) \| Y_{C,i}$.
- **Step 4.b:** Merchant M confirms to the ECS that the service is transferred to the customer. It encrypts the sent encrypted service P_t by using the session key Z as $Y_3 = E_Z(Y_1)$ and sends it concatenated with the encrypted service value $E_{X_{M,j}}(V_M)$ to the ECS.
- **Step 5:** The ECS verifies if both received confirmations correspond. If $Y_2 = Y_3$ and $V_M = V_C$, then the ECS contacts the OTC ATM to check for the validity of the OTC_t. If OTC_t is valid and $OTC_t = V_t$, then the ECS continues the transaction. Otherwise the transaction is rejected, the customer or the merchant or both may be cheating. At this point, the merchant did not get the service value yet and the customer still has only the encrypted service. In All cases, the ECS deletes and replace the used CRPs.
- **Step 6.a:** In case that ECS deems the service as consistent; The ECS provides the customer with the decryption key $Y_{M,j}$, to allow the customer's access to the ordered and paid service.
- **Step 6.b:** The ECS provides the merchant with the payment coin OTC_t to complete the transaction.

In case of conflict, the ECS asks for the session key Z from both parties; i.e. the consumer and the merchant. It decrypts the received messages in steps 1 and 3 and compares the required service from the consumer with the sent one from the merchant.

B. Payment's Management Concept

The payment management concept is described in Fig. 5. It proceeds as follows:

- **Step 1:** the customer orders a one-time coin that has a value equal to the ordered digital product from the service OTC_t. The customer pays (possibly in cash) to the coin generator (seller) to get the OTC_t.
- **Step 2:** the OCT ATM generates OTC_t and provides it to the customer.

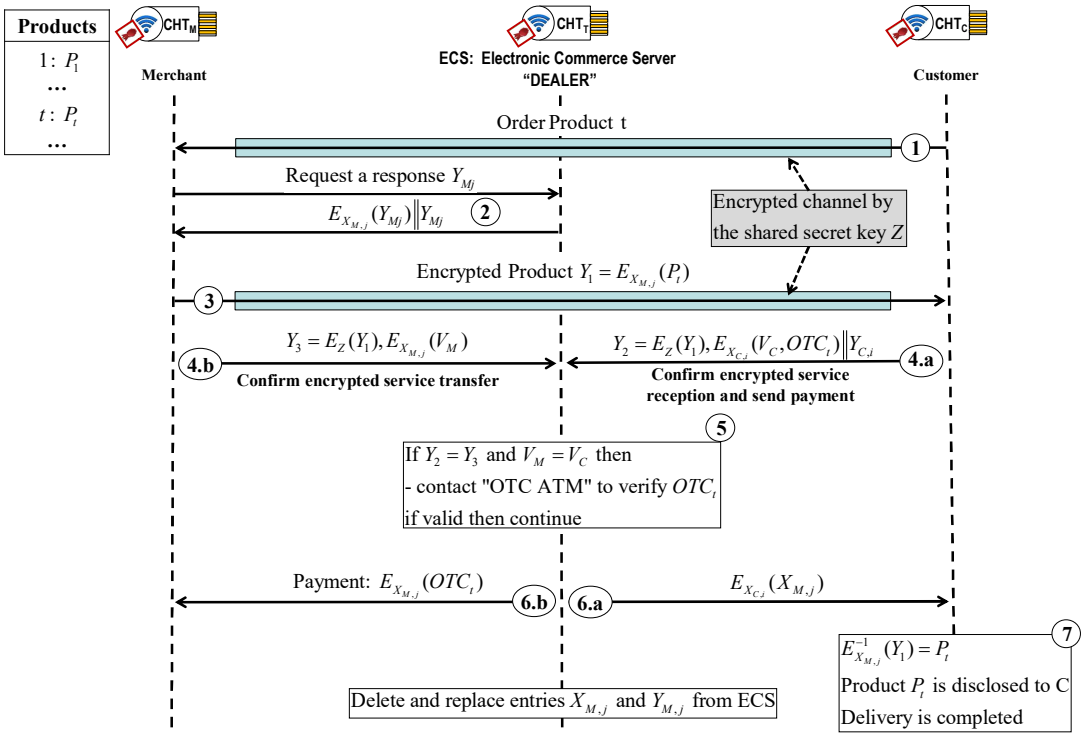

Fig. 4. Fair exchange protocol between the consumer and the merchant

- **Step 3:** The customer forwards OTC_t to the ECS.
- **Step 4:** the ECS sends OTC_t to the OTC ATM to verify its validity and provide its value to the ECS.
- **Step 5:** The OCT ATM verifies the validity of OTC_t. if it is valid, it will provide the ECS with its value, else it declares the invalidity of OTC_t.
- **Step 6:** the ECS receives the value of the OTC_t and verifies if it is equal to the ordered digital product value. If it is not the case, it rejects and aborts. Else, it provides the merchant with the OTC_t and the customer with the decryption key.

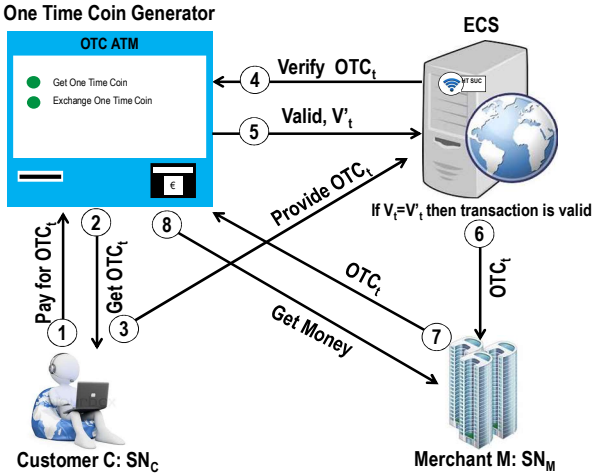

Fig. 5. Payment management system

V. Conclusion

A fair and anonymous electronic e-commerce system dealing with e-goods on open networks is presented. The key operating entities of the transactions are physical clone-resistant Commercial Hardware-Tokens (CHTs) based on Secret Unknown Cipher (SUC) technique. The CHTs accommodate unique digital SUCs as security anchors. The CHT is made clone-resistant by an initial irreversible single-event personalization process as a responsibility of a trustable CHTs Dealer. A dealer-based operation model should make the dealer play the role of just a mediator who takes the responsibility for provable CHT-Authentication without being able to reveal the anonymous users of the CHTs. Such CHTs offer a high degree of anonymity up to a perfect anonymity if the tokens are used just one time. The SUC technique allows protocols to act as agents running the transactions and offering in worst case clear tracing of responsibilities in dispute cases. The intended CHT is expected to be realizable at low-price when using the emerging non-volatile FPGA SoC technologies. The CHTs are also highly resilient as digital replacements for the traditional analog PUF technologies.

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PAPERS

Conceptual Framework for entity integration from multiple data sources

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Abstract – Entity matching and entity resolution are becoming more important disciplines in data management over time, based on increasing number of data sources that should be addressed in economy that is undergoing digital transformation process, with growing data volumes and increasing requirements related to data privacy. It is necessary to automate processes as much as possible by using predefined scenarios supported by frameworks.

I. Introduction

Entity matching process is also called record linkage, data matching or entity resolution in some published works. For long time research about the process was focused on matching entities from same dataset (i.e. deduplication) or from two datasets. Different algorithms used for matching different types of attributes were described in the literature, developed and implemented in data matching and data cleansing platforms.

Entity resolution is element of larger entity integration process that include data acquisition, data profiling, data cleansing, schema alignment and mapping and data merge (fusion).

There is a lot of available literature addressing any of the steps in the process, proposing different options for improvement of results or processing optimization, but the whole process still requires a lot of subject matter specific knowledge and many iterations to produce results that will have high F-measure (both high precision and recall).

Most of the algorithms used in the various steps of the process are Human in the loop (HITL) algorithms that require human interaction. Human is always part of the simulation and consequently influences the outcome. [1]

This paper is a part of the work in progress aimed to define framework that will automate some steps entity integration process and try to reduce requirements for human influence in the process. In this paper focus will be on conceptual process definition and use of existing open source solutions for entity integration process automation.

Contributions of this research and paper (and proposed conceptual framework) are:

- Order of resolution – we have defined algorithm that calculates order of resolution when we have more than two source datasets with different schemas
- Addressed performance issues for scoring by using feature generation and selection methods
- Architecture and logic used for merge / fusion step
- Incremental resolution and resolution of streams, including definition of process when new dataset is added to the architecture

There are other improvements in the process that are not yet addressed within this framework that may be addressed as a part of future work:

- Approach to automated blocking that will have required F-measure and performance using locality sensitive hashing and machine learning algorithms [2]
- Incremental resolution issues, including incremental resolution depending on changes of rules that can become more strict, re-evaluation of existing results [3], dealing with out-of-date and erroneous values [4] and semantic resolution [5]
- Dependencies between resolved datasets [4]

II. Entity Integration conceptual process

Entity integration process has six distinctive steps - Data acquisition, Data analysis and profiling, Data cleansing, Schema alignment and mapping, Data matching (record linkage) and Data merge (fusion)

In the data matching process, data cleansing plays an important role to contribute to high data matching quality. It has been reported that dirty values in data to be analyzed can cost 3.1 trillion dollars a year across businesses and government in the U.S., as they could introduce inaccurate data analysis results and thus unreliable decision making [6]. Relevant data cleansing research and practice efforts has been demanded by data matching practitioners [7].

Existing data cleansing approaches can be categorized as quantitative error driven approaches and qualitative error driven approaches. While the former ones concentrate on detecting statistical outliers in data, the latter ones focus on detecting and repairing violations of constraints, rules, or patterns [6], [8], [9]. Qualitative data cleansing can be divided into two steps, error detection and data repairing; a variety of solutions have been published for each of the step [6]. To improve data-repairing quality, data cleansing solutions start involving more human efforts and a number of approaches are developed to effectively and efficiently interact with users for gaining better cleansing results [10], [11]. Recently, application oriented data cleansing problems and solutions have emerged. Recent research outcomes have demonstrated its potential of leveraging application knowledge to reduce the cleansing costs [12], [13].

In Figure 1. is presented most commonly used schema of data matching process [14]

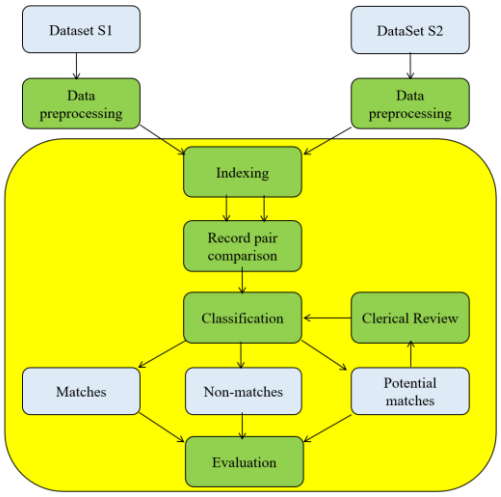

Figure 1. Matching process for two datasets

Data matching process that covers blocking (indexing), comparison, classification and evaluation steps is explained and defined in detail for matching pairs of records from two data sets and this part of the description we can use as state-of-the-art in the field [14]

However, this schema does not address first steps in the process - data acquisition, data analysis and profiling and schema alignment and mapping. The last step, data merge, is also not addressed.

To generalize this process schema, we have added yellow subset of the processes that are strictly related to matching and evaluation that are the same in all the scenarios will be described further it this paper.

Requirements for data matching are effectiveness, efficiency, genericity and low manual effort/self-tuning. [15]. Use of pre-defined framework shall result in improvement of all four listed requirements.

A. Motivational Example

There are different scenarios where data matching and merging should be part of data integration process. Some scenarios can be grouped, based on types of activities that are needed to solve the problem. Each of those scenario groups will have different process flow that should be supported by the conceptual framework.

We will use very common real-life motivational example to describe very common scenario of requirement for data matching as a part of more complex data integration process. Global pharmaceutical company with offices in more than 60 countries worldwide has migrated customer data from various legacy systems in different countries to new common CRM system in the cloud. Migration was phased by regions and countries, with new sources and data incrementally added and merged with data already migrated in previous phases. Entity integration in such case require deep understanding of data architectures, data content and each step of the process. Even with such deep understanding, design and implementation of the solution required many iterations in development process that consumed human resources, time and financial resources. Reducing the number of iterations by automating and optimizing steps in the process can save vast amount of resources.

One important characteristic of described real-life example is that *target schema O is predefined*, based on the data architecture of the target application. Such scenario is eliminating uncertainty from schema alignment and mapping process, because all the mappings between attributes from source schemas and target schema shall be exactly defined.

There may be special situations that there are existing attributes in one or more source schemas that does not have counterpart in target schema and must be loaded to target schema. In such specific cases target schema will be extended to accommodate required mappings.

Another important rule in this scenario that will be helpful for definition of conceptual approach is that for each entity that is present in one or more source datasets there should be one and only one entity in target dataset. We can express that in following definition:

Definition 1: Let there be a set of n source datasets *S* ($S_1 \ldots S_n$) that should be mapped and matched in target dataset M. Each source dataset S_i contain variable number of x attributes and r records, and target dataset M contains y attributes and p records, where $\max(x_{Si} \mid S_i \in S) \leq y$ and $\max(r_{Si} \mid S_i \in S) \leq p$. There is match and merge function $M(S) \rightarrow M$ that defines that $\forall r_i \in Si \rightarrow \exists!\ p_i \in M$

Next real-life situation that we need to consider is that in set *S* we will usually have some datasets that have same or very similar schema and other datasets with different schemas. For example, five countries in same region are using same legacy CRM system and those five sources have same source schema. Based on that observation, we can define two types of matching processes – *single schema data matching* when we are matching two datasets S_i and S_j with same or almost the same schema, and *dual schema data matching* when we are matching two datasets with different schemas. In first case we will have target schema same as source schema and we can do match operations on union of records from both datasets. In second case we will have target schema that will have set of attributes from both datasets and we should use matching function that will produce similarity join.

Some of the source datasets will have more attributes than another. For example, one subsidiary can have legacy CRM source system with detailed information about customer, and additional source system for web-user consent management that will have only information about user first and last name and contact e-mail. It is also possible to have some sources in set *S* that do not share any of the attributes and cannot be matched directly, but only through matches with another source datasets that share same attributes with.

Content of the datasets can be different in various ways. Difference in size happens when some datasets have large number of records and some have significantly lower number of records. Generally, if the local subsidiary is larger, it will have more customers and more source records. Difference in language happens when data from different dataset are in different languages if they originate

from countries where different languages are spoken. There are also possible situations in some countries that have more than one official language where in the same dataset you may have data in different language (i.e. French or Arabic) or using different alphabet (i.e. Latin or Arabic). Difference in data quality occurs when some dataset has higher quality of source data and some has lower quality.

Finally, when initial data integration process is finished, there will be always requirements related to incremental match and merge processes. For incremental processing we should not use the same processing logic, because we need to process only new data and compare it to already matched data, to eliminate unnecessary processing of previously processed data. Intuitively we can see two main types of incremental processing – new records coming from datasets that are already contained in *S*, and new dataset that is not contained in *S*. Such new dataset can either have structure of existing dataset in S, or new schema that is not common with already existing datasets.

All described real-life examples and situations will affect the way how data integration process flow will be defined. Based on described scenario, some assumptions must be defined as a next step of definition of conceptual framework.

B. Assumptions

We have following assumptions:

1. Traditionally, schema alignment and mapping was the step preceding record linkage and data merge. In described scenario, target schema is predefined and attribute mapping shall precede record linkage.
2. We assume that entities can be described with one consolidated dataset with several attributes. Example of such entities are customers, books, movies, mobile phones etc. In this scenario we are not considering schema alignment and data matching for more complex scenarios that include more than one entity, but scenario can be generalized for more than one entity
3. We assume data is available, reasonably clean and with known semantics, so we are not focusing at data acquisition, data profiling and data cleansing steps
4. We assume that each data source may have more than record for some entities, i.e. duplicate records
5. We assume that we have multiple source datasets that can be aligned to one or more source schemas before matching
6. We assume that there are no dependencies between datasets that will be processed, i.e. that there are not fixed-point sets that should be resolved iteratively until convergence [4]
7. Any number of source datasets that will map into consolidated schema can be described with two standard scenarios:
    a. Matching of two datasets with the same structure (single schema data matching) that will result in union of all the datasets with same schema in one dataset. This should be done as the first step.
    b. Matching of two datasets with different structure and some common attributes (dual schema data matching) that will result in join of the datasets
8. Matched dataset M shall be merged in final step to produce merged dataset O

Union and join notations is the generalized schema shall be considered with some restrictions. For single schema scenario, it is not recommended to create union of datasets with duplicates for performance reasons, so recommended approach would be to match and de-duplicate each of the datasets as a first step and after that to create union that will be matched within itself. Join in multi schema scenario is not equality join but rather similarity join. Attributes used for join condition cannot include all attributes in both datasets but only attributes common to both datasets, which will be described in later chapters.

III. ORDER OF RESOLUTION

In real-life scenario there may be tens or hundreds of source datasets that should be integrated. In this chapter we will address recommendations and best practices to create optimal order of the resolution of the datasets that will be based on characteristics of source datasets. In such scenario we will start matching process by matching two source datasets S_i and S_j that will produce optimal match and resulting dataset S_{ij}. We will then remove two matched datasets form set of source datasets *S* and match the resulting dataset S_{ij} with next source dataset that will produce optimal match, until we have matched all available source datasets. We need to define algorithm that will take into account different data source characteristics to create optimal order of resolution that will produce matches with high F-measure that are processed in shortest possible period of time.

A. Order of resolution calculation

First source dataset characteristics that are affecting order of resolution will be defined – source dataset completeness, source dataset reverse size factor, source dataset overlap factor and source dataset accuracy factor, to be able to find two best datasets to start matching process. Matched dataset M with predefined unified schema has defined number of attributes *m*. Each source dataset S_i has number of source attributes $n_i \leq m$. Source dataset that has more attributes will be better candidate to be matched earlier in the process.

Definition 2. *Source dataset completeness factor* C_{Si} of dataset S_i is ratio n_i / m of number if attributes in source schema S_i that can be mapped to attributes in unified schema and number of attributes in unified schema M.

$$C_{Si} = |S_i| / |M|$$

When matching two datasets, if we have more common attributes that we can match in both datasets, probability to get higher scores will be higher. We are defining dataset overlap between two datasets as number of common attributes in both datasets over number of attributes in larger dataset.

Definition 3. *Source dataset overlap factor* O_{Sij} between two source datasets is number of common attributes in both source datasets over number of attributes in dataset with more attributes.

$O_{Sij} = (|S_i| \cap |S_j|) / \max(|S_i|,|S_j|)$

Various datasets can have different numbers of records. If we match large dataset many times, that will need more computing power. For optimal processing smaller datasets should be matched first. Based on number of records for each source dataset, *reverse size measure* can be defined as relative size to sum of the number of records in all source datasets, with smaller source datasets scoring higher. We are also taking into account that some records will be merged. If we assume that final number of merged records when we combine all dataset will be 80% of sum of all source records, we can define merge coefficient μ as 0,8. Number of merged records must be larger than number of records in largest source dataset. If we assume that blocking will affect all source datasets in same way, required computing power for matching will depend more on order of resolution when number of duplicates is high, that will result with less records in merged dataset to compare with remaining datasets, or number of records in largest dataset compared to smallest dataset is larger by one or more orders of magnitude

Definition 4. *Source dataset reverse size factor* RS_{Si} of dataset S_i is reverse relative number of records in S_i to sum of number of records in all source datasets, where smaller datasets will be scored higher. Merge coefficient μ is used for correction for number of assumed duplicates in merging process.

$$RSSi = 1 - len(Si) / \left(\sum_{j=1}^{n} len(Sj) \times \mu\right)$$

Finally, we need to take into account quality and completeness of data in each source dataset. Quality of the data in source dataset can be scored based on source data profiling and analysis (i.e. relative number of null values, relative number of values that are not validated), or it can be defined based on observations of experts in charge of each source system.

Definition 5. *Source dataset accuracy factor* $A_{Si} \in (0..1)$ is correction factor used to weight quality of data in source dataset, with 1 representing data with highest possible quality.

Dataset accuracy factor will be optionally used to ponder completeness, overlap and reverse size of source datasets to establish optimal order of resolution.

We are proposing the following calculation to score order of resolution OR_{Sij} for each two source datasets S_i and S_j:

$$ORSij = \left((CSi \times ASi) + (CSj \times ASj) + (RSSi \times ASi) + (RSSj \times ASj) + OSij\sqrt{ASi \times ASj}\right) \div 5 \qquad (1)$$

Since value of each summands in numerator is in interval (0..1) we are dividing the sum with 5, to be sure that the final score satisfy $0 \leq OR_{Sij} \leq 1$

It is important to note that if source dataset overlap factor $O_{Sij} = 0$, two datasets cannot be matched because they don't have common attributes.

B. *Calculation variations and simplifications*

Calculation that we have defined can be used in this form or in several simplified forms. First simplified form is when we don't evaluate quality of each source dataset. In that case we will not use source dataset accuracy factors A_{Si} and A_{Sj} and we will assume that every source dataset has same level of data quality. Second simplified form is when we either don't have information about number of records in each source dataset or number of records in each dataset is relatively similar. In that case we will not use source dataset reverse size factor in the formula, and sum of all the factors will be divided by 3 instead of 5. Third simplified form is when we will not use both source dataset accuracy factors and source dataset reverse size factors, and that will result in basic formula containing only source dataset completeness factor and Source dataset overlap factor:

$$Sij = (CSi + CSj + OSij) \div 3 \qquad (2)$$

It is important to note that this same algorithm can be used also in various scenarios when we don't have predefined target schema. In such cases in Definition 4 we can use sum of distinct attributes in all source datasets instead of |M| and the proposed algorithm will hold.

C. *Order of resolution algorithm*

Based on proposed calculation, we have defined algorithm that will populate execution plan L, based on the highest OR_{Sij} scores, shown in Figure 2.

Algorithm 1: Algorithm for order of resolution of multiple source datasets matching into predefined schema

Input : Set S of n source datasets where $\forall S_i \in S$ that should be mapped and matched in target dataset T, we know accuracy factor A_{S_i} and number of records N_{S_i}

Output: An execution plan L

1 Calculate C_{S_i}, RS_{S_i} $\forall S_i \in S$
2 Calculate $O_{S_{ij}}$ and $OR_{S_{ij}}$ $\forall(S_i, S_j) \in S$
3 **while** $n >= 2$ **do**
4 Sort $OR_{S_{ij}}$ descending;
5 Filter (S_i, S_j) where $RS_{S_i} = 0$;
6 Find max($OR_{S_{ij}}$);
7 Remove (S_i, S_j) From S;
8 Add $S_{ij} = M(S_i, S_j)$ to S;
9 Add (S_i, S_j) to L;
10 Calculate $C_{S_{ij}}$, $RS_{S_{ij}}$ for S_{ij};
11 Calculate $O_{S_{ijk}}$ and $OR_{S_{ijk}}$ $\forall(S_{ij}, S_k) \in S$;
12 n = n -1
13 **end**
14 return L;

Figure 2. Order of Resolution Algorithm

To illustrate Algorithm 1, we can use the sample with three datasets and ten attributes in table 1:

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	x	x	x	x	x	x	x			
S2				x	x	x	x	x	x	
S3								x	x	x

Table 1: Sample - three source datasets and ten attributes

Number of attributes and assumed number of records are defined in table 2:

Dataset	Attributes	Size
S1	7	250
S2	6	500
S3	3	1.000
M	10	1.750

Table 2: Number of attributes and records

We will assume that $\mu = 1$ and all three source files are high quality and $A_{Si} = 1$.

Based on definitions 2-5, we have calculations as follows for different source dataset factors.

Source dataset completeness factors:

$C_{S1} = 7 / 10 = 0,7$
$C_{S2} = 6 / 10 = 0,6$
$C_{S3} = 3 / 10 = 0,3$

Source dataset overlap factor:

$O_{S12} = 4 / 7 = 0,5714$
$O_{S23} = 2 / 6 = 0,3333$
$O_{S13} = 0 / 7 = 0$

Based on (1), datasets S1 and S3 cannot be candidates for first match.

Source dataset reverse size factor:

$RS_{S1} = 1 – (250 / 1750) = 0,8571$
$RS_{S2} = 1 – (500 / 1750) = 0,7143$
$RS_{S3} = 1 – (1000 / 1750) = 0,4286$

Consequently, calculated scores for order of resolution are:

$OR_{S12} = (0,7 + 0,6 + 0,5714 + 0,8571 + 0,7143) / 5 = 0,6886$
$OR_{S23} = (0,6 + 0,3 + 0,3333 + 0,7143 + 0,4286) / 5 = 0,4752$

As the result of the calculation and proposed algorithm, S_1 and S_2 will be matched and merged first, S_{12} will be added and S_1 and S_2 removed from *S* and then S_{12} will be matched with S_3. Example with three datasets and ten attributes, in which are S_1 and S_2 obvious candidates for the first match is trivial, but real-life situation with tens of hundreds of source datasets with hundreds of attributes is not trivial. We have created two Python programs to test our algorithm, first one to generate structure of source datasets and second one for actual algorithm that will use set of randomly defined source datasets from the first program. Authors are not aware of similar existing algorithms that can be used as baseline for comparison. In experiment that will be conducted in later phase of the research, results of the algorithm will be compared with simplified baseline order of resolution based on algorithm elements (completeness or overlap or size). Experiments will be also used to test the need for different weights for factors used in formula (1)

IV. DATA MATCHING

In this chapter we will describe approach for addressing performance issues for scoring by using feature generation and feature selection methods.

As shown in Figure 1, record linkage/data matching is often modeled as a classification problem and requires generating comparison vectors in the form of various similarity scores. Current implementation of feature generation step in existing record linkage/data matching systems [7] is based solely on heuristic rules created and maintained by users. The rules do not adjust to data and might unintentionally miss some important features. Also, redundant features are generated without examination, which consumes computing resources while not improving classification result. We argue that more feature engineering should be added to the general workflow of probabilistic record linkage.

We propose to separate our concerns into two parts. In the first part, we simply generate as much features that we think are important as possible to capture the similarity relationship of semantics of corresponding attribute values. This forms the feature set, and could be in the form of various similarity metrics, or some other measurable features. This will make sure that we don't ignore any important features. In the second part, we compute comparison vectors for the training data (labeled) with the generated feature set, and apply various feature selection methods to keep only effective features. This will eliminate unimportant and redundant features from the feature set, and reduce the number of features we need to generate from candidate record pairs. According to [16], by properly selecting the important features, we could reduce computing resources needed for feature generation while keeping the good result of the classifier.

In the first part, we could generate more complex features based on their semantics by ingesting domain knowledge. For example, to match restaurant reviews [17], we could extract word embedding's of keywords and generate similarity features based on their semantic meanings that supports inferencing such as that "Californian" is more related to "American" than to "French", so that we are more likely to classify two restaurants with type "Californian" and "American" into match than two restaurants with type "Californian" and "French". In the second part, we apply feature selection methods to a sample of labeled data and select a reduced set of effective similarity features which are then applied to all candidate record pairs. In [16], the authors investigated in a number of feature selection methods and performed experiments showing that it is possible to greatly reduce the number of similarity features while maintaining good classification performance.

By separating our concerns in feature engineering of record linkage into two relatively independent parts of feature generation and feature selection, the augmented workflow makes it easier for users to retrieve most important and relevant features for classification. In the feature generation step, complex features are generated to capture as many potential similarity relationships as possible; in the feature selection step, various feature selection methods could be applied to find most relevant and important features to the classifier to achieve competitive classification results with limited computing resources. This twostep feature engineering in record linkage allows flexibility and optimization.

V. DATA MERGE

In this chapter we will describe ideas for standardization of data merge step. First we will discuss structure of matched dataset M from Table 1. Each Source file have attributes that we will denote with D. Source file S_i has source attribute D_j with different value V_{ij} for each record. Assuming that source datasets can also have duplicates, from each source dataset S_i we can have various number of records that will be matched. We will denote number of matching records in each dataset with n_{Si}. In our example, we assume match result that include one record in

S_1 and two records in S_2 and S_3 each, as in Table 3: Number of matching records and attributes:

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1-1	D1S1-1	D2S1-1	D3S1-1	D4S1-1	D5S1-1	D6S1-1	D7S1-1			
S2-1				D4S2-1	D5S2-1	D6S2-1	D7S2-1	D8S2-1	D9S2-1	D10S2-1
S2-2				D4S2-2	D5S2-2	D6S2-2	D7S2-2	D8S2-2	D9S2-2	D10S2-2
S3-1								D8S3-1	D9S3-1	D10S3-1
S3-2								D8S3-2	D9S3-2	D10S3-2

Table 3: Number of matching records and attributes

Each attribute in matched dataset shall be represented as a set of triplets (S_{ix}, D_{jx}, V_{ijx}) that represent ID of the record X from source S_i, ID of the attribute D_j in record x and value of the attribute, where only triplets where Vij ≠ NULL will be stored and considered. Number of possible distinct values of the attribute is $N_V = \sum n_{Si}$

For our example, we have following triplets for attributes D_1', D_4' and D_8':

D1' (exist only in S1)	(S1-1,D1,D1S1-1)
D4' (exist in S1 and S2)	(S1-1, D4, D4S1-1), (S2-1, D4, D4S2-1), (S2-2, D4, D4S2-2)
D8' (exist in S2 and S3)	(S2-1, D8, D8S2-1), (S2-2, D8, D8S2-2), (S3-1, D8, D8S3-1), (S3-2, D8, D8S3-2)

Table 4: Triplets of matched attributes

Note that D_{jx} may be omitted if needed and there are variations of proposed format, i.e. to use only ID of source dataset and number of occurrences of particular value in that dataset. If values of the attribute from the same source are strictly equal, instead of repeating the triple, we can lower number of triples and use number of occurrences instead of attribute ID. Such structure allows for easy update of matched dataset with results of incremental match. Final step in the process is data merge / fusion to create matched dataset M can be done in two basic ways:

1. By using predefined rules for priority as described in literature - accuracy of the data set, most current attribute, most common value, minimum, maximum or average for numerical values [1]
2. By using Truth Discovery Accuracy algorithm [18]

Detailed data merge / fusion strategies will be described in future work.

VI. INCREMENTAL PROCESSING

For incremental processing, we assume that only new and changed data will be processed. We have identified three different basic incremental scenarios, based on data content and rules:

1. New or changed records from each of existing data sets S_i that:
    a. match with existing matched record in dataset M
    b. create new record in dataset M
    c. un-match existing records and create new match in dataset M [18]
2. New dataset S_{n+1} that shall be included in the process that can have any number of attributes
3. Incremental processing depending on changes of matching rules that can become more strict, re-evaluation of existing results [3]

In our framework, we will assume that we will not have options 1.c (un-match of existing match) and 3 (change of matching rules). In cases 1.a and 2 additional triplets will be added to existing sets of triplets. In case 1.b there will be new sets of triplets created. Three supported scenarios will be described in future work.

VII. CONCLUSION

This paper summarizes work in progress related to development of conceptual framework for entity resolution in areas of order of resolution of source datasets, data matching, data merge and incremental processing. In next phases of this research we will focus on experiments related to algorithm described for order of resolution, work on feature selection for data matching process and work on performance and incremental processing issues.

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Map-Matching on Big Data: a Distributed and Efficient Algorithm with a Hidden Markov Model

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***Abstract*—In urban mobility, map-matching aims to project GPS points generated by moving objects onto the road segments representing the actual object positions. Up to now, map-matching has found interesting applications in traffic analysis, frequent path extraction, and location prediction. However, state-of-art implementations of map-matching algorithms are either private, sequential or inefficient. In this paper, we propose an extension of an existing serial algorithm of known efficiency by reformulating it in a distributed way, in order to achieve great scalability on real big data scenarios. Furthermore, we enhance the robustness of the algorithm, which is based on a first order Hidden Markov Model, by introducing a smart strategy to avoid gaps in the matched road segments; indeed, this problem may occur under sparse GPS sampling or in urban areas with highly fragmented road segments. Our implementation is based on Apache Spark and is publicly available on Github. The implementation is tested against a dataset with 7.8 million GPS points in Milan.**

***Index Terms*—map-matching, big data, trajectory mining**

I. Introduction

Following the wide spreading of mobile devices and enhancements in positioning systems, trajectory data (intuitively, a trajectory is a temporal sequence of spatial positions) has gained much attention. Among the plethora of applications suitable for trajectory mining [1], map-matching aims to project possibly-inaccurate Global Positioning System (GPS) points generated by objects moving in urban areas (example shown in Figure 1) onto the road segments representing the actual object positions (example shown in Figure 2). Up to now, map-matching algorithms had interesting applications, such as predicting moving object (MO) locations [2], generating traffic analysis models [3], [4], and uncovering frequent routes [5].

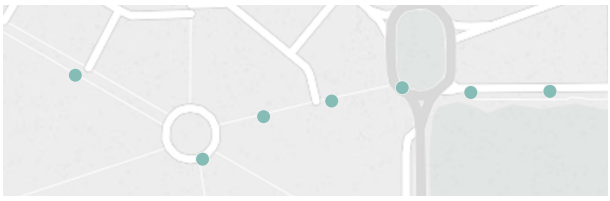

Fig. 1: GPS points of a trajectory in Milan, Italy.

Despite its straightforward applications, map-matching is not easily addressable due the articulated topology of urban networks (parallel roads, roundabouts, road crosses, as seen in Figure 1). Over the years, several models capturing increasingly complex matching features have been proposed. Zehng categorizes four map-matching approaches [1]: geometric (e.g., mapping GPS onto the closest road segment), topological (e.g., mapping relies on local connections of adjacent segments), probabilistic (e.g., mapping is about finding the most likely path under noisy conditions), and advanced (e.g., mappings relies on mixing the above techniques).

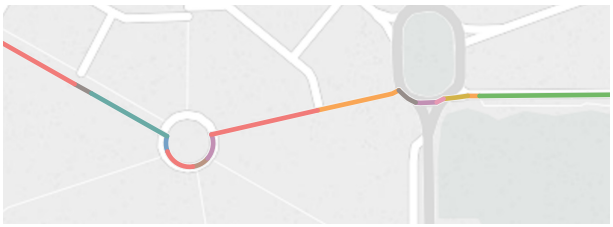

Fig. 2: Sequence of road segments matched to the trajectory in Figure 1; colors represent different segments.

Among the advanced map-matching methods, Luo et al. [6] propose a promising map-matching algorithm based on first-order Hidden Markov Model (HMM) to find the sequence of roads segments with highest probability of being the exact path traveled by a MO. In their experimental evaluation, authors demonstrated that the proposed solution achieves good accuracy performance. However, when it comes to real big data applications accuracy is not all. Indeed, Peixoto et al. [7] introduce a further categorization of map-matching algorithms with respect to sequential and distributed computation. Peixoto et al. highlight that although sequential algorithms achieve high accuracies, they are capable to process only few trajectories at a time. Hence, they do not account for scalability.

In this paper we propose a distributed extension of the sequential algorithm proposed by Luo et al. [6], overcoming its limitations in terms of: (1) distributed, scalable and open-source implementation; (2) higher robustness in case of highly fragmented urban maps; and (3) the inference of MO movement in trajectories with silence periods (i.e., GPS pings are missing or compromised for short time periods). Although distributed algorithms

for map matching do exist, their implementations are either private or less accurate than sequential models. Our implementation is based on the Apache Spark engine [8] and leverages the GeoSpark [9] library. Due to its execution engine and in memory computation, Spark achieves higher performance than Map Reduce [10].

The remainder of the paper is organized as follows. In Section II we introduce the formal background on map-matching and in Section III our distributed implementation. In Section IV we test our algorithm against a real big data case study in the Italian city of Milan. In Section V we discuss a summary of the state-of-art related contributions to our work. Finally, in Section VI we summarize future works to extend our contribution.

II. Formal foundation

A Hidden Markov Model (HMM) is a temporal and finite model that describes a probability distribution over an infinite number of sequences [11]. The HMM is composed of hidden states that emit observable symbols; the goal is to find the most likely sequence of hidden states depending on the observed symbols. The *symbol emission probability* (or simply *emission probability*) determines the probability of a certain state emitting a certain symbol, while the *state-transition probability* (or simply *transition probability*) determines the probability of moving from one state to another. Given an initial state, a *state sequence* is generated by moving from state to state. The sequence of states is a Markov chain, i.e. the transition to the next state only depends on the current state. The state sequence is hidden (i.e., it is not directly observable), while the sequence of symbols generated by the hidden states is observed. One of the applications of HMMs is to uncover the most likely state sequence that generates the observed symbols. Map-matching can be modeled as an HMM, where: states correspond to road segments and symbols correspond to GPS points; the emission probabilities depend on the geometrical relationships between GPS points (i.e., the symbols) and close road segments (i.e., the states), while the transition probabilities reflect topological relationships between consequent segments. Finally, the HMM identifies the optimal sequence of road segments that most likely emits the sequence of observed GPS points. To define emission and transition probabilities of the HMM, we first formalize the concepts of GPS trajectory and road network.

Definition 1 (GPS trajectory): A GPS trajectory T is a temporal sequence of points $\{p_t, p_{t+1}, ..., p_{t+n}\}$ generated by a MO, where each point p_t is a $(latitude, longitude)$ GPS location at time t. The set of GPS trajectories is denoted by $\mathcal{T}$.

Definition 2 (Road Network): A road network is a directed graph $G(V, S)$, where S is the set of road segments connecting the set of terminal points V. A route is a sequence of consequent road segments.

Following the notation provided in [12], let us denote with X_t the index of the road segment in which a MO is possibly located at time t (i.e., $X_t = [1, |S|]$). With a slight abuse of notation, we denote with s_i the i-th segment in S. Then, we define the emission and transition probabilities as follows.

Definition 3 (Emission Probability): Given the set of road segments S, and the MO position p_t at time t, the emission probability $P(p_t|X_t=i)$ is the probability of a state i to generate the observation p_t:

$$P(p_t|X_t=i)=\frac{d_H(p_t,s_i)^{-1}}{\sum_{s_j\in N(p_t,S,\alpha,\tau)} d_H(p_t,prj(p_t,s_j))^{-1}}$$

$N(p_t, S, \alpha, \tau)$ is the operation that returns the *neighborhood* of a point p_t, i.e., the set of α closest segments in S whose distance to p_t is less than a spatial threshold τ; d_H is the great-circle distance[1] between the point p_t and its projection prj to the road segment s_i.

Since road segments are quite dense in urban areas, the road network topology provides constraints to the map-matching process (i.e., a MO cannot "jump" from road one segment to another if they are not somehow connected), thus it should be taken into consideration to define the transition probability. In [6], the authors estimate the (global) average road segment length (i.e., 119 meters) and the (global) average distance between successive GPS pings (i.e., 21 meters) to estimate the transition probability on same road segments (estimated as 3/5), on adjacent road segments (estimated as 2/5), segments separated by one road segment (estimated as 1/5), and 0 otherwise. However, this probability distribution performs poorly on road networks with high variance on segment length (e.g., a road network including highly segmented urban roads and long highway segments) and/or on high variance on GPS sampling rates. Additionally, the higher the resolution of the road network, the worst the transition probability represents the network topology. For instance, a roundabout with 3 exits is modeled with at least 6 segments (i.e., 3 segments for the roundabout and 3 for the outgoing roads). As a consequence, if the sampling between consequent GPS pings is not high enough (e.g., 10 to 20 seconds), then the transition probability assigned in [6] is 0 even if the two points are close but farther than 3 segments in the road network. Thus, while Definition 3 is compliant to [6], we adopt the transition probability from [13].

Definition 4 (Transition probability): Given the set of road segments S, the state-to-state transition $P(X_t|X_{t-1})$ is a $S \times S$ matrix, where $P(X_t = j|X_{t-1} = i)$ is the transition probability from segment i (i.e., the state at time $t-1$) to segment j (i.e., the state at time t)

$$P(X_t=j|X_{t-1}=i)=\frac{1}{\beta}e^{-d/\beta}$$

where

$$d=|d_H(p_t,p_{t-1}) - d_R(prj(p_t,s_j),prj(p_{t-1},s_i))|$$

prj projects p_t and p_{t-1} to road segments s_j and s_i, d_R is the length of the shortest-path between

[1]The great-circle distance is the shortest distance between two points on the surface of a sphere, measured along the surface of the sphere.

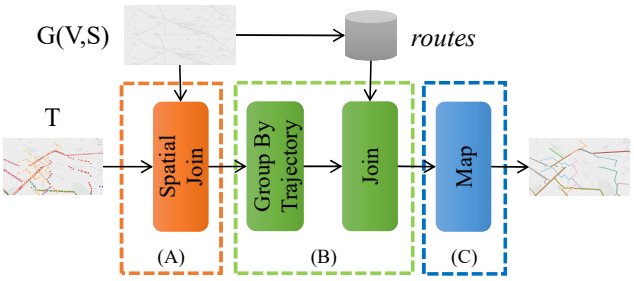

Fig. 3: Main transformations involved in the Map Matching process with respect to steps (A), (B) and (C).

two points, and β is a smoothing parameter [13]. In other words, given two GPS points p_t and p_{t-1}, the transition probability is defined as the difference between the great circle distance between the two points $d_H(p_t, p_{t-1})$ and the road-network based distance between their projections onto segments of the road network $d_R(prj(p_t, s_j), prj(p_{t-1}, s_i))$. In fact, in the actual routes there is typically a small difference between d_H and d_R [13].

The formal definition of the map-matching process is summarized in Algorithm 1.

III. Algorithm Implementation

The algorithm consists of a distributed implementation of [6], which is depicted in Figure 3. The algorithm undergoes the following steps for each trajectory in the dataset: (A) computation of the emission probability, (B) computation of the transition probability, and (C) computation of the result by means of the Viterbi algorithm [14] to infer the optimal sequence of hidden states that generates a sequence of observable symbols. As the Viterbi algorithm map trajectories onto possibly fragmented routes, we embed in this step an aiding process similar to [6]. With respect to the sequential implementation provided in [6], we design the map-matching algorithm in terms of Spark's and GeoSpark's Resilient Distributed Datasets (RDDs) in order to distribute and parallelize the computation of the result for each trajectory.

Our implementation is publicly available at http://www.github.com/big-unibo/map-matching. The adopted versions of Spark and GeoSpark are 2.1 and 1.1.3, respectively.

A. Emission probability

Given a GPS point p_t (i.e., an observable symbol in the HMM), the estimation of its emission probability requires the computation of the neighborhood $N(p_t, S, \alpha, \tau)$ for each point in $\mathcal{T}$. This requires a spatial *range-join* (step (A) in Figure 3), a spatial operation that combines two datasets with respect to their element-wise spatial distance (e.g., finding, for each observed GPS point, the nearby road segments). Note that this transformation is applied to all GPS points in $\mathcal{T}$ independently from the trajectory they belong to, in order to achieve the maximum degree of parallelism. We rely on GeoSpark's spatial RDDs (SRDDs) to distribute and range-join the sets of GPS points and road networks; the result is the set of α road segments closer to p_t than a spatial threshold τ. The efficiency of the spatial operation is affected by τ, as it sensibly reduces the algorithmic search space, whereas α simply determines the size of the output. The setting of these parameters depends on the cluster specifics: the higher τ and α, the greater the number of candidate segments to be considered (and finally returned) for each point.

B. Transition probability

Among S there exist unlikely segment transitions (e.g., segments too far for a correct match, or connected by multiple paths with sensibly different lengths). To lighten the workload, we prevent the computation of transition probabilities that are close to zero (according to Definition 4): given two GPS points p_t and p_{t-1}, we consider as candidate states of the respective points only the road segments that are closer than τ; also, from the list of candidate pairs of segments, we prune those connected by a shortest-route with depth (i.e., the number of segments) higher than θ or a distance on the road network (i.e., d_R) higher than γ. While γ bounds the routes potentially producing transition probabilities close to 0, θ lighten the process of the route creation by preventing the computation of long sequences of segments. Note that the computation of deep routes is necessary in case of highly fragmented urban areas (Figure 2).

To distribute the computation of the transition probability (step (B) in Figure 3), given the result of step (A), we group GPS points by trajectory, we create a sliding window with size 2 on each trajectory (basically, we build pairs of p_t and p_{t-1}), and we compute the transition probability $P(X_t = j | X_{t-1} = i)$ for each pair of candidate segments s_j and s_i, with $s_j \in N(p_t, S, \alpha, \tau)$ and $s_i \in N(p_{t-1}, S, \alpha, \tau)$; note that the information about the neighborhood is kept from step (A). While the estimation of d_H in Definition 4 is straightforward, d_R requires to compute point-wise distance in the road network. To do so, all routes (i.e., sequences of road segments) in $G(V, S)$ with a maximum distance of γ and a maximum depth of θ must be computed; then, d_R is obtained by finding the shortest route for each s_j and s_i pair. Interestingly, as the routes only depend on $G(V, S)$, they can be computed once, persisted in the distributed file system, and then retrieved on demand.

C. Viterbi computation

For a trajectory T with $|T|$ GPS points, we could naively compute $S^{|T|}$ sequences to find the optimal route generating the observed GPS points. However, this solution has an exponential complexity. The Viterbi algorithm is a recursive (optimal) estimation of the state sequence of a time-discrete Markov process [14] (i.e., a sequence of events in which the probability of an event depends only on the state of the previous event) with a polynomial complexity $O(|S|^2|T|)$.

Algorithm 1 Map-Matching Algorithm

Require: T: trajectory, $G(V,S)$: road network, β: prob. smoothing, α: nearest neighbor card., τ: spatial thr., γ: max. route distance, θ: max. route depth
Ensure: M: map-matched trajectory
$routes \leftarrow$ routes of max. distance γ and max. depth θ ▷ pre-computed to determine d_R in transition prob.
$I \leftarrow 1/|S|, \forall s_i \in S$ ▷ All segments are equally probable to p_0
$O \leftarrow P(p_t|X_t=i), \forall p_t \in T, \forall s_i \in N(p_t,S,\alpha,\tau)$ ▷ emission prob. vector
$R \leftarrow P(X_t=j|X_{t-1}=i), \forall p_t,p_{t-1} \in T, \forall s_j \in N(p_t,S,\alpha,\tau), \forall s_i \in N(p_{t-1},S,\alpha,\tau)$ ▷ transition prob. matrix
$M \leftarrow Viterbi(S,T,I,R,O)$ ▷ Viterbi (state space; trajectory; transition, initial, and emission prob.)
return M

The Viterbi algorithm returns the sequence of road segments (i.e., a route) that, with the highest likelihood, generates the observed GPS trajectory (step (C) in Figure 3). The input parameters required by the algorithm are: the trajectory T; the segment (i.e., state) space S; the emission probability matrix O (computed for each point as in Definition 3); the initial probability vector I, where $|I| = |S|$ and $I_i = 1/|S|$ for each segment in S (we consider all the segments equally probable with respect to the initial GPS point); and the transition probability matrix R (computed for each pair of consequent trajectory points as in Definition 4).

Intuitively, applying the Viterbi algorithm to T, returns the route onto which T is map-matched by associating to each GPS point an optimal road segment. However, there is no insurance of consequent GPS points being mapped to adjacent road segments, possibly resulting in fragmented optimal routes. We embed in the Viterbi algorithm an aiding process to fill the gaps. In each iteration over two consequent points p_t and p_{t-1}, if the shortest route between the mapped segments s and s' is shorter than γ and has a smaller depth than θ, we map p_{t-1} also to all the segments included in the shortest path between s and s'. To do so, we leverage the possible route that have been pre-computed as in (B). With respect to [6], the advantage of embedding the aiding process in this step of computation (rather than after computing Viterbi) prevents an unnecessary further iteration on the map-matched trajectories.

The computational complexity of the Viterbi algorithm can be tackled down by addressing both $|T|$ and $|S|$. As to $|T|$, reducing the trajectory length requires a simplification process that is applicable before the map-matching process (hence is out of the scope of this paper). As to $|S|$, the segment space can be sensibly pruned assuming that, among all the roads segments in S, only the segments close to the observed points contribute to the matching process with a non-null probability. For each point p_t, we only consider the candidate segments in its neighborhood $N(p_t,S,\alpha,\tau)$, where α (i.e., the number of retrieved neighbors) constrains the Viterbi search space).

Finally, rethinking the Viterbi algorithm is a distributed environment is not straightforward due to its recursive nature. In this paper we limit to apply Viterbi in a *bag-of-task* fashion, i.e., executing the algorithm to concurrently map each trajectory onto its road network projection (step (C) in Figure 3).

Feature	Value
GPS points	$7.8 \cdot 10^6$
Trajectories	$12 \cdot 10^4$
Avg. trajectory points	65 ± 42
Avg. ping distance (meters)	99 ± 55
Avg. sampling rate (seconds)	7 ± 6

TABLE I: Summary of the dataset features

IV. Evaluation

In our contribution, we engineer the sequential algorithm proposed in [6] in terms of a distributed paradigm. Note that, while the distributed implementations described in Section V approximate the sequential map-matching algorithms, we entirely preserve the accuracy of the implementation proposed in [6]. Although the setting of the parameters does have an impact on the accuracy, the lower bounds that we consider (with reference to Table II) are higher than the values defined in [6], thus guaranteeing the same minimum accuracy. For this reason, the evaluation of our implementation is focused on the efficiency on big data in a real case study. We run our test on a cluster composed by 11 nodes, each equipped with an 8-core i7 CPU @ 3.60GHz and 32 GB of RAM and interconnected by Gigabit ethernet.

A. Dataset

We test our implementation against a real-case study scenario in the Italian city of Milan. The dataset includes 120,000 trajectories ($\mathcal{T}$) that contains an average number of 65 GPS points (resulting in an overall number of 7.8 million of GPS points). The distance between consequent GPS points is on average of 99 meters, and the average sampling rate is of 0.14Hz (i.e., 7 seconds). These values, with their respect variances are summarized in Table I.

Our dataset includes ground truth on 50 trajectories. Ground truth data is leveraged to test the accuracy of the algorithm with respect to α, τ, γ, θ. In addition, we used the 50 trajectories to estimate $\beta = 10$ (as required by [13]).

B. Efficiency

To evaluate our implementation in terms of efficiency, we first measure the impact of each parameter on the execution times of the different steps of the algorithm.

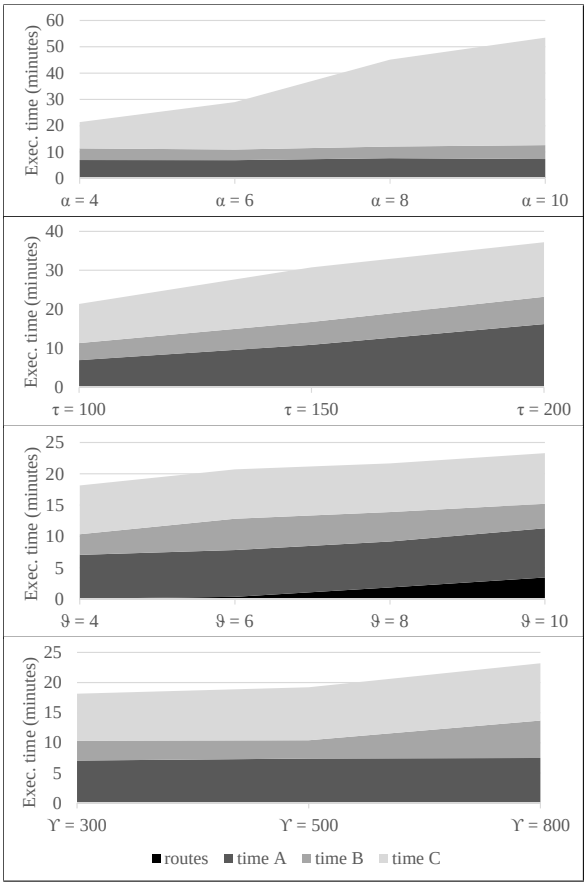

Fig. 4: Execution times of the different steps of the algorithm under different parameter settings; when not specified, it is $\alpha = 4$, $\tau = 100$, $\theta = 4$, and $\gamma = 300$.

We exploit the metrics of Spark's web GUI to obtain the execution times of the pre-computation of the routes and the computation of steps (A), (B) in (C). We start from a base configuration where all parameters are valued at their minimum and, for each parameter, we progressively scale its value up to its maximum. The results (shown in Figure 4) reveal that each parameter impacts only on one of the algorithm's steps. Increasing α means producing more candidate segments for each GPS points, thus increasing the complexity of Viterbi (step (C)). A higher value of τ augments the search space of the spatial join to calculate the emission probability (step (A)). Parameter θ increases the complexity of the pre-computation of *routes*; however, since γ is limited to 300, the depth of the *routes* does not actually increase, thus not producing on effect on step (B). Conversely, a higher value of γ produces a greater number of *routes*, which increases the computation of the transition probability (step (B)).

Finally, we evaluate the performance of the algorithm with respect to the computational power of the cluster and the number of trajectories in the dataset; the results are shown in Figure 5. In the first case, we scale the number of worker nodes from 1 to 10. The results demonstrate that the algorithm effectively takes advantage of the higher levels of parallelism, reducing the execution times

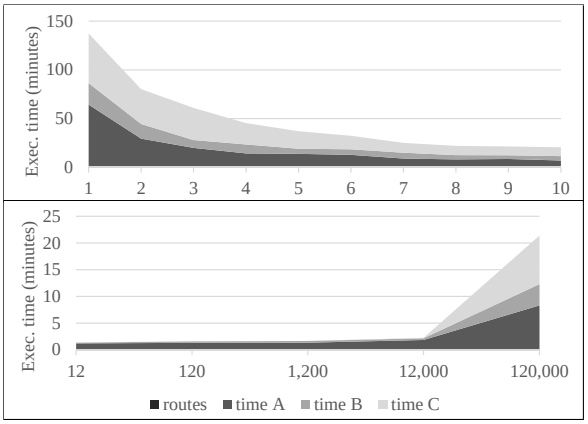

Fig. 5: Execution times of the different steps by scaling the number of worker nodes (up) and the number of trajectories (down).

Parameter	Value	Meaning
β	10	Probability smoothing
α	$[4, 10]$	Candidate segments
τ	$[100, 200]$	Neighborhood thr. (meters)
θ	$[4, 10]$	Route max. length
γ	$[300, 800]$	Road network distance thr. (meters)

TABLE II: Input parameters; range values are empirically determined

from more than 2 hours to as low as 20 minutes. Consistently with Amdahl's law [15], the speedup is bounded by the serial part of the program and converges to 7x with respect to the sequential execution[2]. Lastly, scaling on the number of trajectories shows that execution times increase linearly with number of trajectories in the last step. The same behavior is not observable in the previous steps due to the overhead of the parallel execution framework, which hides the actual workload times.

V. Related Works

In this section, we categorize map-matching related contributions with respect to their sequential and distributed natures.

As to sequential implementations, in [16], Lou et al. introduce "ST-Matching" to handle GPS trajectory data at low sampling rates. The idea is to generate all the possible candidate routes on the map and to identify the-most-likely one by calculating spatial and temporal probabilities. However, this approach is particularly sensitive to noise, as common errors in positioning systems lead to the identification of erroneous paths. Newson et Al. [13] address this problem by adopting a first-order HMM that models the connectivity of the road segments and considers multiple path hypotheses. Further accuracy enhancements are obtained by Lou et al. [6] by leveraging a formulation based on HMM in which emission and transition probabilities depend respectively on geometrical and topological information. Authors leverage the

[2]For the fairest comparison, the original sequential implementation should be considered; unfortunately, however, the authors of [6] have not made the code publicly available.

Viterbi algorithm to extract the route that most likely generates a sequence of observed GPS positions. When estimating the state transition probability, the topological information on road segments enhance the matching with a sampling rate up to 0.1Hz (10 seconds).

With the rise of big data, distributed implementations have aimed to optimize the performance of existing map-matching algorithms. However, the sequential nature of these algorithms hinders a trivial reformulation on a distributed environment. For this reason, a recurring problem in distributed implementations is the trade-off between accuracy and efficiency, which is usually in favor of the latter. Almeida et al. [17] leverage the spatial probability from the ST-Matching algorithm [16] and provide a map-matching implementation in the MapReduce paradigm [18]. However, they do not take into account the latest enhancements in terms of HMM and road topology. Zeidan et al. [19] and Peixoto et al. [7] introduce new algorithms that best exploit the characteristics of a distributed environment. In particular, both contributions rely on the construction of spatial indexes that enable an effective partitioning of road segments and trajectories, with the goal to minimize the amount of shuffled data between the cluster nodes. Although these contributions focus on the scalability to big data applications, they usually approximate exact sequential algorithms and lack a sound accuracy comparison against sequential approaches to map matching (whose good accuracies are well known in the literature). Finally, several spatial libraries (e.g., GeoSpark [9], SpatialSpark [20], etc.) have been built on top of Spark's RDD [8]; however, none of these directly addresses map-matching, as they only provide spatial indexing and querying.

VI. Conclusion and Future Directions

We engineered a Spark-based distributed map-matching algorithm inspired by the sequential implementation provided by Luo et al. [6]. Our algorithm entirely preserves the accuracy of the sequential implementation (which, to the best of our knowledge, achieves a higher accuracy than the existing map-matching algorithms) and it has been tested on a real dataset of 120,000 trajectories (for a total of 7.8 millions GPS points). Also, we overcome the limitations of [6] in case of highly fragmented urban networks. As a future direction, our goal is to address map matching in big-data scenarios with high variance in means of transportation (e.g., car, walk, bicycle), sampling rates (e.g., from seconds to minutes), and road networks (e.g., extending the map-matching from Milan to the entire region Lombardia).

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Structuring the information resources for intelligent ecosystem monitoring system based on camera traps

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Monitoring of animals in the wild using camera traps is one of the promising ways for monitoring animal behaviour and estimation of dynamic of changes in natural systems over the large areas. The installation of camera traps in a predefined place such as animal shelters, trails, watering places provides unique information that is not available by applying other monitoring methods. Present, a lot of methods and algorithms have been developed that allow us to recognize the natural images taking into account the variability of shooting conditions, illumination, location and posture of the animal, as well as a complex textural background, representing various states of the forest, steppe, mountain and tundra landscapes. This paper presents the results of analysis and systematization of monitoring data from images obtained on the protected natural territories in the Krasnoyarsk region. The authors propose the special structure of a centralized data warehouse for an intelligent ecosystem monitoring system. The structure of the data warehouse combines historical, operational and reference data. The content of structural elements of the data warehouse is described in detail. The developed data warehouse combines monitoring data from different sources and makes up a united informational resource for further data processing and solving analytical tasks of environmental monitoring.

Keywords – camera traps; data warehouse; special structure of data; intelligent ecosystem monitoring

I. INTRODUCTION

One of the main purposes of the organization of specially protected natural areas is the study and conservation of biodiversity, the regulation of influence of human activity on the ecosystem. Vast areas of protected territories make it difficult to monitor wild animals and birds by traditional methods. Estimation of the number, species composition and other characteristics based on periodic raids, with an investigation of animal traces, their behaviour, is quite costly, and the obtained results are usually subjective and unreliable. The application of camera traps which record animal events around the clock allows us to get information that is inaccessible to other monitoring methods. Modern video recording tools operate 24/7/365, many of them produce a set of still images of a moving object (e.g. animal, bird or human) in 5-8 seconds while other devices deliver a short movie [1].

The data of camera traps installed in the most likely places of animals such as trails and watering places provide unique information about the state and dynamic of the ecosystem development [2].

Krasnoyarsk region is the second largest federal subject of Russia and the third largest subnational governing body by area in the world. Krasnoyarsk region lies in the middle of Siberia and occupies an area of 2,366,797 square kilometres. The fifth part of the region is outside the Arctic Circle. Krasnoyarsk region is one of the most unique corners of our planet including marine, terrestrial and freshwater biomes. The northern part of the region is dominated by arctic deserts and tundra, the southern part is mostly forest-steppes, more than 70% of the territory is occupied by Taiga. The fauna of this part of Siberia is incredibly rich; the species diversity varies depending on the climatic zone. More than 400 species of birds, over 90 species of mammals inhabit the region territory. However, due to human activity many of them are endangered [3]. In the Krasnoyarsk region, there are 111 specially protected natural territories with a total area of 14,577 thousand hectares [4]. These territories are experiencing a huge anthropogenic load: dozens of people visit the "Putorana" plateau in the "Bolshoi Arctichesky" nature reserve annually, hundreds of thousands of tourists and athletes visit the "Ergaki" nature park, the "Stolby" nature reserve is located within the metropolis and is a favourite resting place for residents and guests of the city.

Currently, as a result of the operation of camera traps, huge amounts of visual information have been accumulated. Therefore, analyzing the images and forming united information resources to create an intelligent monitoring system of ecosystem are topical tasks. At the stage of image analysis, it is necessary to solve such issues as recognizing an event from a series of snapshots, filtering non-informative frames and identifying objects of observation by type, age and individuals. The parametric description of images represents the basis of ecosystem monitoring data. Comprehensive data processing requires to be developed a united informational resource based on systematization, consolidation and centralized storage of monitoring data. The application of modern technologies and methods of analysis to monitoring data will allow detecting new knowledge to study the patterns and characteristics of the state and development of ecosystem.

This paper discusses the basic approaches and methods of image analysis from camera traps. The authors systematize the monitoring data and propose the special structure of the centralized data warehouse of ecosystem monitoring that combines historical, operational and reference data. They filled the warehouse with data obtained from image analysis. The content of the structural elements of the data warehouse is described in detail.

II. PROCESSING THE VISUAL MONITORING DATA

Places for installation of camera traps are selected taking into account the monitoring tasks and the possibility of obtaining the most informative data about animals and birds that live in protected natural areas based on long-term observations [5]. The limited resources and the large extent of the territories of reserves and natural parks do not allow simultaneously covering all habitats of the studied species with a network of camera traps. As a rule, the devices are installed for a long time, during which, based on the analysis of the images, the decision is made either to continue the observations or to move the cameras to a new location [6]. Location of the camera traps and their technical characteristics present critical conditions that affect image recognition. For example, the cameras with a narrow-angle of capture (i.e. 45 degrees and less) allow us to take close-ups of an animal and determine the individual characteristics. Apart from this, large animals (e.g. ungulates, predators) have a permanent habitat for most of the year, so long-term monitoring of feeding places allows us to estimate the number of populations and their movement.

Attribute data of snapshots also provide important information for analysis. For example, the date and time of recorded files give us an opportunity to make a conclusion about the distribution and duration of device operation. Photographing and video recording occur when the motion sensor is triggered, so the volume of series of images may indicate an animal's activity or false triggering of the device (i.e. movement of vegetation during the wind, heavy rainfall, etc.). As practice shows, the number of non-informative images is quite large – from 25% to 75% [7, 8]. Therefore, it is important to provide the ability to automatically exclude "empty" images from further image processing.

In this research, image processing was performed based on the following techniques.

Identification of informative images from a series of large-size snapshots (5-12 Mp) taking into account the constantly changing lighting and weather conditions was performed using the "fast algorithm" described in the works [9, 10]. This algorithm to detect motion uses a modified overlap block mapping method. Initial images are converted to the "grayscale" type and for each of them an integral image is calculated, in which the pixel value with coordinates (x, y) is equal to the sum of the pixel values of the original image located above and to the left of the point (x, y) including this point. The integral image allows us to get the sum of the pixel values of a rectangular area of arbitrary size in constant time, which reduces the computation time. Comparison of the illumination of pixels in blocks of several images separated by a grid and their deviation from the calculated integral values provides processing up to 100 images per minute with an accuracy of determination of 94% [11].

Elimination of local inhomogeneity of illumination of objects of the observed scene was performed using the image enhancement method based on Retinex technology. [12]. This Method represents a modification of the Multi-Scale Retinex in the HSV colour space, where the wavelet transform is used to speed up the computation [13]. The wavelet transform divides each signal into two components of equal size – approximation and detail, which reduces the number of artefacts associated with high local contrast of the original images, as well as, if necessary, increase the contrast. This way of forming the resulting image allows us to generate the desired distribution relative to the target brightness level. Application of a segmentation contour model allows us to solve the problem of variability of shooting conditions, light, location and posture of the animal.

Automatic extraction of the required information from visual data was implemented based on the synthesis of two approaches. The first one is based on traditional processing using a spatial pyramid of images, searching for descriptors and local binary patterns with the subsequent classification of support vectors. [2]. The second approach is based on the use of convolutional neural networks [14], where a binary classifier (i.e. there is an animal / no animal) is used to classify images with subsequent training of ConvNet for animal species, the probability of which, according to expert estimates, is maximum [15].

One of the most difficult problems in object recognizing is a complex textural background. Most of the protected areas of Siberia are located in the zone of dark-coniferous taiga and mixed forest. Shooting in the highlands and in the Arctic zone is also carried out in non-ideal conditions with varying light conditions.

Background extraction on images was performed using the method proposed in work [16] that presents a modified model of a mixture of Gaussians. The modification consists in truncating the pixel values to reduce the dependence on changes in illumination and the presence of shadows with the creation and processing of binary masks instead of real values of intensities. This method is aimed at estimating the background of natural scenes in reserves and national parks. Structural elements, such as trunks of growing or fallen trees, are considered as the regions that change slowly over the seasons, while other textured areas are modelled with texture patterns corresponding to the current season. This approach provides a compact background scene model. In addition, the influence of temporal (seasonal) meteorological attributes of the scene regarding the possibility of its restoration is taken into account. The modified model provides object recognition accuracy of 79-83% at daytime and 60-69% at night for normal meteorological conditions. At the same time, the accuracy of the reconstructed images obtained for bad meteorological conditions is reduced by 5-8%. Figure 1 shows examples of object recognition results.

After pre-processing of images (i.e. eliminating noise and primary selection of objects), images were analyzed using a neural network [14]. As a result, a table of the parametric description of images was created; it contains the characteristics of the observed objects including the type of animal, its gender, age and behaviour. Taking into account the quality of the original images, the neural network allows us to identify the individuals by unique features (e.g. the shape of horns, the size and position of colour spots) and morphometric characteristics. Such data enable us to estimate the number of individuals living in the study area and determine the nature of their migration. [5].

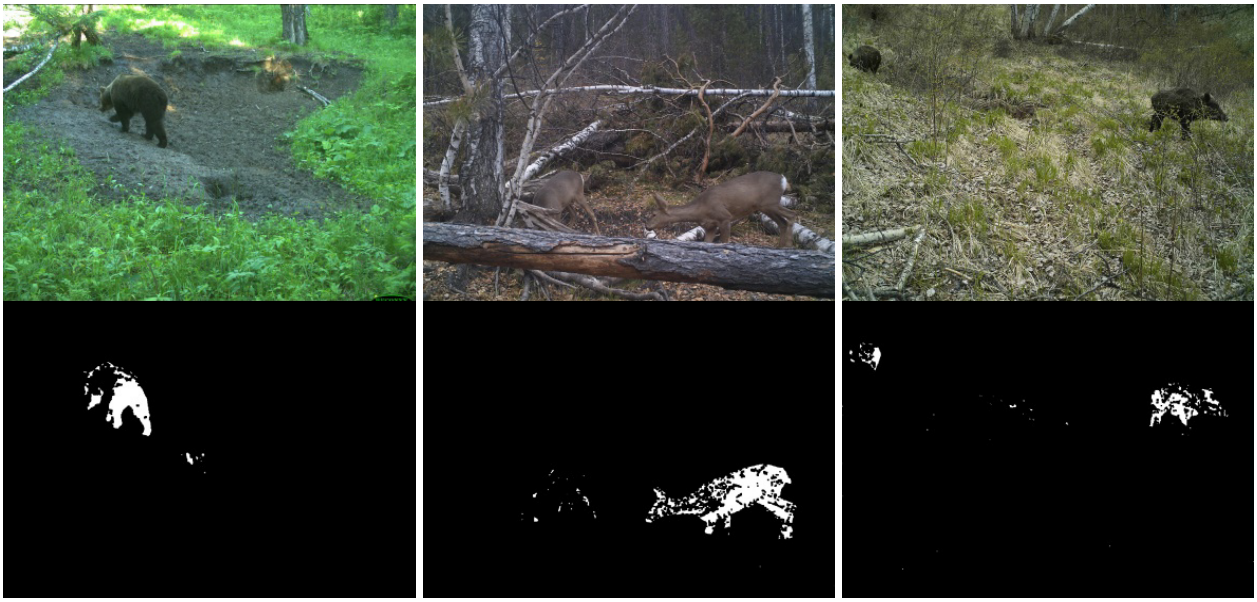

Figure 1. Initial data (top line) and pattern recognition results on the camera trap images (bottom line)

III. DATA WAREHOUSE OF MONITORING DATA

The opportunity of expanding the monitoring fields and the efficiency of solving analytical tasks require the consolidation of monitoring data, automation of data loading and organization of data access, as well as reduction of time for searching and processing data. Data warehouse technology provides the availability, consistency, storage of large amounts of data and the efficiency of analytical queries [17].

The storage schema in data warehouse defines the opportunity to apply such modern technologies as OLAP, Data Mining and Machine Learning. In this research for creating an intelligent monitoring system of ecosystem in the Krasnoyarsk region, the authors systematized the monitoring data obtained from camera traps and developed the special structure and filled the centralized data warehouse which combines historical, operational and reference data.

Depending on the specific features of the domain, the structure of the data warehouse includes three basic layers:

- layer of stationary storage that contains the main part of monitoring data and consists of facts tables and dimensions tables
- layer of analytical objects that contain the analytical models which are used for on-line analytical processing, the aggregates tables and reports
- layer of pre-loading processing that provides loading and preliminary data processing and contains data sources, import and export procedures and temporary tables.

Figure 2 shows the structure and content of the data warehouse elements for ecosystem monitoring. The management of storage structure and data filling are implemented using the special tools of the data warehouse management system developed in the Institute of computation modelling SB RAS [18]. The tools of this system allow us to create storage schemes, data sources, import and export procedures, facts and dimensions tables. Apart from this, they enable to create OLAP-models, form and save analytical reports by applying such visualisation means as tables, charts and maps.

Let us consider the structural elements of the data warehouse in detail.

Connections. This section contains information about the data scheme. The software applied to manage data warehouse allows us to work with various DBMS. In particular, Oracle and PostgreSQL are used for the formation and processing of information resources for ecosystem monitoring.

Stationary storage. This section contains historical, operational and reference data necessary for processing and analysis.

The “Fact Tables” subsection contains monitoring data. Photographs and video materials obtained from camera traps and metadata with attribute information of the source files are stored here. Also, it contains tables of parametric data obtained as a result of image processing. You can see the structure of these tables on the right side

of Figure 2. The location of the camera traps is used to develop environmental maps of protected natural areas; time of snapshot allows grouping them by series, select night images for setting recognition methods. The content of the fields "Animal", "Number" and "Description" depends on the quality of the original image and the effectiveness of image processing. In the case of false alarms of camera traps, these fields remain empty and the records are excluded from storage. Currently, the primary images from cameras have been collected from five basic protected territories of the Krasnoyarsk region that are placed in separate tables.

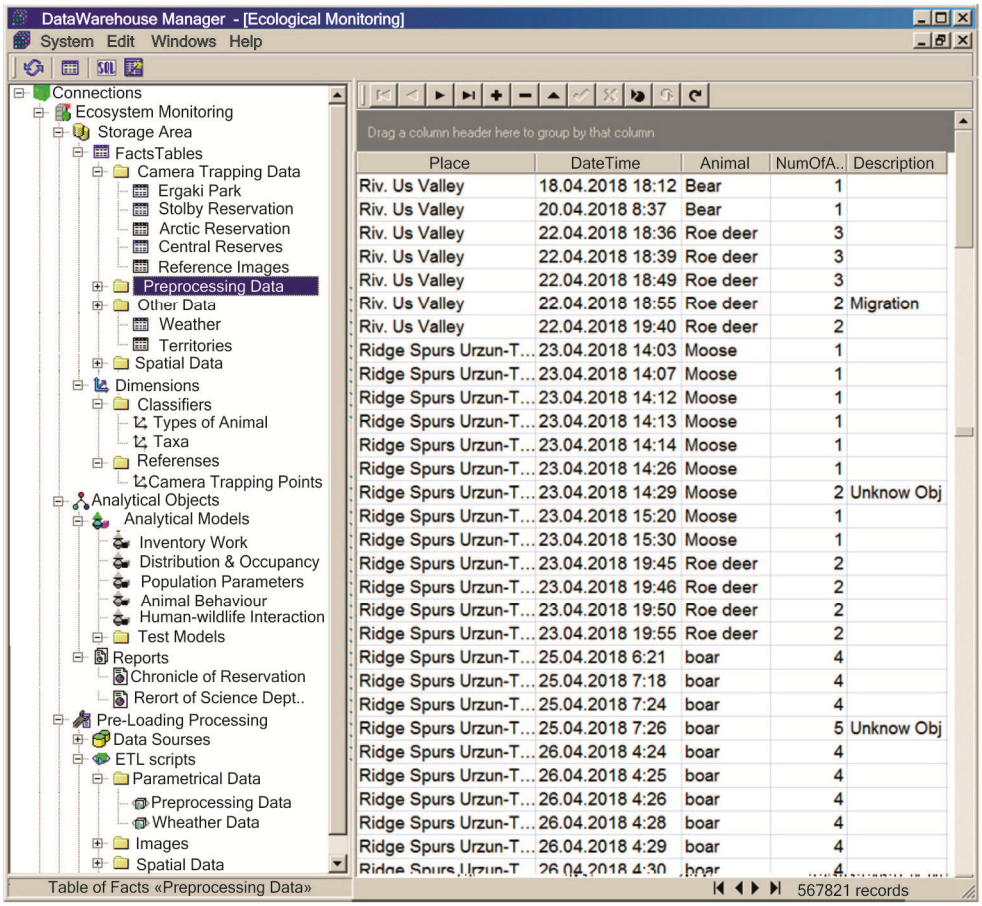

Figure 2. Structural elements of a specialized data warehouse of ecosystem monitoring

In addition, for comprehensive analysis of monitoring data, some parametric data are used. For example, meteorological data is imported into the data warehouse from two sources: the air temperature recorded by the cameras at the time of the shooting enters the tables after image processing; precipitation, wind, pressure and clouds come from the nearest weather stations four times a day. Also, the sunrise and sunset data calculated for all days of the year of each geographic latitude (according to camera location) are used in the light analysis process from open access resources. Besides environment data, parametric monitoring data obtained by GPS trackers, radio tracking and the results of analysis of biomaterial samples come to the zone of stationary storage [19].

For the cartographic presentation of the results of monitoring data analysis, the data warehouse contains spatial data, which consist of a digital topographic base of 1: 100,000 scale and thematic layers of protected natural territories. The content of the spatial data bank is considered in the paper [20]. For ecosystem monitoring the raster maps M1: 50,000 and M1: 25,000 are applied, prepared using QuantumGIS tools and public territory maps from official sites of nature reserves [21].

The “Dimensions” subsection contains references and classifiers for analysing monitoring data. Classifiers of animal types and taxa are compiled based on literature and environmental monitoring methods. The composition and number of classifiers are determined by the type of analytical tasks.

Thus, the primary content of the data warehouse for ecosystem monitoring includes 12 facts tables and 3 dimensions tables.

Analytical objects. This section contains OLAP-models that provide comprehensive data processing and solving the following analytical tasks:

- species registration. Identification of species of animals taking into account the morphological characteristics based on data about the attendance of feeding sites and water bodies.
- habitat definition. Identification of the migration fact of large animals living in a certain part of the territory

(e.g. bears live and carefully guards their own territory). Comparison of long-term data about habitats, weather conditions and food supply capacity.
- abundance and density. Analysis of the number and offspring survival of female ungulates and other large mammals in the in-patient period and after calving.
- behaviour. Control of feeding regimes of rare bird chicks; assessment of the effect of disturbance by indirect evidence (e.g. time and duration of visiting solonetz). [22]
- interspecific interactions. Assessment of the ecosystem balance, food supply capacity, nature of migration based on the number of predators and their potential victims.
- human interaction. Evaluation of threats and the impact of the human factor on the development of biodiversity of ecosystem according to the long-term record of an anthropogenic load of protected territories.

A set of OLAP-models (e.g. Inventory Work, Population Parameters, Animal Behaviour) was developed during this research which makes it possible to assess the state of biocenoses and understand the natural and technogenic threats that is important for planning biodiversity conservation activities.

Pre-loading processing. This section contains a description of data sources, download packages, import and export procedures that provide the data consolidation from different sources. Ecosystem monitoring data is collected from camera traps files, local databases and web resources. Information resources are updated automatically according to the schedule. In the case of a change in the structure of the data source, the data warehouse management system allows you to customize parameters, for example, set the fields of the source tables and the data warehouse, establish communication with classifiers, and generate a report about the loading.

Thus, the developed centralized data warehouse combines data from various sources, forming a united information resource for further processing and solving analytical problems of ecosystem monitoring in the Krasnoyarsk region based on camera traps data.

IV. CONCLUSION

Video and photo camera traps installed in specially protected natural territories represent a source of unique information about the state and development of ecosystem. The analysis of the accumulated images and the formation of united information resources are topical issues for the creation of ecosystem monitoring systems.

This paper presents the results of multi-stage processing of visual monitoring data of the Krasnoyarsk region ecosystem. The basic approaches and methods of image analysis and parametric data extraction are considered here. The authors systematize the monitoring data and propose the original structure of the centralized data warehouse that combines historical, operational and reference data. The authors completed the first filling of the warehouse with data obtained as a result of image analysis, developed a set of OLAP-models and prepared some analytical reports for assessing the state of the ecosystem. The content of structural elements is described in detail. The developed centralized data warehouse consolidates data from various sources, forming a united information resource for further processing and solving analytical problems of ecosystem monitoring.

Future research will be a focus on filling the data warehouse, according to the proposed structure, and analytical processing of monitoring data. Long-term monitoring and analysis of accumulated data using modern methods will allow us to obtain new knowledge about the state and dynamic of the ecosystem and develop effective measures for conservation of biodiversity in specially protected natural areas of Siberia.

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Detecting Credit Card Fraud Using Selected Machine Learning Algorithms

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***Abstract* - Due to the immense growth of e-commerce and increased online based payment possibilities, credit card fraud has become deeply relevant global issue. Recently, there has been major interest for applying machine learning algorithms as data mining technique for credit card fraud detection. However, number of challenges appear, such as lack of publicly available data sets, highly imbalanced class sizes, variant fraudulent behavior etc. In this paper we compare performance of three machine learning algorithms: Random Forest, Support Vector Machine and Logistic Regression in detecting fraud on real-life data containing credit card transactions. To mitigate imbalanced class sizes, we use SMOTE sampling method. The problem of ever-changing fraud patterns is considered with employing incremental learning of selected ML algorithms in experiments. The performance of the techniques is evaluated based on commonly accepted metric: precision and recall.**

Keywords - credit card fraud detection, machine learning, class imbalance

I. INTRODUCTION

In today's ever-growing global society, the issue of committing a fraud has become more relevant than ever. One of the areas that has experienced immense growth is e-commerce. Due to the increased number of possibilities in making payments of any kind and their easiness of use, e-commerce business establishments gained user confidence. Unfortunately, increased number of users followed by increased revenue makes them vulnerable to fraudulent behavior. In 2016, total value of card fraud using cards issued in Single Euro Payments Area (SEPA) was €1.8 billion, 0.041% of total value of card transactions made. Card fraud increased in terms of volume by 92% compared with 2012 [1]. Most common card fraud types are application fraud, lost or stolen card, account takeover and counterfeit cards [2]. Fraud caused by obtaining physical card or falsifying one by using counterfeit data is of less interest in the context of credit card fraud detection (CCFD) tools and analysis of cases of fraud. The reason being is that the majority, of all fraudulent transactions made are card-not-present (CNP) fraud (i.e. 73% in 2016). In CNP scenario, credit card information is obtained without the knowledge of card holder and is used remotely in attempt to commit fraud [3].

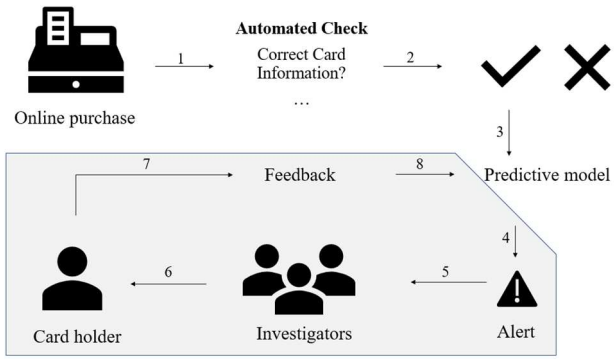

Figure 1 Typical credit card fraud detection scenario

Fraud detection assumes identifying fraud as quickly as possible once it has been committed. Methods for detecting fraud are continuously adapting to everchanging fraud strategies. Presently, fraud detection has been implemented by several methods such as statistics, rule engines, artificial intelligence and data mining. Fraud detection occurs on different levels, in terms of time expired from the occurrence of the single transaction. As shown in Figure 1, first level is automated card validation, which is performed in real time, for the benefit of user satisfaction. If a card is not rejected, transaction goes through the second level, denoted as *Predictive model*. Throughout the past decade, there has been increased interest in applying machine learning as a data mining approach for second level of credit card fraud detection [4].

The second level takes place in respective amount of time after transaction is made [5]. Automated part of the second level, predictive model, discovers fraud from anomalies in data and patterns. For the suspicious transaction an alert is raised which then requires human expert intervention. The shaded part in the Figure 1. happens only for those transactions. After examining detailed transaction data and, in some cases, contacting card holder, investigators decide whether the transaction is fraudulent or not and provide feedback in order to improve the accuracy of the used predictive model [6].

Solving fraud detection problem with data mining technique boils out to classifying transactions to one of the two categories: fraud or nonfraud. Classification is a data mining method that assigns items in a collection to target categories or classes. The goal of classification is to accurately predict the target class for each case in the data.

The simplest type of classification problem is binary classification where the target attribute has only two possible values [7]. Credit card fraud detection is, in fact, binary classification problem. This paper implements supervised machine learning algorithms for classification of a credit-card transaction as either fraudulent or not-fraudulent.

The rest of this paper is organized as follows. In Section 2, the challenges concerning credit card fraud detection as well as some of the state-of-the-art solutions for individual challenge are described. Section 3 introduces required concepts and proposed setup. Section 4 gives all the details about performed experiments. Finally, the paper ends with conclusion and future works.

II. CHALENGES IN CREDIT CARD FRAUD DETECTION

A. Data defficiency

Essentially, the biggest problem in dealing with CCFD scientifically is that real data is hardly ever available for exploration, due to the issue of confidentiality [8]. Nevertheless, researchers are not discouraged by this obstacle given the fact that they can often carry out scientific work in cooperation with respective industrial partner, provider of the data. Also, some suggest using synthetic data which simulates dataset of transactions [9].

B. Imbalanced data

As mentioned earlier, on the global level fraudulent transaction are amounted to less than 0.05% of the total transactions. This ratio is detained in the distribution of any credit card fraud dataset, resulting in highly imbalanced classes [10]. If this problem had not been taken into consideration, any machine learning algorithm that classifies correctly only genuine transactions would perform outstanding, with accuracy level above 99%, disregarding the fact that all the minority class transactions are classified falsely. There are possible solutions to this problem both at data and algorithmic level. We will focus on data level further on. Data level methods, such as oversampling and under sampling, alter the size of the dataset used for training. While the level of imbalance is reduced, problems of overfitting and ignoring useful data appear, respectively [11]. Possible improved approach is using one-sided selection methods focusing on removing some outlier or noisy majority class examples to decrease the disproportion between classes [12]. Outlier is an extreme data value that does not come from the typical population of data. In a normal distribution, outliers are typically at least 3 standard deviations from the mean [7]. Example of another complex sampling method is SMOTE, which oversamples the minority class generating synthetic examples by interpolating k minority class nearest neighbors [13]. Through this process the classifier builds larger decision regions that contain nearby examples from the minority class, which has shown improvements in application.

C. Behavioral variation

Fraudulent behavior tends to alter over time in order to avoid detection. Therefore, CCFD predictive model should not be static, i.e. constructed once and never updated [8]. In terms of machine learning, this problem is known as concept drift. It occurs during learning in nonstationary environment and manifests in changes in underlying data. Known methods used for overcoming this problem are adaptive base learners and ensembles [14]. Adaptive base learners have a drift detection mechanism that updates the current model when the drift is detected while ensembles have natural ability to simultaneously retain relevant information and acquire new knowledge [15]. In terms of CCFD, ensemble techniques are widely used [8], [15], [16].

D. Cost sensitive problem

CCFD is a cost sensitive problem, meaning that the cost produced by misclassifying genuine transaction (false positive) is different than the cost of misclassifying fraudulent one (false negative) [5]. When a CCFD system marks a genuine transaction as fraudulent, the financial institution has a measurable cost of employee engagement for examining and arbitrating the status of suspicious transactions and the immeasurable cost of customer dissatisfaction. On the other hand, failure to detect a fraudulent transaction (false negative), causes the financial loss of the amount of that transaction. The cause for the misclassification, besides concept drift in fraudulent behavior, lies in the distribution of the data. Precisely, the problem occurs because of the overlapping data - when many genuine transactions resemble fraudulent ones and vice versa, resulting in false positives and false negatives [10].

E. Evaluation metric

As mentioned in the chapter 2.2, accuracy is not a suitable metric for CCFD, due to the class imbalance. Metrics that are commonly used for fraud detection combine precision, recall (true positive rate) and fall-out (false positive rate) all shown in TABLE I. Metrics are based on a well-known machine learning concept confusion matrix with the following four categories defined:

- TP (true positive) - correctly predicted positive class
- FP (false positive) - incorrectly predicted positive class
- TN (true negative) - correctly predicted negative class
- FN (false negative) - incorrectly predicted negative class.

The main goal here is to improve the classification of false negatives – recall without hurting the classification of false positives – precision [17]. This is difficult because the two measures have an opposite relationship: decrease in one results in increase of the other [8]. The reason why we need to improve evaluation of both types (FP, FN) of the incorrectly classified examples is that each type causes different cost, making this cost sensitive evaluation [18].

Cost of false negatives is of financial kind, its significance varying depending on the amount of the transaction. On the other hand, cost of false positives is measured in terms of customer dissatisfaction. Metric that combines TPR and FPR is called The Receiver Operating Characteristic (ROC) curve and is represented by calculating area under the ROC curve (AUC). AUC is a well-accepted measure for handling class imbalance [6].

TABLE I. COMMON METRICS

Precision	$\frac{TP}{TP + FP}$
Recall (TPR)	$\frac{TP}{TP + FN}$
Fall-out (FPR)	$\frac{FP}{FP + TN}$

Technique that takes into account ranking of the examples is Precision-Recall curve, which gives Average precision, calculated as area under P-R curve [19].

The important aspect to consider regarding to detection costs is also time dimension. Fraud should be detected promptly after it occurred, as it then enables more potential frauds to be prevented [19]. Therefore, single algorithm can be evaluated as superior among others if it can detect fraudulent transactions before every other algorithm.

III. EXPERIMENTAL SETUP

The focus of this study is to examine performance of three selected machine learning algorithms. The selection of algorithms is based on our previous research [20] and complies with the most often used ML algorithms in CCFD. To overcome the unbalanced classes issue we use oversampling technique described later. This section describes the data used for training and testing the models, learning approaches and performance measures used.

A. Dataset

The dataset used in experiments is the only publicly available dataset suitable for the CCFD [21]. Dataset contains transactions made in September 2013 by European cardholders, during the period of two days. Among 284807 transactions there are 492 fraudulent ones. Therefore, the dataset is highly unbalanced, having only 0.1727% fraudulent transactions, which are positive class. Due to confidentiality issues, the original information about the data is omitted. Dataset consists of 28 numerical input variables (named V1 - V28) which are the result of transformation made by provider of the dataset and 2 additional not transformed variables - Time and Amount. Time is presented in the shape of seconds elapsed from the first recorded transaction, whereas Amount shows amount spent in a single transaction. In terms of supervised machine learning, all the above described variables are features. The dataset also contains field named Class representing the information whether the transaction is fraudulent or not. Possible Class values are 1 if transaction is fraudulent and 0 otherwise, making this a binary classification problem. Each transaction is considered as one input value, i.e. one transaction is represented with single vector.

B. Data preparation

Considering all the above stated guidelines regarding individual challenges, for handling class imbalance we have chosen SMOTE method. This method is, according the scientific literature, one of the most used [15],[16],[22]. The sampling strategy parameter, representing the desired ratio of the number of samples in majority class over the number of samples in minority class, may vary. The value used in experiments equals to 0.4 (number of minority samples is increased to 40% of majority class size). It was determined empirically by choosing the best performing value among various attempts.

In the dataset used, before it was made public, due to data privacy issue, features were already transformed using PCA (Principal Component Analysis) [23] for dimensionality reduction. Because of the unknown meaning of the original or the constructed features there was not enough information for creation of additional features. The only other preprocessing done on the dataset was scaling the feature Amount. It was standardized by removing mean and scaled to unit variance.

C. Algorithms

Based on our previous research, in experiments we used three algorithms that are among five most used in CCFD: Random Forest (RF), Support Vector Machine (SVM) and Logistic Regression (LR) [20].

Random Forest is an ensemble of decision tree models that are quite popular for various machine learning problems because they are easy to use and interpret. Each decision tree by itself is sensitive to overfitting, but combined they perform well. Random Forest is a bagging classifier and it implements two stochastic decision levels in its process of learning – for each individual decision tree in ensemble it chooses subset of samples as well as subset of features for training [24].

SVM is a classifier that maps features from the non-linear input space to feature space of higher dimension. The reason for this transformation is to convert initially more complex classification problem to linear in a higher dimensional space. This mapping is achieved by using kernel functions [25].

Finally, Logistic Regression has its history in appliance in fraud classification [3]. Logistic Regression is probabilistic model – it assigns probability to each classified sample. This gives us more possibilities than pure binary classification. In terms of CCFD, this allows us to rank the transactions by their probability to be fraudulent and choose the threshold for most probable frauds that will raise the alert by predictive model.

Parameters for the models were determined from a variety of preliminary tests conducted on training data. For Random Forest, number of trees is set to T=100. For SVM, we use Gaussian radial basis function as kernel which performs better than linear kernel, prone to overfitting in this case. The cost parameter C and the kernel parameter gamma were set to values 10 and 0.01 respectively. These values were selected after cross validation grid search which included different combinations of these values. In Logistic Regression we set C to 100 and used L2-regularization.

D. Learning approaches

There are different approaches to the learning process. The simplest, but still most widely used, is static approach which creates predictive model by processing available items all at once in a single learning batch [19]. The major drawback of such one-time trained model is its inability to adapt to any changes in the input data i.e. to support concept drift. Periodic re-training approach is more resistant to nonstandard input items, although changes that occur after the last trained data will not be included in the classification model. As opposed to static, incremental approach has been introduced [16]. Incremental learning is suitable for nonstationary environment because it processes data in chunks as they arrive. Due to the unpredictability of fraudulent behavior, it may happen that patterns once used and then altered may re-occur in the future. For that reason, incremental approach uses an ensemble which contains all previously generated classifiers that are evaluated on the newest data chunk and the classifiers with the best current performance are used in prediction. In that way, it preserves knowledge from the past while learning from new observations.

In experiments, we compared influence of static and incremental learning on chosen algorithms. In static approach, training and testing was done once using all data. For incremental learning, we divided data into two chunks, representing two days that are observed. We are aware that real life scenario includes larger number of data chunks, but this limitation is caused by the available data. Training and testing were done on each data chunk separately which generated two models. We implemented weighted ensemble of models h_i, which is defined as

$$E = \sum_{i=0}^{M} w_i h_i \quad (1)$$

where M denotes total number of models (in our case two). Weight w_i is calculated as precision (formula in TABLE I.) on observed data chunk and then normalized to 0-1 range.

E. Metrics

We decided to evaluate our results by two measures, area under the ROC curve (AUC) and average precision (AP). ROC curve is plotted as Recall (TPR) against Fall-out (FPR) at various classification thresholds. Transaction with fraud probability that equals or is above threshold value is considered fraudulent. The best classifier corresponds to the point (0,1) where there are no false positives or false negatives [24]. AUC metric measures how much is the ROC curve of single classifier close to the optimal point.

Second measure, average precision, approximates area under the precision-recall curve. A precision-recall curve is a plot of precision versus recall at different probability thresholds. Intuitively, each threshold represents rank and we want to examine how specific model performs for highest ranked transactions. Average precision is calculated as mean precision averaging over recall values [26].

Since data set, used in experiments, includes transactions made in just two days it did not make any sense to perform evaluation that includes time aspect.

IV. EXPERIMENTAL RESULTS

All the required programming code is written in the Python programming language, and standard scikit learn implementation was used. We used cross-validation for learning process and measuring model performance. Data set is divided into a training set and a test set in the typical ratio of 70:30. Results of evaluating models by AUC are shown in TABLE II. Results of evaluating models by average precision are shown in TABLE III. and Figures 2. and 3., respectively.

TABLE II. AUC SCORES

Static learning	Random Forest	0.9148
	SVM	0.8877
	Logistic Regression	0.9114
Incremental learning	Random Forest	0.9013
	SVM	0.8678
	Logistic Regression	0.9107

AUC scores reveal that all three algorithms have similar performance, with SVM having slightly lower results than the other two algorithms. All three algorithms have better AUC scores for static models than incremental ones.

AP, shown in table below, determines Random Forest as best option in terms of static learning. On the other hand, all three algorithms have similar performance in incremental version, while SVM is somewhat better when measured with Average Precision, as oppose to its performance measured with AUC. When comparing same algorithms in their static and incremental version, Random Forest is better in static (same as when measured with AUC), and SVM and Logistic Regression are better in incremental, with latter having substantially better results than its static version.

TABLE III. AP SCORES

Static learning	Random Forest	0.8483
	SVM	0.7978
	Logistic Regression	0.7337
Incremental learning	Random Forest	0.8293
	SVM	0.8036
	Logistic Regression	0.8413

Figure 2. shows comparison of all three algorithms measured with AP (plotted as Precision-Recall curve) in terms of static learning. In Figure 2. is their comparison in incremental learning.

Because the curves are overlapping, there is no conclusion on which algorithm is significantly better than the others. In Figure 2., for lower recall values, Random Forest and SVM are performing similar, while for the higher recall values Logistic Regression comes closer to Random Forest and SVM decreases in performance. In Figure 3., SVM is better for the low recall values and both Logistic Regression and Random Forest outperform it for higher recall values.

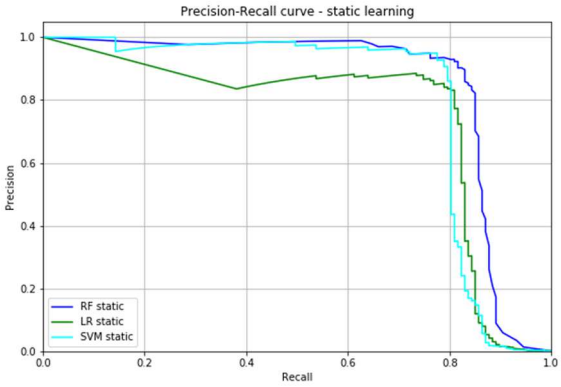

Figure 2. Precision-Recall curve – static learning

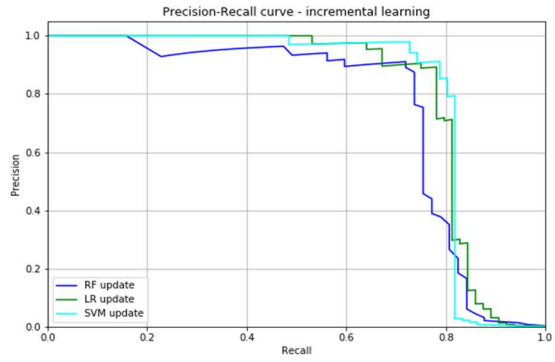

Figure 3. Precision-Recall curve – incremental learning

V. RELATED WORK

Since the data set, we used in experiments, is currently the only publicly available data set based on real-time data, there are a number of papers in which authors report on their results in similar research. In [27] authors also compared three algorithms (Naïve Bayes, k-nearest neighbors and Logistic Regression). Skewness was overcomed by a hybrid technique of undersampling and then oversampling. Their evaluation metrics includes precision and sensitivity (i.e. recall). Results show k-nearest neighbors as superior across all used evaluation metrics on different data distributions.

In [28] classification is done with Logistic Regression, nearest neighbors, SVM, Decision trees, Random Forest and Naïve Bayes. Evaluation is done by several metrics, also including precision and recall. All algorithms were applied on skewed data, without any balancing techniques. Logistic Regression outperformed other algorithms.

Importance of evaluation technique used in CCFD is pointed out in [29]. They compared ROC and Precision-Recall curves using Logistic Regression as on algorithmic level and random undersampling on data-level. Results show that Precision-Recall curve has more advantages than ROC curve in dealing with CCFD on this dataset with conclusion that the former captures the effect of improving both precision and recall better than the latter.

Authors in [30] put focus on data sampling methods used for overcoming class imbalance. They propose new technique called VOS (Variational Oversampling) and compared it with two existing oversampling techniques, one of them being SMOTE. Performance of three algorithms (Logistic Regression, Multi-layer perceptron and Random Forest) is evaluated by precision and recall, as well as accuracy. The proposed VOS method achieved the best score among all compared algorithms.

VI. CONLUSION

In this paper we have outlined main issues in the CCFD field and proposed state-of-the-art solutions. Using the only publicly available dataset suitable for the CCFD we have implemented and measured performance of three selected ML algorithms: Random Forest, Support Vector Machine and Logistic Regression. The selected algorithms belong to the most often used ML algorithms in CCFD and its selection came from scientific literature review we have performed in our previous research. Experiments were done using two approaches: (i) static and (ii) incremental learning of chosen algorithms. The following measures are used to evaluate the performance of the algorithms: area under the ROC curve (AUC) and average precision (AP). From the results presented in paper, it is evident that SVM shows the poorest performance in both static and incremental setup. The difference in performance between RF and LR is slight. LR shows marginally better results in incremental setup but this should be taken with caution because of the limitations of the dataset used - it contains transactions made in just two days. Since static training approach is not a long-term solution, we plan to investigate incremental learning on more realistic dataset. Richer datasets are not publicly available so to further our research we plan to work on producing realistic synthetic data.

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An empirical study on the impact of new participants on final price savings and process of electronic reverse auctions

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***Abstract* - The electronic reverse auction as a popular procurement mechanism, whose use can secure higher objectiveness of prices or utility of products and services across different industries, is the subject of research already for several years, however, the range of empirical studies is still lagging behind. The current paper extends the empirical findings on the subject of the electronic reverse auction. The aim of our study is to examine the impact of including new participants in the auction process. The study is based on the database of 4,442 real auction data cases of various companies including both public and private entities and different types of auction collected by the most significant reverse auction solution provider in central Europe. The research results confirmed the impact of new participants in the electronic reverse auction. According to our analysis, we have identified that there is a positive effect of new participants on final price savings.**

Keywords - Electronic reverse auction, Supply chain management, Empirical study

I. INTRODUCTION

One of the possible way how to increase usage of information technologies in the company is to adapt electronic reverse auction into purchasing mechanism. Compared to the traditional auction mechanism where one supplier meets many interested buyers, the "reverse" means auction mechanism where a number of pre- defined suppliers meets one buyer [1]. Electronic reverse auctions are defined as the online real-time dynamic auction between one buying organization and the group of pre-qualified suppliers who are bidding to win the contract for supplying certain goods or services under given conditions, design, quality, and other requirements using the specified auction software [2][3].

Electronic reverse auction became one of the most popular procurement mechanism over the past twenty years. There are plenty of advantages of the auction usage, mostly in transparency, effectivity and savings. Reverse auctions are increasingly popular among buying organizations, although, they are sometimes marked as controversial and are accompanied with ethical concerns in the sourcing world [4][5]. One-sided focus on price savings in auctions is considered to be at odds with the benefits of long-term cooperative buyer-supplier relationships [3][6]. On the other hand, reverse auctions are relatively easy to use and result in positive outcomes across a wide range of offerings and contexts [3][7]. Another issue connected to auctions is abnormally low bids (ALB). ALB is a part of an important ethical question that is related to the use of auctions to decrease the purchase price. It is likely that suppliers will submit ALB more often to win the tender. ALB may occur as a consequence of incorrect cost estimates or as an attempt to stay in business [8]. ALB is hard to analyze as its definition is not uniform. For example, in some countries is ALB defined as a deviation from the client's cost estimation or as a deviation from the average bid [9]. There have been suggestions to use statistical methods to determine bid abnormality [10][11]. For example, in Czech Republic, it is very hard to detect ALB, since the legislation does not define the abnormality of bids in a mathematical way. By the Act no. 137/2006 Coll. on Public Procurement [12] ALB requires evaluation from a special committee.

At the auction, different behavior of participants occurs, as every participant can use different approach to bidding and entire auction. A number of competitors is also important, as it may alter the approaches and behavior of participants in a way that there is bigger competition which brings more bids and better final price in many cases. More competitors mean bigger competition and less selfish behavior of participants because competitors are less likely to follow their approach and their normal behavior [13][14][15].

Series of papers show the opposite relation between the level of competitive behavior and the number of competitors [13][14][15]. They argue that fewer participants are more competitive than larger group because of competitive arousal or desire for social comparisons. Ku, Malhotra and Murninghaj [13] analyzed data from live and internet auctions and laboratory experiment and measured competitive behavior in terms of how auction participants exceed their bidding limits. Their results showed that participants of live auctions were more likely to exceed their bidding limits when a number of bidders was low and they were near the end of the auction as they were in time pressure. From further testing, they found out that time pressure and a small number of bidders caused an increase in the probability that participants exceed their own bidding limits. In the lab experiment, undergraduates responded to questions based on a script that changed the number of bidders and

sunk cost (amount of time spent on researching the auction item). Results showed a small number of other bidders (bidders except questioned person) and high sunk costs raised the probability of a high bid which means that bidders were more aggressive in bidding. Authors of the study claimed that this behavior was the result of competitive arousal that was made from social facilitation, rivalry, time pressure and effort to be first. As Ku, Malthotra and Murninghan said, with fewer other bidders there is more competitive action and participants feel more excited and anxious [13].

Most of the papers explore a number of participants in the auction but it is hard to find something about the type of participants. As a type, we can talk about experienced

bidders or new bidders who are beginners. Wang and Xu [16] observed that new participants lost more money than experienced participants in pay-to-bid auctions. Also Caldara found that new participants had a tendency to bid more frequently than optimal with increased overall revenues in a short period [17]. From these findings, we can assume that something similar will happen in reverse auction.

The outline of this paper is further divided into three chapters. The next chapter describes the methodology and enclose the used dataset. The third section presents our analysis and the final chapter contains few concluding remarks.

II. METHODOLOGY AND SAMPLE DESCRIPTION

To examine the impact of new participants in electronic reverse auction (online reverse auction or eRA) we have used real eRA data collected by the most significant eRA software in central Europe – PROEBIZ, provided by NAR marketing company. The data were collected between the years 2005 - 2016 and include e-auction data realized within both private and public organizations of various industry sectors. The database consists of 4442 e-auction data of 55 832 items purchased.

These data needed to be further processed and cleaned to secure sufficient data quality, while they included various technical mistakes, e.g. incorrect data regarding misunderstanding between value for piece and package, missing data, and others.

To examine the impact of new participants in the eRA, we have selected data with at least 2 participants and the number of new participants was limited to 10, while in reality, it is very difficult to find even one new participant/ supplier. The final database included 2014 e-auction data cases and the descriptive statistics of the final database is presented in the Table I.

TABLE I. DESCRIPTIVE STATISTICS OF THE DATABASE

	Min	***Max***	***Mean***	***Std. Deviation***
Comparative price	0.045	71999609.650	323025.312	2426177.822
Initial price	0.040	63959813.650	317608.539	2356507.412
Winning price	0.037	61209323.178	278443.527	2001145.214
Saving comparative price	100	69.182	13.797	20.321
Saving initial price	0	68.845	11.047	12.781
No.participants	2	324	7.427	12.661
No.items	1	1067	12.694	40.444
No.changes	0	7718	86.208	241.575
No.prolongation	0	742	18.089	49.714
New participant attendance	0	1	0.627	0.484
No.new participants	0	10	1.670	1.907
No. winners	0	13	1.222	1.385

A. *Comparative vs. Initial price saving calculation*

The explanation of the saving calculations for determining the auction impact is crucial for further analysis. Proper price identification that should be compared to the final negotiated price with the aim to calculate the saving achieved by the auction is problematic. We differentiate between two basic types of price used in the proportion to the final price with the aim to calculate savings: comparative and initial price.

The comparative price is the price set by the procurer based on his market research or at the last contracted price. This price is subjective and there is a high dependence on procurer's estimation abilities or market transparency. In the case of using the price from the last contract, the time period length and the type of product is highly important.

The initial price, on the other hand, is the best price offered by supplier in the first, input phase of eRA process [18].

The saving could be, therefore, calculated as the difference between either initial or comparative price and the winning price as a proportion to the winning price.

According to the saving calculation methods, we decided to decrease the range of data used to minimize the data mistakes mentioned above. In the case of saving calculated using comparative price to the interval <-100, 70> and in the case of saving calculated using the initial price to the interval <0,70>. Because the initial price is derived from the first phase, the winning price has to be at this value or better. Due to this fact the negative values are possible only in the case of using comparative prices.

III. RESEARCH

The aim of the paper is to examine the impact of the new participants in the eRA on the final price saving and the eRA process. To approach this objective, analysis of the difference between the cases when there is at least one new participant and the cases without any new participant presented was performed. The impact was analyzed on both cases - the comparative price saving and the initial price saving.

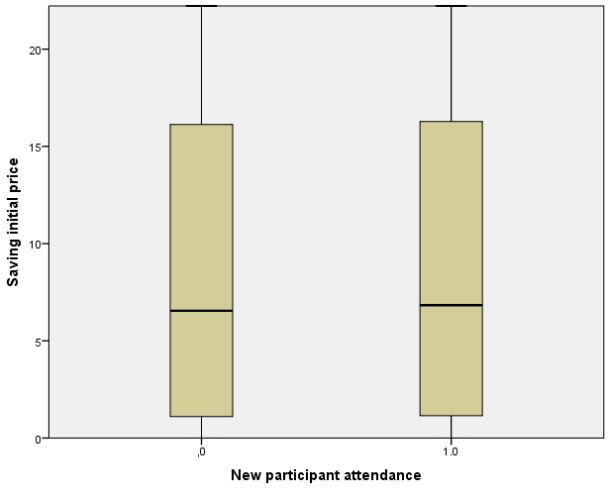

Figure 1. Box-plot analysis of initial price saving based on the new participant attendance

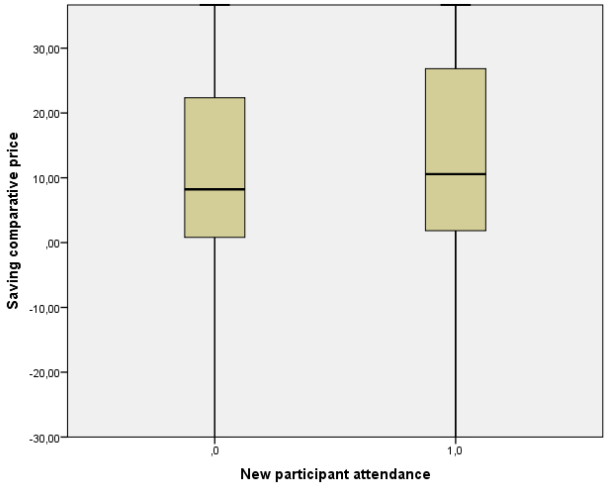

Figure 2. Box-plot analysis of comparative price saving based on the new participant attendance

In Fig.1 and Fig.2, the results are shown. The cases with new participants are marked by 1 and the cases without new participant by 0. Both figures show the positive effect of the new participant at the final price saving, however, in the case of using initial price the difference is quite small, that results from the method of the final price type categorization itself. Initial price setting takes the price of all (including new) participants into attendance, while the comparative price does not include prices of participants.

The mean value of comparative price saving is 11.88% without new participants and 14.94% with new participants. In case of initial price saving is the mean 10.77% without new participants and 11.21% with new participants. Both cases confirm the positive impact of new participants on price saving.

The Fig.3 and the Fig.4, clearly indicate the positive impact of the increasing number of new participants included in an auction on the final price saving. In the case of a lower number of new participants the effect on the saving is quite small, however, with the higher number of new participants is the positive effect of their attendance clear. Adding only one new participant will not create sufficient pressure on other participants that suggests also the median values of the final price saving, in this case that is not markedly different from the zero new participant case. With an increasing number of new participant, we can also see the lowering negative final price saving values and increasing value of the median that also confirms the increasing effectiveness of the auction process.

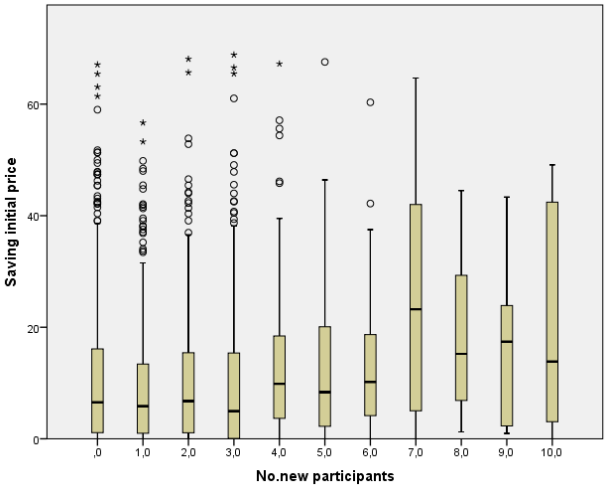

Figure 3. Box-plot of initial price saving according to the number of new participants in the auction

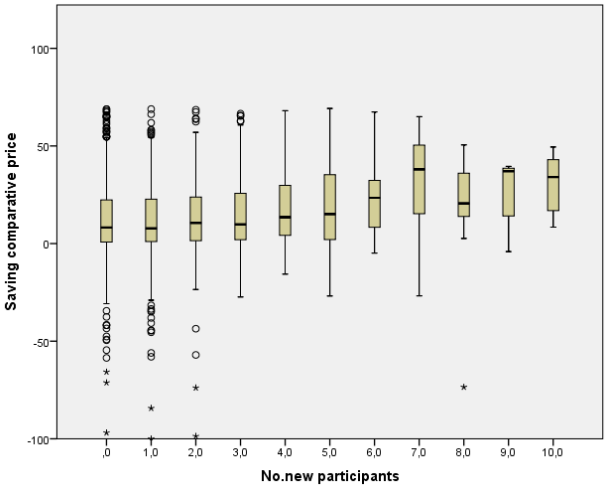

Figure 4. Box-plot of comparative price saving according to the number of new participants in the auction

To confirm the visual findings about difference in medians depending on the number of new participants, we performed normality tests followed by median tests. Shapiro-Wilk normality tests (Tab. II), performed on the whole dataset all numbers of participants included,

TABLE II. SHAPIRO-WILK NORMALITY TEST ACCORDING TO SAVING CALCULATION METHODS

			W	p-value
Saving calculation method	*comparative price*		0.93684	2.20E-16
	initial price		0.80279	2.20E-16

TABLE III. KRUSKAL - WALLIS RANK SUM TEST

Saving calculation method		CHi^2	df	p - value
	comparative price	95.012	15	1.14E-13
	initial price	68.236	15	9.19E-09

TABLE IV. PAIRWISE WILCOX RANK SUM TEST

Number of new participants	Saving calculation method: *comparative price* (p-values)	Saving calculation method: *initial price* (p-values)
1	0.1775	0.0074
2	0.0228	0.9472
3	0.0074	0.0729
4	0.0006	0.0053
5	0.0020	0.0285
6	0.0001	0.0421
7	0.0000	0.0000
8	0.0049	0.0029
9	0.0539	0.2517
10	0.0110	0.3451

resulted in p-values less than 0.05, which means that savings, regardless the method, are not following the normal distribution.

Not normal distribution of the data led us to use non-parametric Kruskal- Wallis rank sum test. Test indicates if samples originate from the same distribution. We were comparing samples according to the number of new participants. As the p-value is less than 0.05 we can conclude that significant differences exist among the tested samples.

Kruskal- Wallis test showed significant difference, however, not specifically the samples which are different. For identification pairwise significance, we used Pairwise Wilcox Rank Sum Test (Tab IV.). P-values from the table suggests that savings calculated with comparative price are significantly different when at least two new participants are in the eRA. According to initial price sav-

ing not that consistent. In case of 1 or from 4-8 new participants, difference seems to be significant. On the other hand, 2,3,9 or 10 new participants are not generating significantly different savings from the situation of no new participants in eRA.

The Fig.5 and the Fig.6 show the difference between cases when the winner was old (the seller was already a participant in the procurement activity of the current procurer) or the new participant. In case of new participant victory, the mean value of final price saving is higher compared to the mean of final price saving in the case of old participant victory. This lead us to the statement that including a new participant in the auction leads to higher final price saving.

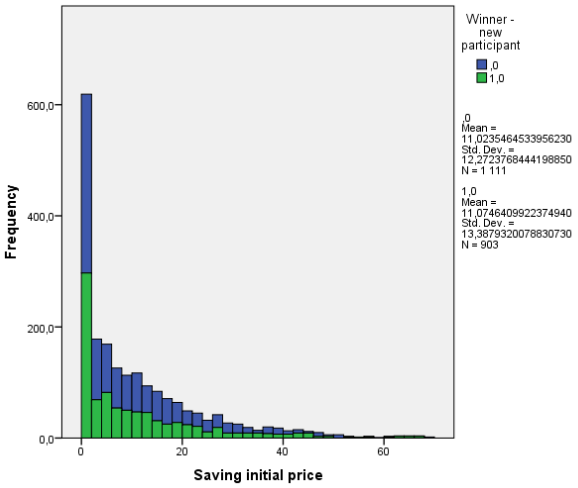

Figure 5. Histogram of initial price saving according to the winning of old o new participant

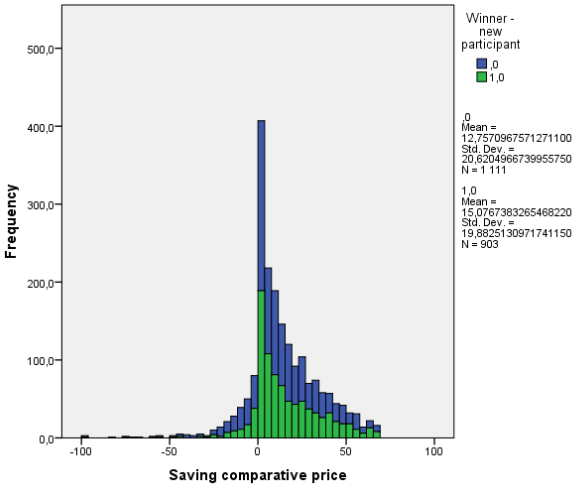

Figure 6. Histogram of initial price saving according to the winning of old o new participants

IV. CONCLUSION

The paper presents an empirical analysis of the electronic reverse auction data from both public and private sector within various industries from one of the most significant auction data provider in central Europe. The range of the database belongs to one of the largest databases analyzed in the subject of electronic reverse auction data. The aim of the paper was to examine the impact of the new participants on the final price saving. The added value of the paper is also the specification of the final price saving calculation and further analysis including various types of savings.

Our results show the positive impact of including new participants on both initial and comparative price saving. The analysis confirmed that the increasing number of participants has a positive impact on final price saving in both calculation cases. Statistical tests show that there is a significant difference between the sample with no new participants and within samples with new participants.

ACKNOWLEDGMENT

This contribution was supported by the Slovak Research and Development Agency within the project APVV-16-0368 “Determinants of Digital Single Market development and implementation in the field of global supply chains and in relation to changes of behavior of participants on the market”

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Big data for smart factories: A bibliometric analysis

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***Abstract* - The use of big data is rapidly growing in recent years, as a result of access to huge amounts of data, which can be obtained from various sources. Big data has played a significant role in all sectors, for example, the manufacturing sector, where it plays a very important role due to its ability to provide economic growth. Several studies have been done regarding the use of big data at smart factories, for this reason, the main aim of our study was to conduct a bibliometric and phrase frequency analysis that covered the name of most frequent authors, journals and organizations, year and country of publication and the frequency with which words and phrases appeared in the literature. Using the keywords "big data" and "smart factory," we searched bibliometric units from the Scopus database. We found out that research on big data and smart factories is increasing rapidly and is mainly focused on machine learning and cloud computing.**

Keywords – big data; smart factory; Industry 4.0; bibliometric analysis

I. INTRODUCTION

Big data refers to large databases, i.e., large amounts of data. Furthermore, the concept of big data encompasses not only the capacity but also the technology and tools that enable the capture and manipulation of data [6], for example through data mining, which is a powerful technique that can be applied to data for the purpose of generalization, characterization, association, classification, clustering, pattern matching on a fundamental level, high level, and multiple-levels [2], and which, in addition to this, includes detection of abnormal information [5]. Sources of big data include the web, social media, mobile applications, different types of records and databases, geospatial data, surveys, and scanned traditional documents. [1]. Even more, in the upcoming years, big data is projected to continue its rapid ascent [1] and will play an increasingly prominent role in promoting the development of society [7].

With the rapid development of the manufacturing sector, there are growing requirements for the application of big data technology. Not only is the rapid development of the manufacturing sector influencing the extensive application of big data and data mining, but big data also offers certain conveniences for management, in regards to gathering and taking advantage of information [4].

II. METHODOLOGY

The SCOPUS database was used to search for documents containing the TITLE-ABS-KEY "big data" and "smart factory." Using Wordstat 8.0 text mining capabilities, a bibliometric analysis was conducted, where the year of publication, a number of publications for individual journals institutions, organizations and authors and country of publication as looked at.

With the help of Wordstat 8.0 text mining capabilities, phrase frequencies were determined, along with the number of different articles in which the phrases appeared and the importance of each phrase within the collection of documents on the topic of big data and smart factory. Finally, the proximity between phrases within the documents was studied with the help of Wordstat 8.0 cluster analysis capabilities.

III. RESULTS

When searching for big data and smart factory, we found that there were no documents before 2013, as can be seen in Figure 1. Altogether, 114 documents were found on the SCOPUS database.

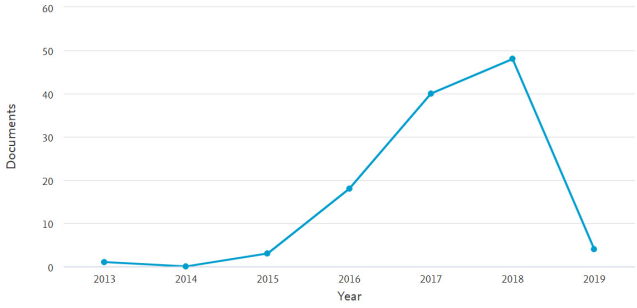

Figure 1. Documents published between 2013 and 2019.

Most of the documents were found in regards to Computer Science (37.2%) and Engineering (25.2%), while the remaining 37.6% of documents fell into the category of Mathematics (9.7%), Decision Science (4.4%), Social Science (4.4%), Materials Science (4.0%), Business and Management (3.5%), Energy (2.2%), Physics and Astronomy (2.2%), Biochemistry (1.8%) and Other (5.3%) (see Figure 2.)

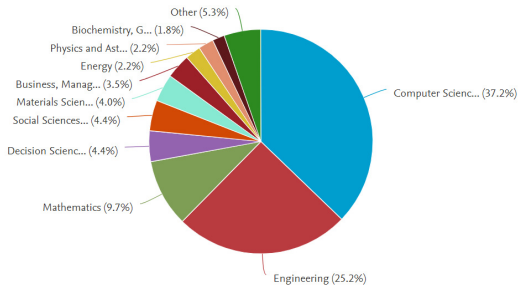

Figure 2. Percentage of documents, on big data and smart factory, published in differents fields of research

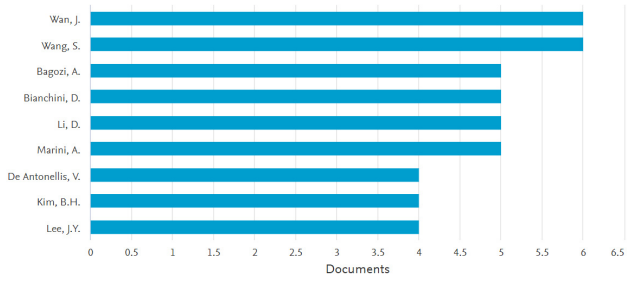

Figure 3. Authors that published 3 or more documents on the topic of big data and smart factory

The following scientists contributed to the publication of 3 or more articles (see Figure 3):

- Wan Jiafu (South China University of Technology, School of Mechanical & Automotive Engineering, Guangzhou, China)
- Wang Shiyong (South China University of Technology, School of Mechanical & Automotive Engineering, Guangzhou, China)
- Bagozi Ada (Università degli Studi di Brescia, Department of Information Engineering, Brescia, Italy)
- Bianchini Devis (Università degli Studi di Brescia, Department of Information Engineering, Brescia, Italy)
- Li Di (Shanghai Jiao Tong University, School of Mechanical Engineering, Shanghai, China)
- Marini Alessandro (Università degli Studi di Brescia, Department of Information Engineering, Brescia, Italy)
- De Antonellis, Valeria (Università degli Studi di Brescia, Brescia, Italy)
- Kim Bohyun (Korea Institute of Industrial Technology Evaluation and Planning, IT Converged Process R&D Group, Cheonan, South Korea)
- Lee Juyeon (Korea Institute of Industrial Technology Evaluation and Planning, IT Converged Process R&D Group, Cheonan, South Korea)

Countries that published three or more articles on the topic include South Korea, China, Italy, Germany, United Kingdom, Spain, United States, Switzerland, and Turkey (see Figure 4)

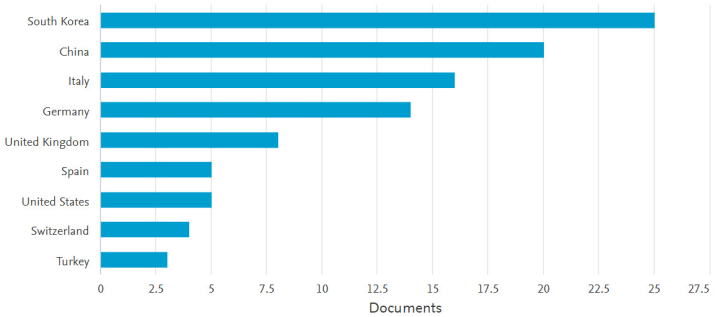

Figure 4. Countries that published 3 or more documents on the topic of big data and smart factory

TABLE I. Most cited articles

Paper	# of citations
Wang, S., Wan, J., Li, D., Zhang, C (2016). Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*	196
Wang, S., Wan, J., Zhang, D., Li, D., Zhang, C. (2016). Towards smart factory for industry 4.0: A self-organized multi-agent system with big data-based feedback and coordination. *Computer Networks*	176
Kang, H.S., Lee, J.Y., Choi, S., (...), Kim, B.H., Noh, S.D (2016). Smart manufacturing: Past research, present findings, and future directions. *International Journal of Precision Engineering and Manufacturing - Green Technology*	142
Zhou, K., Liu, T., Zhou, L. (2016). Industry 4.0: Towards future industrial opportunities and challenges. *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015*	82
Yue, X., Cai, H., Yan, H., Zou, C., Zhou, K. (2015). Cloud-assisted industrial cyber-physical systems: An insight. *Microprocessors and Microsystems*	42
Turner, C.J., Hutabarat, W., Oyekan, J., Tiwari, A. (2016). Discrete Event Simulation and Virtual Reality Use in Industry: New Opportunities and Future Trends. *IEEE Transactions on Human-Machine Systems*	28
Chen, B., Wan, J., Shu, L., (...), Mukherjee, M., Yin, B. (2017). Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges. *IEEE Access*	22
Petrasch, R., Hentschke, R. (2016). Process modeling for industry 4.0 applications: Towards an industry 4.0 process modeling language and method. *2016 13th International Joint Conference on Computer Science and Software Engineering, JCSSE 2016*	11
Preuveneers, D., Ilie-Zudor, E. (2017). The intelligent industry of the future: A survey on emerging trends, research challenges and opportunities in Industry 4.0. *Journal of Ambient Intelligence and Smart Environments*	10
Park, K., Baek, C., Peng, L. (2016). A development of streaming big data analysis system using in-memory cluster computing framework: Spark. *Lecture Notes in Electrical Engineering*	9

Institutions that had 3 or more publications were South China University of Technology, Università degli Studi di Brescia, Korea Institute of Industrial Technology Evaluation and Planning, Electronics and Telecommunications Research Institute, Sungkyunkwan University, Shanghai Jiao Tong University, Swiss Federal Institute of Technology EPFL and Jiangxi University of Science and Technology (see Figure 5.). Table I, on the other hand, shows the most cited articles, which had at least 9 citations.

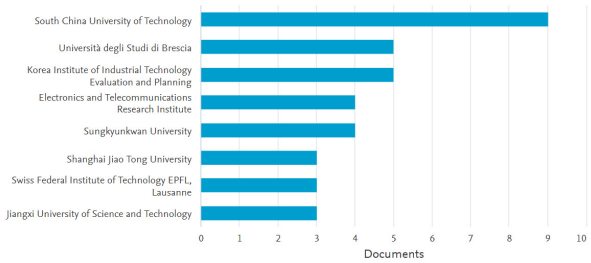

Figure 5. Institutions that published 3 or more documents on the topic of big data and smart factory

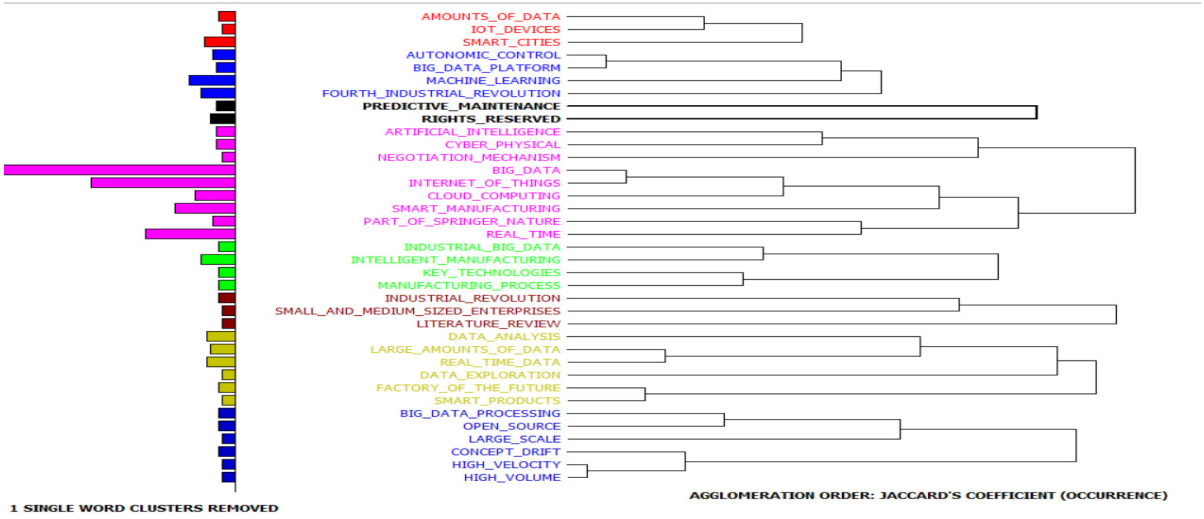

Figure 6. Proximity of phrases within clusters. Each color represents a unique cluster.

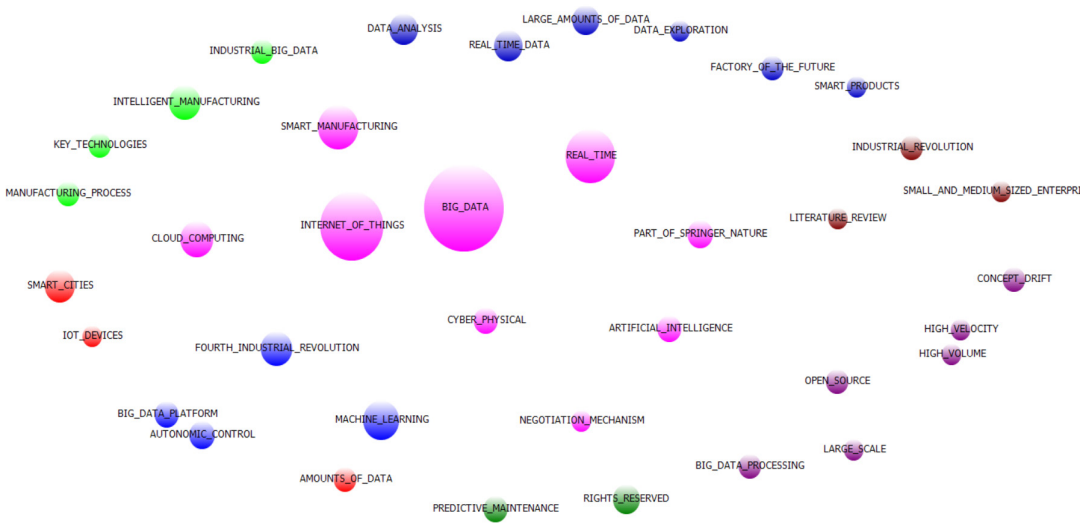

Figure 7. The proximity of phrases within clusters. Each color represents the cluster within which phrases appear.

TABLE II. Most frequent and most important phrases

	FREQUENCY	NO. CASES	% CASES	LENGTH	TF • IDF
BIG DATA	116	78	70,27%	2	17,8
INTERNET OF THINGS	51	46	41,44%	3	19,5
CYBER PHYSICAL	46	39	35,14%	2	20,9
REAL TIME	45	27	24,32%	2	27,6
PHYSICAL SYSTEMS	27	23	20,72%	2	18,5
CYBER PHYSICAL SYSTEMS	23	20	18,02%	3	17,1
INDUSTRIAL REVOLUTION	18	17	15,32%	2	14,7
CLOUD COMPUTING	14	14	12,61%	2	12,6
DATA ANALYTICS	18	12	10,81%	2	17,4
DATA ANALYSIS	17	12	10,81%	2	16,4
MACHINE LEARNING	16	11	9,91%	2	16,1
AMOUNTS OF DATA	15	11	9,91%	3	15,1
FOURTH INDUSTRIAL REVOLUTION	11	10	9,01%	3	11,5
SMART MANUFACTURING	20	9	8,11%	2	21,8
CYBER PHYSICAL SYSTEM	11	9	8,11%	3	12
AMOUNT OF DATA	9	9	8,11%	3	9,8
RIGHTS RESERVED	9	9	8,11%	2	9,8
BIG DATA ANALYTICS	10	8	7,21%	3	11,4
DATA COLLECTION	10	8	7,21%	2	11,4
PART OF SPRINGER NATURE	8	8	7,21%	4	9,1
PUBLISHING AG	8	8	7,21%	2	9,1
INTELLIGENT MANUFACTURING	12	7	6,31%	2	14,4
SMART CITIES	11	7	6,31%	2	13,2
PRODUCTION SYSTEMS	8	7	6,31%	2	9,6
ARTIFICIAL INTELLIGENCE	7	7	6,31%	2	8,4
DATA PROCESSING	10	6	5,41%	2	12,7
REAL TIME DATA	10	6	5,41%	3	12,7
LARGE AMOUNTS OF DATA	9	6	5,41%	4	11,4
BIG DATA ANALYSIS	7	6	5,41%	3	8,9
FACTORY OF THE FUTURE	6	6	5,41%	4	7,6
MANUFACTURING SYSTEM	6	6	5,41%	2	7,6
OPEN SOURCE	6	6	5,41%	2	7,6
KEY TECHNOLOGIES	6	5	4,50%	2	8,1
MANUFACTURING PROCESS	6	5	4,50%	2	8,1
CYBER PHYSICAL PRODUCTION SYSTEMS	5	5	4,50%	4	6,7
DATA COLLECTED	5	5	4,50%	2	6,7
MANUFACTURING SYSTEMS	5	5	4,50%	2	6,7
SMART PRODUCTS	5	5	4,50%	2	6,7

Figure 6 and 7 show the proximity, within clusters, of various most frequent phrases, while Table II shows the most frequent phrases and their importance within the collection of documents (TF • IDF).

IV. DISCUSSION

As was expected, the most frequent phrase in the results (see Table II.) was Big Data, as that was also the main search term. Using the search term big data, along with the smart factory, also produced the most frequent phrases Internet of Things (IoT) and Cyber-Physical. Out of the list of most frequent and most important phrases, in regards to big data and smart factories, the following are most relevant for cyber-physical systems (CPS) and IoT (see Table II): cloud computing, data analytics, data analysis, machine learning, smart/intelligent

manufacturing, big data analytics, artificial intelligence, data processing, real-time data, large amounts of data.

CPS refers to all technology and systems within a factory that is connected to other technology and systems through the IoT, for example, actuators, sensors, and computers with user-friendly interfaces that help factory workers control non-automated aspects of cyber-physical systems [8][9][10]. As such, various programming and engineering skills are necessary, in order for the CPS and IoT hardware and software to function for smart manufacturing and big data manipulation [9][11] [12][13], as such it is no surprise that decision science, engineering, and computer science were the most research fields in SCOPUS, in regards to big data and smart factories.

IoT and CPS appear together in the cluster analysis (see Figure 6 and 7) with artificial intelligence, cloud computing and real-time in cluster 4. These computing mechanisms, for example, artificial intelligence and machine learning, appear with big data platform and big data, in cluster 2 and 4, respectively. In cluster 2 it can be seen that big data is connected to the fourth industrial revolution and automatic control. Industrial big data will as such play an important role as a key technology in intelligent manufacturing and manufacturing processes in general, as can be seen in cluster 5. This kind of data processing will possess qualities, as seen in the final cluster, such as open source, large scale, high velocity, and high volume. This kind of data analysis, as seen in the 7th cluster, will be associated with large amounts of data, will be conducted on data collected in real time, and will explore data collected by smart products in the factory of the future.

Out of all of the authors involved in the studies, only 10 published more than 3 papers. However, none of the authors published more than six papers (see Figure 3.). The 10 authors were associated with one out of four different universities. The universities are situated in China, Italy or South Korea. Out of the four universities, three appeared in the top three universities that published 3 or more articles, the South China University of Technology, Università degli Studi di Brescia, Korea Institute of Industrial Technology Evaluation and Planning (see Figure 5). Overall, out of the three countries South Korea had the most publications, China came in second and Italy third. However, the following countries also published several articles, such as Germany, Spain, United States, Switzerland, and Turkey (see Figure 4). It is interesting to note that out of the 114 articles; only 10 articles had 9 or more citations. However, this is likely due to the articles being a maximum of 6 years old, with most being less than 2-3 years old (see Figure 1. and Table I.) According to [14], for bibliometric indicators of citation to be accurate, articles have to be at least 2-3 years old.

V. CONCLUSION

Based on the results of our bibliometric and database tomography analysis, big data will play an important role in smart factories. However, the results of this study only provide a superficial look at the role of big data in smart factories, and as such a more in-depth look needs to be performed on the topic in the future. To shed some more light on the topic, an extensive in-depth literature review can be performed on the documents found in this study.

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Game-to-Game Prediction of NBA Players' Points in Relation to Their Season Average

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Abstract* – NBA attracts a great deal of attention among sports analysts and sportsbooks regarding the prediction of various outcomes of each game, together with the parameters which affect them. Performance of NBA players is influenced by many unknown and random factors, such as players' psychological condition, social life and injuries. The stated factors hinder game-to-game predictions of players' performance in relation to the expectations set by their past performances. In this paper we leverage the publicly available statistics to create a dataset pertaining to the performance of a single player during a single season. A comparison between points that a player has scored and his current season average was done in order to classify the player's performance as 'over' or 'under'. Using various statistical data concerning previous games of the season, a binary classifier was trained in order to distinguish between those categories for future games. The classifier performed with an accuracy score of 56.7%. Since sportsbooks tend to give 50/50 odds of a player going 'over' or 'under' in relation to their season points per game, these results represent an improvement of 6.7%. Although top features are predominated by offensive statistics (e.g. how many minutes the player plays, how many shots he takes and how strong the offense of his team is), a newly generated feature, which represents tiredness of a player, has shown to be among top 15 informative features.

I. INTRODUCTION

Basketball is a sport abundant in statistical data and thus a great candidate for pattern recognition and outcome prediction. NBA (National Basketball Association) is the most watched, media covered and analytically scrutinized basketball league in the world, and for that reason was chosen as the main focus of this paper. The main goal of our research was to collect the necessary data, analyze it and discover patterns which may conform to the existing domain knowledge accumulated throughout the years of watching sports. Additional ideas were derived from previous work done in the field of sports analytics.

In this paper, each game played by a player is labeled with one of the two classes: 'over' or 'under'. Value of the label depends on whether a player scored more or less points in a currently observed game compared to his current season average. The difficulty of this problem lies in its formulation, since the goal is not to predict the performance of a player, which could be done much more successfully, but rather to identify whether he will outperform or underperform in relation to the expectations set by his previously shown performance. Our developed predictive model will showcase a clear advantage over a currently prevalent method of randomly chosen estimation of performance. After providing Related Work in Section II and explaining the possible applications in Section III, collection and preparation of Data was explained in Section IV. The Model, together with the results, is presented in Section V while the ideas for Future Work are discussed in Section VI. Section VII concludes the paper.

II. RELATED WORK

Throughout the years, different authors tried to tackle different problems regarding the NBA. Wheeler gives a good general idea about the features that may be good indicators of player's performance in [1]. Apart from the obvious features, the author discovered two interesting informative features: opponent's shots taken within 10 feet and opponent's shots taken near the rim.

Players' performance can differ depending on how injury-prone they are and how the process of aging affects them [2]. Also, it has been shown that players whose contract is expiring tend to perform above their standards in order to promote themselves for a future contract.

When it comes to predicting who the winning team will be, there are four most indicating features in prediction of the winning team are: defensive rebounds, the points scored by the opposing team, and the number of blocks and assists made by the opposing team. This is a strong indicator that, in order to win a game, it is more important to prevent the opposing team from playing well and scoring points, instead of solely focusing on playing well offensively [3].

Player's performance is most often measured with Player Efficiency Rating (PER). PER sums up positive accomplishments achieved by a player, subtracts the negative accomplishments and returns a per-minute rating of a player's performance. A downside of statistics like PER is a lack of context in which a player performs [4]. For instance, metrics which are based on points differential (e.g. PER, +/-), model the home team's lead dropping from 5 to 0 points in the last minute of the first half in the exact same way that they model the home team's lead dropping from 30 points to 25 points in the last minute of the game. Another problem is that basketball statistical information tends to emphasize offensive performance since there are not nearly as many discrete defensive factors to record in a box score as there are offensive factors. As such, metrics like PER can be

biased against defensive specialists. Therefore, the authors propose a win-probability model for evaluating the impact NBA players have on their teams' chances of winning. This allows them to identify players whose high impact is not captured by existing metrics.

III. Motivation and Aplication

A well-known problem, comparable to the one discussed in this paper, is stock investing. The goal of investing is to buy stocks which have more likelihood of price growth. Investors want to know how does the price of a stock compare to the value of a stock so they can decide whether the stock is overvalued or undervalued. If a stock is undervalued, the investors can be more confident that the price of a stock will rise in the future. Real value of a stock is impossible to determine since there is so much information unknown to the investor. Even if all possible information was available, incorporating them correctly would be a challenge. The same goes for predicting outcomes in sports. The market value of a stock rests on an objective foundation (asset value, debt, income, expected growth etc.) the same way that an offer given by a sportsbook rests on a foundation of different sports parameters. These foundations are influenced subjectively by the law of supply and demand. Although this model cannot predict the subjective influence of people betting on a certain event, it can either help the sportsbooks to set a stronger foundation or help a 'player' to exploit those subjective influences.

A variation of this model can be used by players and teams directly. They can see how does each feature impact the player's performance or the performance of the team and work on those features. For example, if they notice that an opposing team defends the rim poorly, they can try and exploit that weakness.

IV. Data

A. Data Collection

In order to predict future events, one often needs to leverage historical data, often in abundant quantity and quality. Basketball Reference has advanced statistics available for all NBA games played in recent history [5]. We used Beautiful Soup library to collect large amounts advanced data for all active teams and players in regular season of 2017-2018 [6]. Each player (and team) was modelled through a separate data frame, where each row represents one game of the season, and each column represents a piece of information about that game such as points scored, minutes played, assists, rebounds etc. An example of a subset of Steph Curry's data frame for season 2017-2018 can be found in Table 1, together with a subset of his team's data frame in Table 2.

Our goal is to predict the performance of a chosen player Y in a chosen game X. The data will be converted in a way that one instance of the data set contains previously available information about the game X: date of the game, the opposing team, the player's, his team's and the opposing team's past performances.

Table 1. Stephen Curry

Date	G	Tm	Opp	TARGET	PTS
2017-11-04	5	GSW	OKC	1	16
2017-11-07	6	GSW	HOU	0	7
2017-11-10	Inactive				
2017-11-11	7	GSW	SAS	0	7
2017-11-15	8	GSW	LAL	0	5

Table 2. Golden State Warriors

Date	G	Opp	FGA	FTA
2017-11-04	5	OKC	80	22
2017-11-07	6	HOU	70	25
2017-11-10	7	DEN	87	15
2017-11-11	8	SAS	78	20
2017-11-15	9	LAL	60	10

When it comes to real life data, missing values are a common occurrence. For example, some players (for example Dwight Howard) are not good three-point shooters and as such do not even attempt any three-pointers. Looking at one of Howard's games, the following can be seen: 0 three-point shots made (3P), 0 three-point shots attempted (3PA) and a percentage of successful three-point shots (3P%=3P/3PA) with a non-existing value (*NaN*). *NaN* stands for a missing value, since division by zero is not defined. To deal with this, missing values can be replaced by season average, or if season average is also not existent, with 0. After removing all players who have not played at least 17 games with an average of 10 minutes per game, we are left with a total of 432 players.

If a player missed a game for any reason (suspension, coach decision, injury etc.) that game was removed from the data set and information about its deletion was recorded with a new variable. The variable 'missed games' starts with the value of 0 and for every game a player missed, it increases in value by 2, and for every game a player plays it decreases by 1 (with the minimum value of 0). The idea behind this is that if a player missed 1 game, he needs to play 2 games to negate the effect of his absence. This approach is oversimplified and needs to be addressed in future work. One of the problems is that the reason of absence is neglected. A broken nose, a knee injury and a suspension do not have the same effect on player's ability to perform after coming back.

B. Target

For every game X in the season, player's season average was calculated ('PTS_average') for the games played before the game X. Points scored ('PTS') in the game X were then compared to the 'PTS_average'. If 'PTS' was greater than 'PTS_average', the target variable takes the value of 1, if not, it takes the value of 0.

Table 3. History window, size=3, slide=2

Game	Steals	FTA	FGA	FGA-1	FGA-2	FGA-3	TARGET
1	4	12	20	NaN	NaN	NaN	1
2	2	9	15	20	NaN	NaN	0
3	1	9	17	15	20	NaN	1
4	3	4	12	17	15	20	0
5	4	12	14	12	17	15	1
6	2	9	15	14	12	17	0
7	1	9	5	15	14	12	1
8	3	4	8	5	15	14	0

C. History Window

With the idea of capturing relevant past information, creation of new 'history' features was done. Past information can be captured by looking at every game played before the game X. For each relevant statistic of that game, creation of a new aggregated variable, such as the mean or the median, can be done. Although this does capture the player's behaviour in the past, it gives the same importance to all the games, neglecting the time factor. Therefore, usage of the history window is suggested. This history window is defined by two parameters: the size of the window and the slide of the window. The size determines how far in the past we want to look, while slide defines by how many steps we want to move the window through the data. Table 3 shows the creation of three new variables: 'FGA-1', 'FGA-2' and 'FGA-3', where 'FGA-1' represents the field goal attempts a player took one game before the current one. As it can be seen, *NaN* values are present in the first three examples and as such will not be used for training. With a higher window size, more information is available but also the dimensionality of data increases. With a small window slide, more data will be available, but this causes same information to be present in different instances of the data set, as shown in the green and blue cells in Table 3. More data is preferable which is why the slide of size 1 was chosen. Variables from the games which were played six or more games ago did not seem to carry enough information and therefore a window of size 5 was chosen.

D. Rest

Statistics available on Basketball Reference do not offer any information on how well rested the players are. Therefore, a new feature which models this attribute is proposed (1).

$$rest = 1.5x_1H_1 + 1.3x_2H_2 + 1.2x_3H_3 + 1.1x_4H_4 + x_5H_5 \quad (1)$$

where, x_i takes the value of 1 if a player played a game *i* days before the current game, 0 otherwise, and H_i is a value which helps differentiate "home" from "away" games. If a game, which was played *i* days ago was an away game, H_i takes a value of 1.2, if it was a home game, it takes a value of 1.

The idea behind this formula is that away games take away more energy, both mentally and physically due to travel and absence of friendly audience. Furthermore, the games played yesterday should have a stronger effect on the present in comparison to the games played five days ago.

It needs to be noted that current formula ignores travel distance in away games. For example, Los Angeles Lakers and Los Angeles Clippers play in the same arena which makes the travel distance between them non-existent. On the other hand, Portland and Miami are around 5000km apart. Since we expect that this travel distance may have a significant effect on the predictive power on the modelled variable, in our future research we will try to integrate geographical data in our dataset and further develop the above formula.

Table 4. Data after merging, Stephen Curry

Date	G	Tm	Opp	TARGET	PTS	FGA_team	FTA_team	FGA_opp	FTA_opp
2017-11-04	5	GSW	OKC	1	16	80	22	59	18
2017-11-07	6	GSW	HOU	0	7	70	25	60	20
2017-11-11	7	GSW	SAS	0	7	78	20	77	30
2017-11-15	8	GSW	LAL	0	5	60	10	55	15

E. Merging Data

Using the cleaned data, three types of new variables are created for every existing feature: the season average, the average over the last five games and new variables for last five games using the history window. On top of the player data, information about the player's team and the opposing team was added following the principle showed in Table 4. In the end, every example contains around 1200 variables which include player data, player's team data and the opposing team data.

V. Model

First games of the season tend to be highly unpredictable and for that reason, the first six games each player has played were removed from the data set.

Before doing any serious modelling it is necessary to split the data into training and test sets. Two approaches were considered. The first approach was to use a chronological split, leaving out few last games of the season of each player for testing and use the rest for training. This raised some concerns since the context is different based on how far the games were in to the season. Perhaps some players' teams are in the race for the playoffs and may play harder at the end of the season than at the start of the season. Alternatively, maybe some players' teams are last, with no hope of making the playoffs, and just want to rest, avoid injury and start preparing for the next season. Looking at Fig. 3 it can be seen that time is a factor since volume of games and relations between classes differ from month to month.

The same analysis was done on 2016-2017 season and an identical pattern (Fig. 1) has appeared. This is a strong indicator that in every month of the season except for the last one (April), it is more probable for a player to score less points than his average. This all results in a conclusion that chronological split might not be the optimal choice, which is why we settled for a random split in 80/20 ratio.

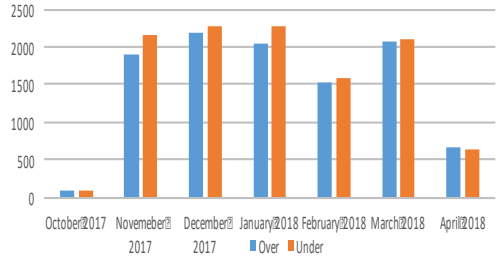

Figure 1. Dependance of time and frequency of over/under

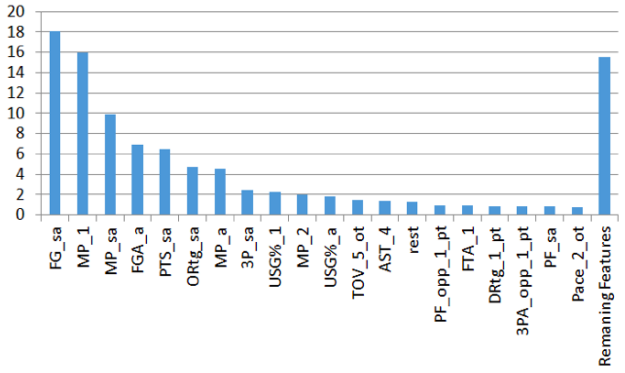

Figure 2. Feature importance

Using Linear SVM with L1 regression, dimensionality of data was reduced to 105 features. The top features are shown in Fig. 2. It is important to distinguish between '_pt' and '_ot' features. The first type ('_pt') represents features that are taken from the players' teams, and '_ot' are features that were taken from the opposing team. 'MP_1' simply represents how many minutes the player played the last game, 'sa' stands for 'season average' and 'a' stands for 'last five games average'.

A description of every statistic can be found in [8]. Two models were tried: Linear SVM and Logistic Regression. In order to prevent overfitting, each model was validated using 5-fold cross validation. All modelling was performed using scikit-learn [7]. After using a grid-search to iterate over the models and parameters, it was found that the Logistic Regression and LinearSVM tend to tperform about equally good, but due to advantage of 0.1%, Logistic Regression was chosen.

Using the random split of data, information about the games in test set could be present in training set due to historical variables. In order to address this concern, the data from season 2016-2017 was collected and used for training, while the data from 2017-2018 was used for testing. This way, we get to keep both datasets representative and independent. The performance of this model did not differ from the performance of the model trained and tested on one-year worth of data. This indicates two great things: patterns in players' behaviour in two consecutive seasons do not differ, and approach of a random data split does not affect the ability of a model to generalize.

Combining datasets from both seasons and then doing a random split, train and test data sets were created, and the process of fine tuning was repeated. The results are

Table 5. Classification report on the test set

	Precision	Recall	F1-score
Under	0.57	0.64	0.60
Over	0.56	0.48	0.51
Average	0.56	0.56	0.56

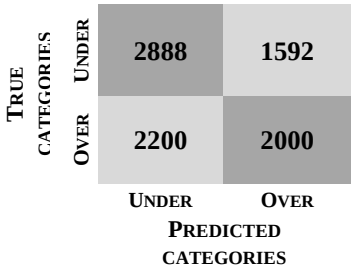

Figure 3. Confussion matrix

presented in Table 5 and Figure 3.

Since no similar models comparable to this model could be found, a comparison was done between the model and the way in which the sportsbooks (sports betting institutions) model the expectations of a player. Sportsbooks tend to offer a certain estimation of a player's points for which they believe that the odds of a player going 'over' or 'under' are 50/50. This estimation is always expressed in a half point number (e.g. 23.5 or 12.5) and a player's season average is used as an anchor. The estimation will differ from a sportsbook to a sportsbook and from a player to a player, but will, in most cases, stay within 1 point range of the player's average. For example, if a player has a season average of 23.4 points per game, it is not uncommon that the sportsbooks will give 50/50 odds of a player scoring more or less points than 24.5 points (1 point higher than his average). One of the reasons for these deviations from the average is player's availability. If a top player is not playing, it is expected from other players to take more shots and score more points than they usually do. Also, sportsbooks tweak their offers based on how people bet on them, and since people tend to bet on a player to score more than his average, rather than less, these offers tend to be higher than players' averages.

Together with the fact that sportsbooks do not give estimations for every player in the league, but only for a certain subset of top players, these facts make the comparison between their models and the model presented in this paper, unfair. Performance of an F1 score of 56.3% and accuracy of 56.7%, presents an improvement of 6.7% in relation to the 50/50 model. Although this comparison is not fair, it is the only one that can be made at this moment.

VI. Future Work

Defensive strength of the opponent (team or a player) could help the performance of the model significantly. Some defensive statistics are present in the model, but there is a lot more information that could be helpful: Who is guarding the player? How well does the opposing team defend the position of that player? If a player scores most points by shooting three-pointers, how well does the opposing team defend the three-point shot? If a player

scores a lot of points by shooting free throws, how often does the opposing team foul etc.? Getting all this information could be challenging, but if successful, very helpful.

At the moment of writing this paper, Dallas Mavericks have the best home record and the worst away record in the league. This indicates that teams, therefore players, perhaps Ado not perform the same when playing away and when playing home. An entire new set of features could be created distinguishing statistics of home games and statistics of away games. This would yield a huge amount of new features.

Some teams like Golden State Warriors find themselves leading by 30 points differential (in basketball terms, a blowout) coming into the fourth quarter. Since they are leading by 30, there is no need for starting players to play and risk an injury, therefore the bench players are given a chance to play. This results in some of the players playing fewer minutes than they are used to, taking less shots and scoring less points. Engineering a new feature which indicates the likelihood of a team to blowout an opposing team, or to be blown out by an opposing team could improve the performance of the model.

The same way how data was combined using two seasons, collection of more consecutive seasons could be used for training the model.

On top of everything stated above, there are a lot of possibilities for new features, not only using statistics but using information from social media and media in general. All of that could be examined in the future given the necessary time.

VII. CONCLUSION

The goal of our research was to identify when the player will outperform and when will he underperform in relation to the expectations of his performance set by past performances. In our case, those expectations were set to be the player's season average.

Using available data, with the help of history window and new 'rest' feature, we managed to achieve an accuracy score of 56.7%. This represents a 6.7% improvement to the 50/50 model. A lot of room is left for improvement and we believe that the inclusion of separate *home* and *away* features, together with more advanced defensive statistics, could have a significant impact on the results.

Two features were engineered by the author: 'missed games' and 'rest'. The first of the two had no impact on the performance of the model. This seems intuitively wrong since it must be significant if a player has missed a certain number of games together with the cause of that. Although 'rest' seems to be informative, coefficients which were used to calculate 'rest' came from intuition and tuning of those coefficients needs to be addressed. The 'rest' feature's formula can be further developed by collection and integration of additional data, most notably the distance that team needs to travel in order to get to the game.

In order to keep as much data as possible, history window slide of 1 was used. Since the importance of history features such as 'MP_5' was near 0, a history window of size 5 was used. The tuning of these hyperparameters will also be addressed in the future research.

Possible applications of this work is seen in sportbooks domain and direct application by teams and players in order to improve their game or exploit the weakneses of the opposing team.

ACKNOWLEDGMENT

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Analysis of the simulation-based procurer behavior determinants

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Abstract - **Digital economy brought higher transparency of the markets where more non-price factors are important in the procurement decision-making of global competition. Procurers state that numerous researchers in marketing have recognized the critical roles of corporate reputation in customer's buying behavior, which means corporate reputation plays a fundamental role. The process of the procurement forms a large part of both corporate and public activities and absorbs many financial and non-financial costs. To decrease those costs, it is essential to understand the dynamics of the procurer - supplier relationship. The purpose of this article is to identify main characteristics that include a price and non-price oriented determinants of the suppliers that are crucial for the procurers. The impact of these characteristics was determined by descriptive statistics, decision trees and correlation analysis over a database of simulations completed by professional procurers of the Slovak companies. The results of the analysis suggest the most influential analyzed parameter is the supplier's price level, but procurers are also influenced by non-price factors as internal and external loyalty ratio to set the preferences about suppliers.**

Keywords – suppliers' preferences, simulation games, digital economy, procurement, e-procurement

I. INTRODUCTION

Tender evaluation and contractor selection are still important and interesting for organizations responsible for providing outcomes. It is one of the most critical points in bringing effectiveness directly related to success and achieving the objectives as profit or performance. Complications arise in identifying suitable and relevant criteria and assigning appropriate weights that may depend on many factors and preferences of organizations or evaluators. Selection is too complex and difficult for a contractor to choose from all these varieties of criteria available [1][2]. There comes the question, which criteria or determinants are the most significant in contractor selection. Is price more important than experience, loyalty or some rating? Is some determinant more important than others for all or does it vary from project to project or do evaluators have different standards?

Most of the procurers may consider a price as the most important determinant as it brings the biggest savings, but mostly only in a short period. In a long period, contracts price is still important, but it may be less important compared to other determinants that resemble services. The authors of the Forrester report presented a study where clients emphasize they were willing to re-purchase from suppliers who have a transparent pricing system and offer consistently low prices, excellent service and a wide range of products. Under excellent service, they understood the individual approach, assistance during the purchasing and after-sales service [3].

Procurement becomes a more important process of trading over the years in both private and public sector. In case of the business sector, the importance of supply chain management intensifies and creates competitive advantages. Same applies to internal procurement processes which are one of the most important for achieving a competitive advantage that leads to an increase in organizational performance. Business to Business Electronic Commerce (B2B EC) has become more important over the years as internet technologies that mediate and facilitate a transaction between buyers and sellers around the world [4].

One of the most important determinants is trust. Studies are using the role of trust based on the premise that trust beliefs about a trading partner mitigate the uncertainties related to vulnerabilities such as opportunistic behaviors, imbalance of power, information sharing and conflicts. The higher level of trust may cause taking a higher risk from a side of a trusted trading partner in adopting B2B EC [5].

Trust may be understood as a condition or situation in which join-action behavior perceptions and attitudes are likely to occur, rather than motivating variable [6]. Trust is too specific as it can be perceived more as a psychological factor that represents the accumulated knowledge about or experience with another party. Trust also include internal ratings, loyalty etc. Trust became more important in times of internet and B2B EC as it promotes these services and is the main reason to use them [7]. For example, Hart and Saunders found out that suppliers' trust in customers increases the suppliers' use of EC services [8]. Zaheer and Venkatraman examined the electronic linkages in the insurance industry and found that insurance agencies' trust in a carrier increases their business toward the carrier over electronic channels [9]. Klein, Rai and Straub report that mutual trust between trading partners increases IT customization for supply chain coordination and improves strategic information sharing about marketing strategies, capacity

planning, production schedule etc. [7]. Trust also increase supply chain's responsiveness, mitigate the variability of inventory levels and improve in-time order fulfillment rate [10][11].

Loyalty is next determinant that has a close connection to trust. Numerous studies analyze the antecedents of client loyalty in the field of B2C EC [12][13][14]. The topic of trust is important for business but there are relatively few studies investigating the antecedents of client loyalty in the relationships between firms in a traditional B2B environment or B2B EC [15][16][17]. Many authors believe that client loyalty is crucial to a firm's survival, especially in the context of e-commerce. That kind of loyalty is not achieved simply with technology, but also requires improving the customer's experience. By the Reichheld & Schefter e-commerce did not change the laws and rewards of building customer relationship but changed the place where these rules hold and the speed with which companies must improve their products and services if they want to attain and maintain client loyalty [18].

The paper is focused on the analysis of a price, non-price and reputation oriented determinants of procurement decision-making processes of Slovak companies.

The paper is split in few different sections. In section II the methodology of the research is explained and used data are described. In section III are shown the results of our research divided into two parts. The analysis performed on the full database is located in Part A. This analysis led to further research with minimization of the positive effect of the price in Part B. Last part IV shows the summary of the analysis results and overall conclusion.

II. METHODOLOGY OF THE RESEARCH

In this paper, we are studying the role of different determinants in procurement decision-making for a winner selection primarily with the focus on reputational factors as ratings and loyalty from internal and external environment extended by price, financial health and social responsibility. The objective of this study is to examine, how different types of reputational management mechanisms can be significant in procurement decision-makings and what behavioral patterns exist in procurement decision-making between commercial procurers. This research was realized by experiment through web-based simulation environment where different procurement situations were simulated and procurement managers from practice were asked to rank three suppliers with different parameters of their offer according to their preferences. Each offer was described by:

- Price (P) with rank from 1 - 5, where 5 was the best price (lowest)
- Internal rating (IR) from 1 – 5 and NA, where 5 was the best rating assessed within procuring organization from historical transaction
- External rating (ER) from 1 – 5 and NA, where 5 was the best rating assessed in the global environment (e.g. market or other business platforms), not by the procuring organization.
- Internal loyalty (IL) from 2 – 4, where 4 is the longest history of business transactions within the procuring organization
- External loyalty (EL) from 2 – 4, where 4 is the longest history of business transactions on the global market or external business platforms
- Financial health of supplier organization (FH) from 2 – 4, where 4 is the highest financial credibility
- Social responsibility (S) from 2 – 4 and NA, where 4 is the highest level of social responsibility in the supplier organization

In parameters internal rating, external rating and social responsibility in specific cases the NA symbol appears. It is a symbol for missing information in this area, so the procurer is unable to detect these parameters.

As mentioned above, in every selection, the procurers have to assign a first, second and third place to the three possible supplier's offers.

The experiment was conducted with 773 procurement or business managers from Slovak companies, where each of them realized approximately 28 cases of a selection of suppliers on average. Altogether we analyzed 21,871 cases generated by the simulation.

Due to the strong influence of the variable price on the preferences of purchasers, we performed analyses also on selected cases in which the value of winning price was lower than the value of the second price. In this case, where the price cannot have a positive impact on preferences, we observed the decisional impact of the non-price parameters. After the filter, the sample consisted of 5,984 cases.

III. RESULTS OF THE RESEARCH

A. *Full database analysis*

To achieve our goal, firstly we performed descriptive statistics in form of box-plot graph visualization (Fig.1).

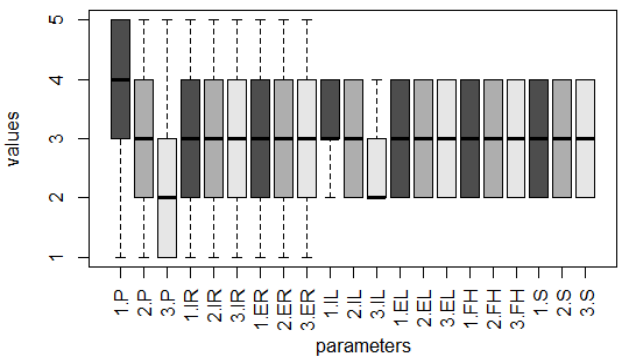

Figure 1. Box-plot of all parameters according to the places

Depending on the supplier position the most visible are the differences in price and internal loyalty. In parameter price, with increasing place numbers the medians are decreasing by one from value 4 in the first place down to value 2 in the third place. It can be caused by the fact that more than 61% of the suppliers with the best prices (value 5) are listed in the first place. Alternatively, the least favorable third place consists of 62.6% of the worst prices (value 1) offered by supplier. Values of the internal loyalty suggest a similar pattern as price - negative relation with placement. 80% of the values in the first place were medium or high (3 or 4) and 42% of all the highest values (4) were present here. Place three contains 51% of the low values (2). Other variables did not indicate the differences according to the position through this method.

Decision tree based on the C5.0 algorithm (Fig.2) identifies the decision-making of the vendors deeper.

The most significant variable is price dividing the tree into groups of worse and better prices. The second level of both branches and the second most important factor is internal loyalty. If the price is inconvenient (values 1, 2) and internal loyalty is low (value 2) with 73% probability the supplier will be placed in the third position. In the case of unfavorable price, even good internal loyalty does not necessarily mean a better position. More than 43% of the cases with better internal loyalty ended in the third place, 39% in the second place and only 17% of these cases were able to achieve the first position. If the price of the supplier was better (values 4, 5) and internal loyalty was average or good 63.8% of the suppliers were aligned to the first place. Cases with a higher price but low internal loyalty shows mixed results when all three positions achieved around third of the cases. A determining factor in these cases is external loyalty. A low value of external loyalty means in 48% third place. A

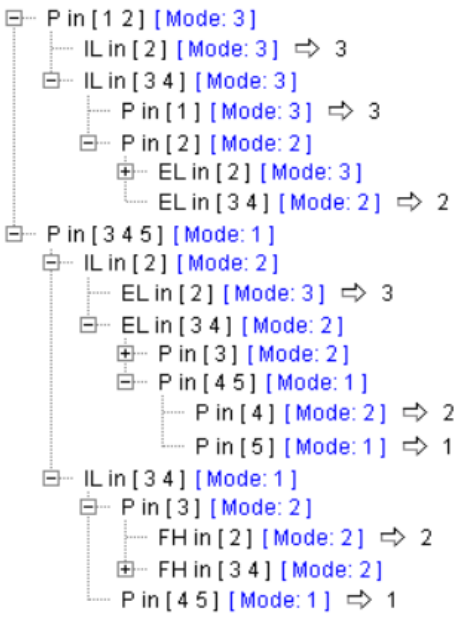

Figure 2. Decision tree - text rules

TABLE I FREQUENCY TABLE OF THE MISSING VALUES

		Parameters		
		IR %	ER %	S %
Position	1.	19,9%	26,0%	19,8%
	2.	29,5%	32,8%	29,3%
	3.	50,6%	41,3%	50,9%

middle or high value of external loyalty with a medium price (value 3) means a bit more than 40% probability to be in second place.

Specific cases in the simulation contained an unknown value of at least one of the variables - internal rating, external rating or satisfaction. These settings reflect real-life conditions where purchasers do not work with the supplier yet (IR value is unknown), the supplier is unknown on the market (ER value is unknown) or vendor cannot access the social responsibility level of the supplier (S is unknown). According to the results of the simulation (TAB.I), unknown characteristics of the suppliers leads to doubts and vendors would prefer to work with suppliers that they know and are an active part of the market. We can point out the fact that the variable external rating has noticeable more missing values in the first and second place than other two variables, so the procurers are less sensitive to missing external rating than to missing values in two other variables. Procurers tend to choose suppliers that provide them with more information.

Finally, we decided to confirm the results with Kendall's tau correlation analysis between achieved places of the supplier's offer and parameters (TAB.II). All variables suggest a negative impact on the offer's place, which means that with the lowering of the variables the achieved places are increasing. This is in accordance with the settings of the simulation that bigger values of the parameters represent a more favorable situation for procurer. The strongest correlation signifies parameter price. 14.5% of the total variation in places is related to price and 4.8% of the variation is related to internal loyalty. Internal rating, external loyalty and financial health reached almost the same values less than -0.1. The slightest impact on the supplier placement according to the Kendall correlation has parameter social responsibility.

B. Minimalisation of the positive effect of the price

The abovementioned analysis is highly influenced by the parameter price. To reduce the price impact, we analyzed only the cases in which the price in the first place is worse than in the second place. This filter minimized the positive influence of the price, and we focused on the non-price variables influencing the

TABLE II CORRELATION TABLE BETWEEN PLACES AND PARAMETERS

Kendal's tau	P	IR	ER	IL	EL	FH	S
Places	-0,38	-0,10	-0,06	-0,22	-0,11	-0,11	-0,05

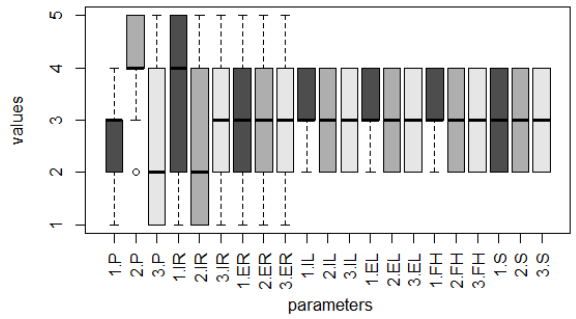

Figure 4. Box-plot of all parameters according to the places in a sample

decision-making process.

Box-plot graph from the filtrated database uncovers more parameter movements between places than in the original database (Fig.3). Because of the filter settings, the price is moving differently than in the original dataset. The price in the first place is lower than the price in the second place, but third place contains of the large span of values even though its median is lower. Internal rating value in the first place has higher values, but notice-worthy is the development in the second and third place. The median of internal rating's second place is 2, which is lower by a 1 apart from position three with a median value of 3. The reasons for such difference could be rooted in the several issues. The second position consists of 29.4% more lowest internal rating values (value 1 and 2) than the third position. This could suggest that in the second and third place procurers do not use parameter internal rating to decide.

This explanation is elegant, however, the second reason for listing suppliers in this order could be the appearance of missing values. During plots creation, the missing values are omitted nevertheless vendors' decisions were influenced by missing/unknown values. As a consequence, the third place consists of more than 47% of the internal rating missing values. This ratio represents 21% more missing values in third place than in the second place. Parameters internal and external loyalty and financial health reveal the minor differences in the box-plots, even though the medians are in all three positions the same. Each parameter has in the first place at least 40% of all the high values (value 4). With the increase of the places, the frequency of the smaller values increase.

The decision tree revealed that the most significant variable in decision-making is internal loyalty followed by external loyalty (Fig.4). Internal loyalty similarly as a price in a full sample divides the cases to two categories – group of low values and group of medium and high values. With low internal loyalty (value 2) there is only a 14% chance to be in the first position and in combination with low external loyalty, the chances are below 10%. With low internal loyalty and higher external loyalty, there is less than 16% chance to be in the first position. This shows the enormous importance of internal loyalty for the purchasers. Even though external loyalty would reach higher values (value 3 or 4), an increase between probabilities of being in the first position with a lower

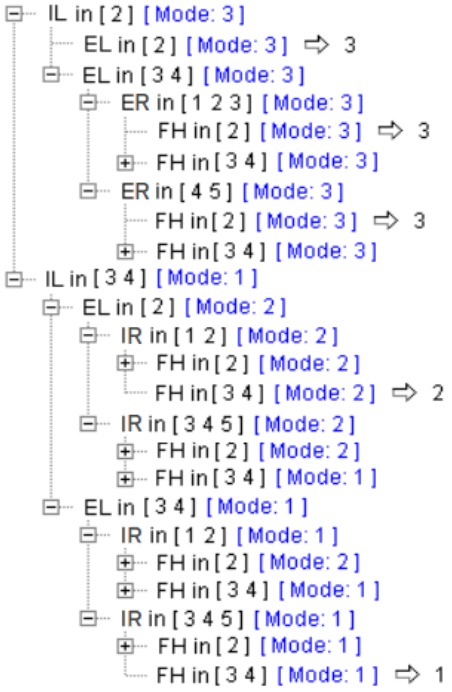

Figure 3. Decision tree of the sample - text rules

external rating (values 1, 2 and 3) or with a higher external rating (values 4 and 5) moves from 12% to 21.5%. Low internal loyalty, in any combination with other parameters, will end up with almost 40% probability of the supplier positioned in the third place.

On the other hand, with a higher value of internal loyalty, the chances for a supplier to be in the first position are 43%. If the supplier has, besides that, higher also external loyalty, the probability increases to almost 52%. Higher internal loyalty in combination with low external loyalty generates 26% chance of being in the first place. With a higher possibility of 40%, this supplier would end up in second place. To be in the first place with 66.98% supplier would have to have higher values of all internal and external loyalty, internal rating and financial health. Internal rating and financial health are the third and fourth level of the decision tree.

A frequency of missing values in the filtered database increasing when the position of supplier's offer is increasing (TAB.III). This result confirms the result of the analysis of the whole database performed above. We can also identify the difference in sensitivity of procurers to external rating, and also that in this parameter frequency in the second and third place is almost

TABLE III FREQUENCY TABLE OF THE MISSING VALUES IN THE SAMPLE

		Parameters		
		IR	ER	S
Position	1.	14,0%	20,9%	14,1%
	2.	38,9%	39,0%	38,5%
	3.	47,1%	40,1%	47,4%

TABLE IV CORRELATION TABLE BETWEEN PLACES AND PARAMETERS IN THE SAMPLE

Kendall's tau	P	IR	ER	IL	EL	FH	S
Places	0,01	-0,16	-0,1	-0,24	-0,14	-0,11	-0,07

identical.

Kendall's tau correlation analysis between achieved places of the supplier's offer and parameters revealed a positive correlation with the price and negative with other parameters (TAB.IV). A small positive correlation is due to the settings of the filtration. The biggest negative correlation is between positions and internal loyalty with 5.47% of the variability related to internal loyalty. Higher correlation with positions also has an internal rating, external loyalty and financial health. Other two parameters explain less than 1% of the volatility of the positions.

IV. CONCLUSION

The paper is focused on the analysis of a price, non-price and reputation oriented determinants of procurement decision-making processes. The impact of these determinants was measured by a web-based environment where procurement or business managers from Slovak companies rank simulated offers based on their preferences. In accordance with the research results, it can be assumed, that the most significant factor of the procurement decision-making process is the price. With price influence elimination we observe non-price factor internal loyalty to be the most important non-price oriented determinants of procurement decision-making processes. The noticeable influence of the factor internal loyalty may be a strong cultural phenomenon of post-communist countries, where the fear of changes in supply chain stability and changes in general, is higher than in market-advanced countries. Variables external loyalty and internal rating are also representing the variables with high impact on the preferences of the purchasers. On the other hand, the factor as social responsibility seems to have the lowest impact on decision-making processes.

Our research, in the field of missing values in suppliers' offers, confirms that additional information increases confidence in the decision-making process and therefore full awareness is prioritized to the first places.

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The Automation of the Data Lake Ingestion Process from Various Sources

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***Abstract* - In a big data environment, it is often necessary to ingest data from different sources into a unique storage. Because of low memory price, system distribution and failure tolerance, that storage is typically HDFS. It enables users to manipulate data with different tools from the Hadoop ecosystem. The process of data ingestion seems simple. However, because sources can be different database systems, structured, semi-structured and unstructured data complicate the ingestion procedure. It is usually not enough to just store everything. Data needs to be stored in such a way that enables users to quickly access and manipulate it. There are many ingestion-specific solutions in the big data ecosystem. This paper will describe an implemented system for data ingestion from MSSQL, MySQL and Postgres into a Hive database. The process starts with creating tables with corresponding metadata, continues with the ingestion process and ends with a description of how the process is automated. The implementation of Sqoop as an open-source tool and Hue, a web user interface from Cloudera, will be described.**

Keywords - hadoop; sqoop; hive; data ingestion automation; big data

I. INTRODUCTION

Big data is a buzzword that has been around for more than 10 years. It is a set of new and emerging technologies created with the desire to better handle data with "3V" properties: velocity, variety, and volume [1].

Therefore, big data technologies are tools for managing data that arrives fast and is captured constantly (sometimes in near-real time), data that arrives in different formats (structured, unstructured, semi-structured) and needs to be stored (so we need a lot of storage space to archive large volumes of data).

Big data tools are not here to replace traditional OLAP or OLTP systems (including relational database systems, data warehouses, etc.). Instead, these two paradigms are supposed to coexist and they are complementary [2]. Some big data tools are open source and some are commercially licensed.

However, there are commercial distributions (bundles) of popular big data tools (Hadoop, Hive, Spark, etc.) that significantly simplify the process of software installation and maintenance. These bundles usually come with a free commercial license. However, their support is not free. Two most popular examples are Hortonworks HDP [3] and Cloudera CDH [4].

II. PROBLEM DESCRIPTION

The requirement of our project was to ingest tables into an HDFS archive on an hourly/daily/weekly basis. Data must be easily readable and explorable using standard SQL. Data sources in our case are: Postgres, MySQL and MSSQL, as well as server logs in text format. We need to make incremental copies to save space where possible[a]. High-level architecture is shown in Fig. 1.

One source contains unstructured data (text log files). To prepare those text files and enrich data (e.g. append appropriate keys etc.), R Studio Server was used, and the result is a data frame stored in HDFS as a Hive table.

Finally, another requirement was to export some tables (extract phase) to a relational database where they will be prepared (transform and load phases) for data warehousing.

An important requirement is to avoid dependency on optional Big Data Appliance software: Oracle Big Data Connectors, Oracle Data Integrator, and Oracle Golden Gate [5].

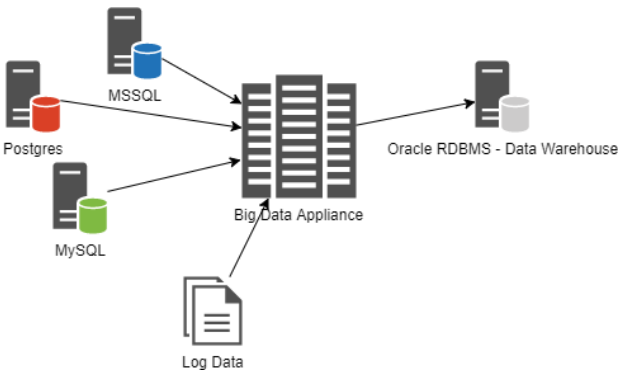

Fig 1: System architecture

III. TECHNICAL ENVIRONMENT

The big data environment we used is Oracle's engineered Big Data Appliance that consists of a rack with 6 servers and the Cloudera CDH Enterprise software. The most important hardware and software specifications are shown in Table 1 and Table 2 [5].

[a] Some tables have edit timestamps in each row, therefore it is not necessary to make complete snapshots of those tables with each load.

TABLE I. HARDWARE COMPONENTS

Component	Description/Version
Complete HW/SW engineered system	Oracle Big Data Appliance X6-2
Number of nodes	6
Operating system	Oracle Linux 6.9
Processor (per node)	2x22 Core Intel Xeon (2.2 GHz)
Memory (per node)	8x32 GB DDR 4
Storage (per node)	12x8 TB

TABLE II. SOFTWARE COMPONENTS

Component	Version
Cloudera CDH	5.12
Apache Hadoop	2.6.0
Apache Hive	1.1.0
Hue	3.9.0
Apache Sqoop	1.4.6
Apache Oozie	1.4.0

IV. SQOOP

Sqoop is a set of open-source tools for data transfer between relational databases and HDFS. A Hadoop cluster (single node or distributed) is a precondition to run Sqoop [6].

It offers a possibility of data transfer to and from Hadoop. Data transfer can be parallelized using a map-reduce infrastructure. Sqoop is a command line tool with no graphical user interface. It is built for Linux and supports many relational databases and Hadoop versions. The command line interface has the following structure:

```
sqoop tool-name [tool-arguments]
```

Table 3 shows a list of some available Sqoop tools. We choose a tool depending on the action we wanted to perform. Sqoop accepts two types of arguments: generic and tool-specific. For example, the Sqoop "import" tool has the following structure:

```
sqoop import [GENERIC-ARGS] [TOOL-ARGS]
```

Generic arguments (preceded with a single dash) must always precede tool arguments (preceded with two dashes).

This paper will focus on a few important Sqoop tools listed in Table 3. One tool will be presented with an example and its explanation.

To import an entire table from RDBMS to HDFS, we would issue the following command:

```
sqoop import \
--connect jdbc:mysql://mysql.example.com/sqoop \
--username sqoop \
--password sqoop \
--table cities \
--target-dir /etl/input/cities
--where "country = 'USA'"
--num-mappers 10
```

This piece of code uses the import tool to copy data into HDFS from a table called "cities", which is stored in the MySQL database. We have provided the connection string, username, and password, as well as defined the final location on HDFS for the imported data. We can specify a condition so only a subset of the data will be imported. The last parameter defines the number of concurrent processes to execute the import. Sqoop fetches metadata from RDBMS and automatically splits rows using the table's primary key [7].

This example is simple and uses a plaintext password. This is very insecure, because the password will be stored in logs and can be easily read. It can be read by other OS processes as well. It is better to use a password file or the Credential Provider API on Hadoop instead. One should be careful when setting the number of mappers. The "num-mappers" parameter sets the maximum number of parallel processes that read single table's data. When this value is too low, then the data throughput might be suboptimal. When this number is too high, Sqoop might overload RDBMS's resources, which might cause a suboptimal throughput as well and cause problems for other users of RDBMS. Furthermore, this example imports a single table. If we want to import many tables, we could use the "import-all-tables" tool. Instead of only importing data into HDFS, it is possible to create Hive tables using the metadata from RDBMS and automatically populate them.

When using Sqoop to move many tables (hundreds) to HDFS, we faced several issues that caused import jobs to fail. Some tables have SQL keywords as column names (e.g. "order") or contain special characters which are unsupported in Hive table names or column names. Also, we noticed that timestamps get imported as Linux epoch timestamps (Hive bigint type). To override Sqoop's SQL queries which it runs against RDBMS, we had to use free-form queries for each table. This is an option which significantly limits Sqoop's features. It allows the user to import only a single table at a time and does not support the option to import into a partitioned Hive table (only non-partitioned Hive tables are supported for free-form query imports). These limitations required us to write bash scripts to automate two or more import steps. These steps are logically organized as workflows.

TABLE III. IMPORTANT SQOOP TOOLS

Tool	Description
create-hive-table	Import a table definition into Hive
export	Export an HDFS directory to a database table
import	Import a table from a database to HDFS
import-all-tables	Import tables from a database to HDFS
list-databases	List available databases on a server
list-tables	List available tables in a database

V. WORKFLOW PROCESSES

Our proposed solution bypasses Sqoop's limitations stated in Chapter 4. The functional requirements are:

- A periodical import of data from Postgres, MySQL and SQL Server databases into Hive tables.
- The user must be able to select the tables for import.
- The imports can be full copies or copies of incremental changes where possible (new increment contains data that is created or updated since the last increment).
- There needs to be an option to filter data before the import (i.e. in the WHERE clause).
- Hive tables need to be in a format that supports partitioning and is readable by Impala as well.
- Since there are many tables, they need to be created automatically using metadata from RDBMS and the list of tables should be defined by the user.
- There needs to be a log that contains a status for each process.
- Processes must be scheduled so they can be automatically started at a defined time.

A. *Workflow Design*

Workflows are atomic units of work that can be nested and are written as BASH scripts. There are two levels of workflows: nested workflows and outer workflows. There are three types of nested workflows: create a Hive table, import data into Hive or export data from Hive to an external RDBMS. The outer workflow controls the start of nested workflows (nested workflows are often started in parallel). Fig. 2 shows the basic workflow schema with inputs and outputs. The workflows take one configuration file. Each row in that file contains information: source schema and table, destination schema and table, filter conditions, source table primary key, optional data type mappings and a list of timestamp columns. A user can optionally submit a file with table/column name pairs. Each row is a pair (old table name, new table name) which allows the user to bypass the naming limitations in Hive.

A workflow can have one of four states: "Not started", "Success", "In process", or "Error". A workflow instance is defined by its unique ID, name, start time, and status. Nested workflows follow a certain set of rules regarding states. If all nested workflows are in the "Success" state, then the outer workflow is in the "Success" state. If any nested workflow is in the "Error" state, then the outer workflow is in the "Error" state, regardless of other nested workflows, unless there are workflows in the "In process" state, i.e. if any inner workflow is in the "In process" state, then the outer workflow is in the "In process" state.

Once the main (most outer) workflow is started, all nested workflows will be started subsequently or in parallel. Outer workflows accept a parameter that defines the degree of parallelism. It is the number of nested workflows that are started simultaneously and depends on the available Big Data Appliance resources, network bandwidth and source database resources.

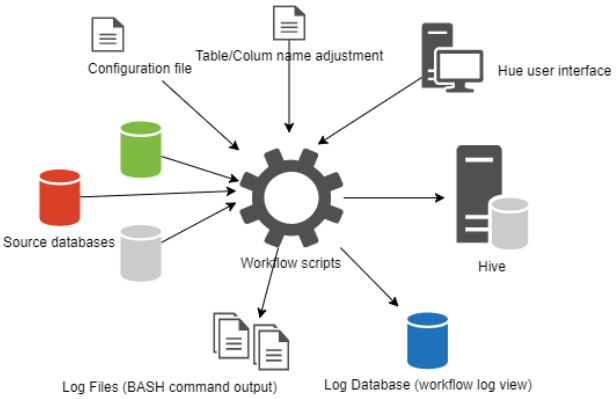

Fig 2: Workflow architecture

B. *Workflow Logs*

An important part of this design are the log table and the consolidated view. Whenever a workflow is started, a new entry is stored in a table in an external relational database. All workflows follow the same pattern of writing logs. The log table contains the following columns (Fig. 3):

1. Workflow ID
2. Workflow name
3. Load time
4. Status time
5. Comment (optional)

When a workflow starts, it stores a new row with a unique incremental ID. When a workflow ends (either with the "Success" or "Error" status), a new row is stored in the log table again. This (second) entry has an identical ID to the corresponding entry that was stored when the workflow was started.

Table data is consolidated using a view by combining rows with the same workflow ID. Columns defined in the view are:

1. Workflow ID
2. Workflow name
3. Load time
4. Workflow duration in seconds
5. Status
6. Start comment
7. Start time
8. End time
9. Error time
10. End comment (optional)
11. Error comment (optional)

The workflow view consolidates rows from the workflow table and simplifies status checking. These log entries are used to control subsequent starts of the same workflow and incremental data imports. Workflows can be started an arbitrary number of times by the user, however, before starting the workflow, the log view is queried. If the pair ("Workflow name", "Load time") already exits with the "Status" column marked as "Success", the workflow simply exits with a successful internal state (no entries are written to the log table). If the pair exists with "Status" column marked as "Error", then the workflow is started from the beginning. Of course, if the pair does not exist, the workflow is started normally. This way, workflows are idempotent, i.e. they can be started without the risk of data duplication.

Similarly, the workflow log view is queried before importing incremental data. Incremental imports require an upper bound and a lower bound. In this case, bounds are defined by the "Load time" column. The lower bound is always the largest "Load time" value for the given workflow name. The upper bound is defined by the user before starting the main workflow. If the largest "Load time" is smaller than the current user defined parameter (or it does not exist), the workflow is started from the beginning. Otherwise, the workflow simply ends with a successful inner status (i.e. nothing is written in the status table). Again, the risk of data duplication is eliminated.

C. *Hive Table Format*

Our solution uses the Parquet table format for storing data in Hive. The most important reason for using Parquet is its compatibility between Hive and Impala. Both can read and write to Parquet tables. Parquet supports table partitioning and it can be read by Pig and map-reduce. However, there is one significant limitation. Hive does not support SQL UPDATE or DELETE statements on Parquet tables. We bypass this limitation by partitioning all tables by load date. Once the data is imported, there is no need for updating or deleting rows [b]. Since all tables are partitioned, we can use the ALTER TABLE … DROP PARTITION statement do delete entire partitions and reimport them if necessary.

[b] The architecture assumes insert/append operations on the data, not update or delete.

Workflow ID	Workflow Name	Load Time	Status Time	Comment
61734	Sample_outer_workflow	20190223_000000	20190224_144255	
61734	Sample_outer_workflow	20190223_000000	20190224_144352	
61735	Sample_inner_workflow_1	20190223_000000	20190224_144255	
61735	Sample_inner_workflow_1	20190223_000000	20190224_144417	
61736	Sample_inner_workflow_2	20190223_000000	20190224_144316	
61736	Sample_inner_workflow_2	20190223_000000	20190224_144352	

Fig 3: Log table

VI. AUTOMATED TABLE CREATION AND IMPORTS IN HIVE

A. *Creating Tables*

Since the system needs to able to handle potentially many tables (hundreds or thousands), we need a way to automate the process of tables creation in Hive. This is done by using Sqoop. Sqoop provides a tool to create tables in Hive with corresponding data types from source databases. The tool is called "create-hive-table" and it is listed in Table 3. It populates Hive metadata (almost) exactly as seen in a source database. However, this tool has certain limitations, so we decided to create a two-step process (workflow). In the first step we use the usual Sqoop import tool (that creates a Hive table if one does not exist). In the second step we use Hive's Beeline tool [2]. The reasons for that are as follows:

- It was necessary to append an extra column to every table to mark the load date for every row in Hive
- It was necessary to have an optional column name and table name adjustment for compatibility between source systems and Hive
- Sqoop does not handle datetime columns well, those columns are mapped to the *bigint* type in Hive, which makes the column unreadable by the user. Datetime columns need to be converted to string type columns.

The creation process is controlled by a configuration file. A single row in the configuration file contains the following columns: target database (in Hive), source schema, source table, list of datetime columns (if they exist), and a primary key column. Optionally, the user can add another configuration file where each row is a pair (old table name, new table name) which allows the user to bypass naming limitations. The creation workflow has two iterations.

The first iteration creates temporary databases and temporary unpartitioned tables with original columns (metadata is read from RDBMS), adjusted column names

(if necessary), new columns containing datetime values formatted as string, and a LOAD_DATE column at the end. Sqoop "import" is the tool used in this iteration. The result is a set of unpartitioned tables.

The second iteration creates final databases and partitioned tables using metadata from temporary tables. Beeline is the tool used in this iteration. It is the Hive command line interface that supports execution of SQL commands (e.g. DESCRIBE TABLE, CREATE TABLE etc.).

B. Importing Data

Once the necessary tables are in place, we can begin importing data. There are two workflows used for this purpose: one workflow for the full table import, and another for the incremental import. Each workflow uses two configuration files, same as described in Subsection A.

Free-form queries are used for importing data with Sqoop. First, we read metadata from Hive tables using Beeline. With this metadata, we construct a SQL query with necessary aliases, casts, timestamp reformats, and filters. Then, an import command is run (Sqoop) and all incoming data is stored in a parquet file on HDFS. Finally, we import data into Hive using Beeline (LOAD DATA INPATH command). The incremental load is similar, but it adds conditions in the WHERE clause that only filters data for a new increment. For filtering, we read the necessary dates from the workflow logs described in Section 5.

This process is written as a BASH script which uses Sqoop and Beeline tools. BASH scripts are incorporated into Oozie using Cloudera's open-source tool Hue which provides a user-friendly graphical interface for accessing HDFS, Hive, and Oozie scheduler [8].

VII. OOZIE WORKFLOWS AND SCHEDULES IN HUE

The last step of creating an automated process of data ingestion is incorporation of a user-friendly interface. The Hue web application comes bundled with the Cloudera CDH environment and we can use it for managing Oozie workflows and schedules.

The Oozie workflow (shell action) in Fig. 4 is the entry point for our BASH scripts. It provides a single place to manage files (code and configurations) and input parameters.

Oozie scheduler in Fig. 5 is the entry point for managing scheduled workflows. The scheduler can provide input parameters for its workflow. For example, we provide the LOAD_DATE parameter depending on the date when the workflow started.

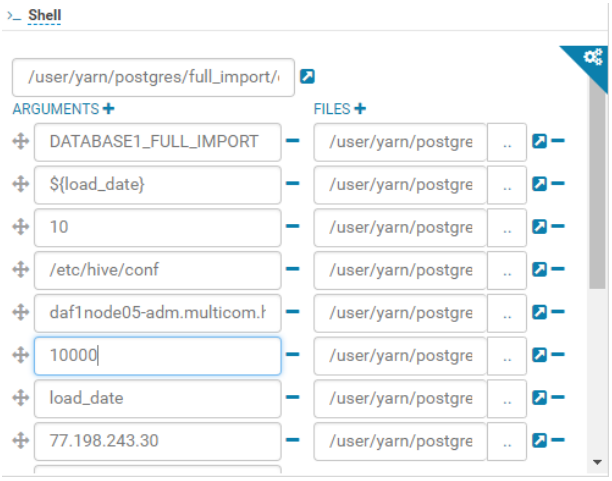

Fig 4: Oozie workflow in Hue

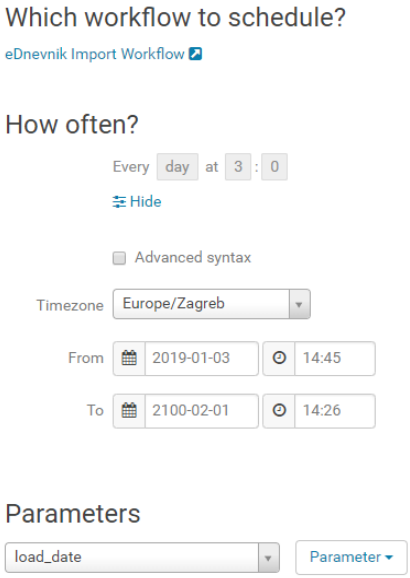

Fig 5: Oozie scheduler in Hue

VIII. DISCUSSION

The solution described in this paper was developed in a hardware and software environment provided as-is by the customer. It would be possible to use Spark instead of Sqoop, since Spark is a part of this Cloudera distribution. However, we decided to use Sqoop because its purpose is exclusively the data transfer between Hadoop and relational databases.

The process of automated table creation takes a long time, approx. two minutes per table, compared to a CREATE TABLE statement in Hive that takes under a second to complete. This may or may not be an issue, considering that table creation is a one-time action.

Sqoop can verify imports by comparing row counts in the source table and destination table. However, this option is not supported when using free-form queries. It would be good to have a separate module for verification which could restart a workflow in case a mismatch between row counts is found.

Workflows rely on metadata from Hive tables to create SQL queries which fetch data from RDBMS. If a table in RDBMS changes later (e.g. a new column is added, or a column is dropped), then those changes must be manually propagated into Hive.

IX. CONCLUSION

The variety of big data technologies and tools can make appropriate implementation somewhat challenging. They are not meant to replace standard relational databases, but instead they are complementary. We saw first-hand there were some obstacles to overcome. Enough time for research should be planned before a big data project starts. Research, education, experience (if exists), and proper planning are crucial since big data tools are relatively new and immature. Documentation for Hive and Sqoop is not very detailed, so we recommend reading books listed under references before starting a project. The work on this project is not finished, there is space for optimizations and modifications that will add more robustness to the design.

X. ACKNOWLEDGMENT

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Mining Learning Management System Data Using Interpretable Neural Networks

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***Abstract* - The paper presents the work on data analysis of LMS data related to the course Programming 2, one of the introductory courses at the first year of the study of Informatics at the Department of Informatics of the University of Rijeka. In order to improve the course we analyze the data from the Learning Management System (LMS) with the emphasis on some additional activities which are not graded, such as watching video lectures. We are interested whether these activities have positive impact on the student success. The data analysis can objectively evaluate their role, the effect of improvement, and their impact on the learning process. The paper presents discovery of knowledge about the process of learning using batch data analysis performed by Artificial Neural Networks (ANNs). ANNs are not a common method in the field of educational data mining. Although highly accurate, the resulting black-box model is not interpretable, which is a major drawback. For the opening of the ANN black-box model, as well as for other models of this type, a number of agnostic methods have appeared recently, some of which we illustrate in the LMS system analysis.**

Keywords – Educational Data Mining, predicting student success, LMS system, Interpretability, Interpretable Machine Learning, model interpretation

I. INTRODUCTION

Within the Learning Management Systems (LMS), large amounts of data are collected. By analyzing the data we can gain valuable insights about the learning process and the meaning of certain course activities for achieving learning outcomes. In the fields of Educational Data Mining (EDM) and Learning Analytics (LA) a large number of works have been published in the last two decades, especially after the massive availability of educational content within mass open online courses (MOOC) [1, 2, 3].

The paper presents the study continuing the line of work presented in [4, 5, 6, 7]. We analyze the significance that watching video lessons within the course Programming 2 has on the final success of students. In the data analysis we use feedforward artificial neural network (ANN). Watching video lectures is a student activity for which students do not get scores. The objective is to confirm the hypothesis that watching video lessons has a positive impact on the student course success.

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ANNs are powerful data analysis tool for modelling relationships between system parameters for the most accurate prediction of outcome. Trained ANN holds significant information related to the research hypothesis. However, the ANN model is the black-box model type and does not support generating the predicted outcome interpretation [8, 9, 10, 11]. Because of this deficiency, ANN is not frequently used in EDM and LA [12]. One of the goals of this paper is to supplement the neural network prediction with the interpretations based on the visualizations obtained by the agnostic and non-agnostic methods of the black-box model interpretation to get explanations for predictions [10]. An explanation of a predicted outcome is of great importance in the exploration of the research hypothesis. Additionally, it helps to get personalized information in the learning process that will help students in guiding their activities.

The paper is organized as follows. Section two presents related work in the field of student success prediction, and opens the state of the art issue box regarding the use of ANN in the EDM field. Section three introduces the data set and presents the methods we use in order to predict student grades and explain outcomes. The discussion of the results is given in section four. We conclude with some open issues for future work.

II. RELATED WORK

Since LMS systems incorporate both teaching and assessment of student work, they generate large amounts of data. Data mining techniques have to be used for their analysis [2, 3, 13]. Applied methods and goals in the field vary but they all aim at supporting decisions on how to improve teaching and learning processes.

Several approaches deal with the task of predicting student success on the basis of log data of student course activities [14, 15, 16, 17]. In [14] authors analyze relationships between various online course student activities (e.g. video streaming online learning activity, number of chat messages and questions) and students' learning performance. Reference [17] presents a research applying Large Margin Nearest Neighbor Regression in student performance prediction on the basis of activities such as blog, microblogging tools, and collaboration activities. In [16] a grammar guided genetic programming algorithm, G3P-MI, has been applied to predict whether

the student will fail or pass a certain course and to identify activities which promote learning in a positive or negative way from the perspective of Multiple Instance Learning (MIL). Another approach uses genetic algorithm (GA) designed for discovering association rules classifying students in order to predict their final grade based on features extracted from logged data [15].

Most of the research in data analysis of the LMS system data, as well as in predicting student success, have applied the white-box models (e.g. Decision Trees, Logistic Regression). These methods are not all equally successful for various data sets in the field of education [12]. Reference [18] present a meta-learning approach which recommends the most appropriate white-box model subset for a given Moodle data set in the problem of predicting student course success. The authors argue that white-box models are better choice than black-box models e.g. Support Vector Machines and ANNs, although the latter is more accurate but lacks interpretability [12]. One of the newest EDM methods survey [19] lists only four ANN approaches in the period from 2002 to 2010. There are several approaches applying neural network models with higher prediction accuracy as their main strength but at the same time disregarding the model interpretation [20, 21, 22].

Opening the black-box of neural networks by introducing model interpretations is essential for various application fields. The black-box systems are based on black-box as the predictor in the task of predicting sensitive individual information like credit score, insurance risk, health status, and in our case student success. In the paper "Survey of Methods for Explaining Black-box Models" [10] the authors argue that data could be a source of human biases and prejudices, measurement errors possibly leading to wrong and unfair decisions. The General Data Protection Regulation (GDPR) introduced the right to get an explanation for all individuals in order to obtain "meaningful explanations of the logic involved" when automated decisions take place [23].

In the case of predicting student grade this kind of explanation helps teachers to enrich their expertise on the learning process. Explaining the model prediction outcome is crucial also for students. Students need information about critical model predictors in order to change their learning behavior to achieve the planned learning outcomes. Reference [10] presents recently developed agnostic approaches for explaining black-boxes. An agnostic explanator works with any black-box type providing an Interpretable Machine Learning system. Examples of methods solving the model outcome explanation problem are LIME [8], LORE [9] and ANCHORS [11], providing a locally interpretable model that is able to explain the prediction of the black-box in terms understandable for humans for a specific instance.

TABLE 1: DATA SET ATTRIBUTES AND THEIR DESCRIPTIONS

ID	*Attribute*	*Description*
1	lectures	The total number of scores the students received within the lectures
2	quizzes	The total number of scores the student received on two quizzes
3	labs	The total number of scores the student received in labs
4	videos	The total number of views of the video lectures
6	grade	Binary: PASS / FAIL

III. DATA SET DESCRIPTION AND METHODS

A. *Data set description and the research problem*

The data set "EDU408" used in the research comes from the programming course "Programming 2" from the Moodle type e-learning system at the University of Rijeka, Department of Informatics. We work with the anonymized data set containing 408 instances for five generations of students (2013/14-2017/18) and 5 attributes (Table 1). The course is a blended course including face-to-face classroom activities assuming 70% of student presence as well as e-learning in the Moodle environment. The grading system for individual activities is: labs including homeworks (0-57), lectures (0-7), and quizzes (0-36). We investigate the significance of the additional activity of watching video lectures, "videos" for the student performance. There are in total 13 individual video lectures and the duration of one video is 10-15 minutes. The video of a lecture becomes available to the students after that lecture so they can adjust learning to their own pace (Fig. 1).

B. *Artificial Neural Networks (ANN) and EDM*

A number of studies dealing with the use of ANN in the field of EDM [20, 21, 22] do not provide explanations for their outputs. Our study illustrates how to open the ANN black-box giving information

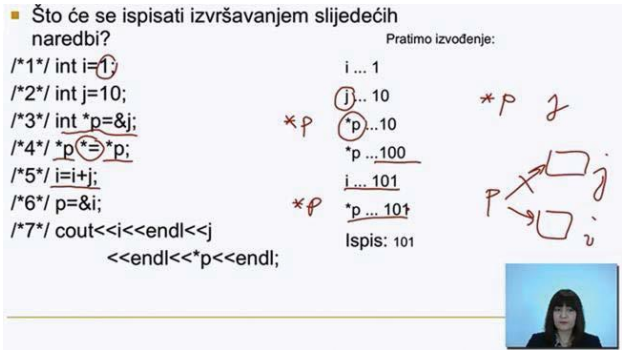

Figure 1. Screenshot from a video lecture

on the impact of all attribute values that relate to the output variable. We use feedforward ANN with a single hidden layer. Cross-validation is used to select the best model by tuning the number of hidden nodes in the network and the rate of decay for changing the neural network weights in the back-propagation algorithm. More details about training ANNs can found in [24].

C. *Garson's algorithm and Lek's profile method*

In our analysis we apply also two non-agnostic approaches developed for explaining importance of neural network predictors [25, 26]. There is a flexibility in modelling complex input variables relationships due to a large number of adjustable weights connecting neural network neurons to the outcome neuron. Garson's algorithm identifies all connections between each predictor and the outcome variable. The algorithm as the result gives the relative predictor importance.

Lek's model can be applied only for continuous predictors. The general idea is to observe each predictor by keeping the others fixed. Each variable is divided into a certain number of equal intervals between its minimum and maximum values. The profile of the output variable is plotted for the values of the variable considered. We obtain a set of profiles of the variation of the output variable according to the increase of the input variables [25, 27].

D. *Explaining Black-box Model and Model Outcome*

A black-box predictor is a machine learning obscure model with either unknown internals or internals uninterpretable to a human [10]. Interpretability implies giving explanations of concepts to people in understandable form. In the prediction problem, the goal is to explain certain decision for a particular entry.

When the model is fully interpretable, we are talking about global interpretability. If it is possible to understand only the reasons for making an individual decision, we are talking about local interpretability. Examples of interpretable models often used are decision trees, rules, linear models. The problem of explaining a black-box is actually giving a global explanation of the black-box model using an interpretable model that mimics the behavior of a black-box and is human understandable, i.e. it is globally interpretable.

For a given black-box and an input example, the problem of explaining the outcome consists of providing a black-box explanation for that input example. It is not necessary to explain the whole logic of a black-box, but just the reason for the prediction on a particular input example. The assumption is that the interpretable local model cl was created based on the black-box b and the instance x, and then the explanation was derived from the cl. Reference [10] gives the following definition for outcome explanation problem.

Definition: Given a black-box predictor b and an instance x, the outcome explanation problem consists in finding an explanation e $\in$ E, belonging to a human interpretable domain E, through an interpretable local predictor cl = f (b, x) derived from the black-box b and the instance x using some process f ($\bullet$, $\bullet$). An explanation e $\in$ E is obtained through cl, if e = ε l (cl , x) for some explanation logic ε l ($\bullet$, $\bullet$), which reasons over cl and x.

Agnostic methods of explaining the output of a black-box implement function f in a way that any type of black-box b can be explained. These approaches by definition generalize well and return an understandable local predictor cl. The LIME method [8] is used to explain predictions in a classification or regression problem by local approximation based on an interpretable model. LIME interprets complex models by building a qualitative connection between input variables and the output. The model is approximated with smaller models which are easier to interpret.

IV. RESULTS

A. *Exploratory data analysis and White-box Model Example implementing Decision Tree*

Exploratory data analysis for the variable videos reveals a certain number of outliers (Fig. 2), e.g. students who accessed video lectures more than 25 times (even 50). The video lectures plots (Fig. 2) are the simplest interpretable indicators alerting us that there are students struggling to pass the course.

A decision tree model is simple for interpretation, but it is not competitive with the best supervised learning approaches such as ANN in terms of prediction accuracy. Also if there exist strong predictors in the data set, along with a number of other moderately strong predictors,

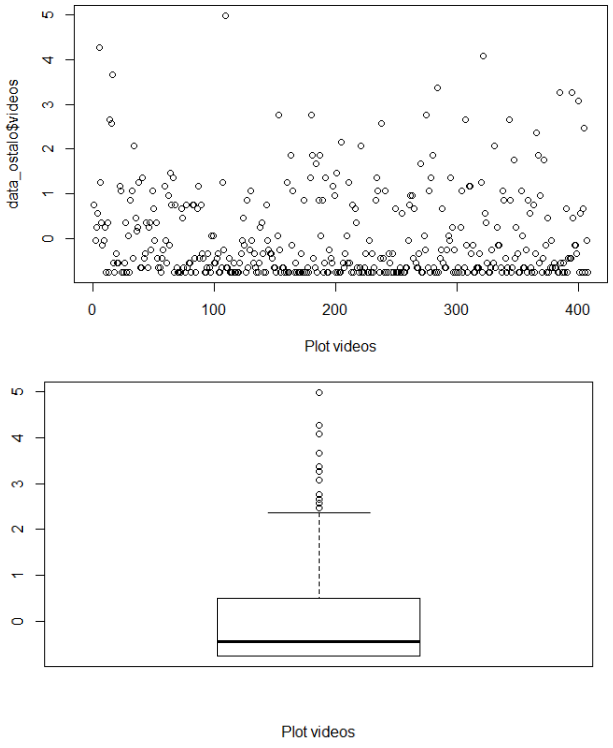

Figure 2. Scatter plot and boxplot for variable videos: x axis of the scatter plot shows students (1-408) while the y axis of both plots shows total number of all accesses for a student to the video lectures (0-51)

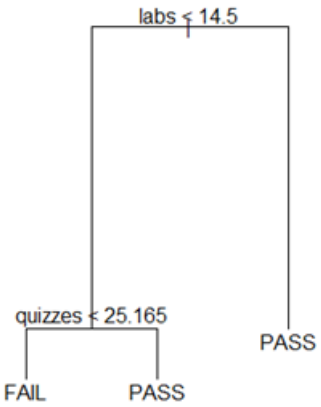

Figure 3. Decision tree model for EDU408 obtained using R Tree package (version 1.0-39)

the strong predictors will be used in the top tree splits. The obtained decision tree model for the data set EDU408 is interpretable but it tells as nothing about weaker predictors, videos and lectures (Fig. 3). The model accuracy is good (94%).

B. Training the neural network model for data set EDU408

A feedforward neural network with a single hidden layer is trained using cross-validation on the data set with continuous input variables lectures, quizzes, labs and videos and binary output variable grade (PASS / FAIL). The data are normalized. Trained neural network model accuracy is 96%.

C. Revealing ANN input variable importance with Garson's algorithm and Lek's sensitivity analysis

We are using Visualization and Analysis Tools for Neural Networks – package NeuralNetTools (version 1.5.2). The obtained relative importance of each predictor suggests the highest relevance for predictor labs followed by lectures, quizzes, and videos (Fig. 4).

Setting the bar_plot argument to TRUE we can also get the plot of relative importance (Fig. 5) showing similar results. The attribute videos is less important because the activity is not graded.

Visualization based on Lek's algorithm shows (Fig. 6) six groups obtained by fixing input variables at their minimum value, at 20th, 40th, 60th, 80th quantiles, and at their maximum value. The outcome probability for grade shows significant variance for predictors lectures and videos.

```
> round(garson(model.ann,bar_plot = FALSE),3)

         rel_imp
labs       0.490
videos     0.022
quizzes    0.208
lectures   0.280
```

Figure 4. Attribute relative importance, Garson's algorithm

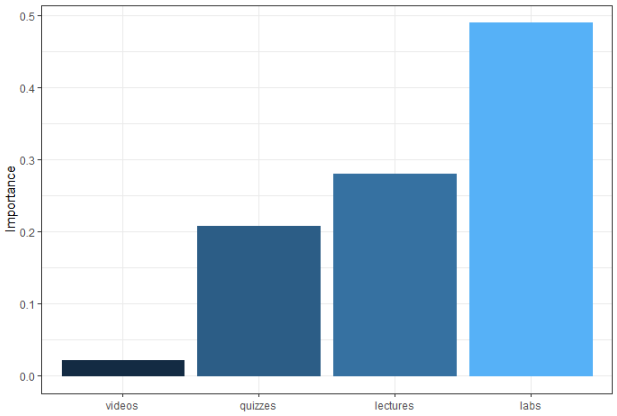

Figure 5. Attribute relative importance plot, Garson's algorithm

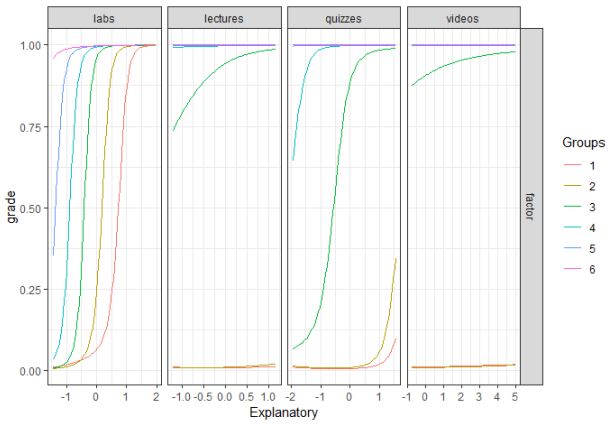

Figure 6. The relationship between outcome probability for grade and input variables (Lek's algorithm)

D. Local Interpretable Model-agnostic Explanations (LIME)

The LIME method is applied using R lime package (version 0.4.1) [8] (Fig. 7). Function lime() argument data is the data set, model.nn is neural network trained model which is to be explained. Function explain() returns prediction explanation for given instances (28:31). Explanations are given in visualizations (Fig. 8 and 9). Two outcomes 0 and 1 denote grade value of FAIL and PASS, respectively. Colors represent feature weights (green – positive, supporting the outcome; red – negative, contraindicating the outcome). Low values of the attribute labs (labs<=-0.971) support outcome value FAIL and contradict the outcome PASS, while high values support outcome value PASS (students 28 and 31). The results for the attribute lectures are similar but the support is weaker. The attribute videos gives weak support for PASS when its values are higher, and weak support for FAIL when its values are lower (Fig. 8). Fig. 8 can be explained as follows: for case 28, the student who was inactive in all activities, the probability for FAIL almost equals 1. The low value of the attribute videos supports only the outcome FAIL (case 28), contradicts the outcome PASS (case 30), while moderate and higher values support the outcome PASS (cases 29 and 31). The support of videos is of lower intensity but this is consistent with the role of this additional activity on the course.

```
library(lime)
explanation<-lime(data,model.nn)
exp_3<-explain(data[28:31,], explanation,
        n_labels = 1, n_features = 4)

plot_explanations(exp_3)
plot_features(exp_3, ncol = 2)
```

Figure 7. Generating explanation using LIME method

IV. CONLUSION

The initial hypothesis of the research that the activity of watching video lessons has the significance for student success is confirmed by the interpretations obtained through agnostic and non-agnostic methods based on the model of the black-box of a neural network trained for the EDU408 data set. The intensity of support that the video lessons give to the outcome PASS is relatively small compared to the activities of the courses which are graded and to a large extent correlate with the final grade of the course. It is interesting that the attribute videos helps in noticing students who need additional help on the course already in the exploratory data analysis phase. Interpretation for individual instances could provide personalized approach and feedback for students. Additionally, by analyzing data streams generated in the LMS system during the course, students could get timely information and course grade prediction along with interpretation (e.g. using Recurrent Neural Networks).

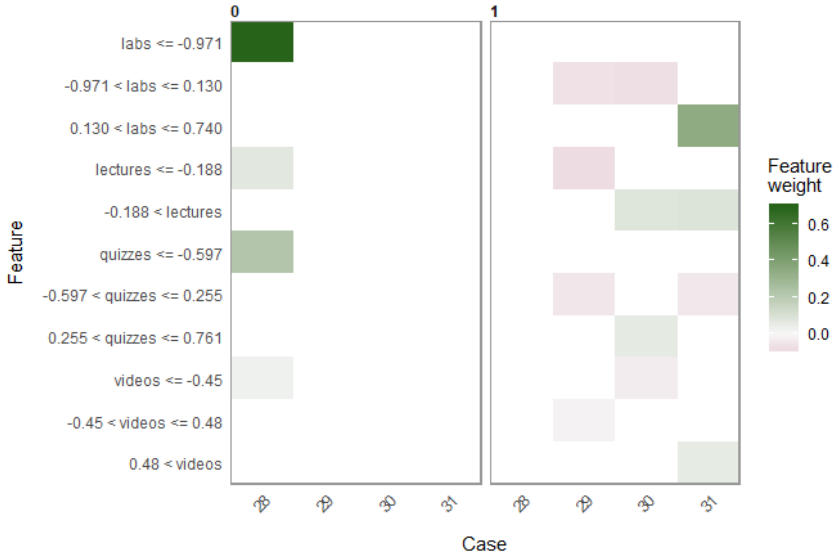

Figure 8. Feature combinations heat map visualization for selected instances 28-31

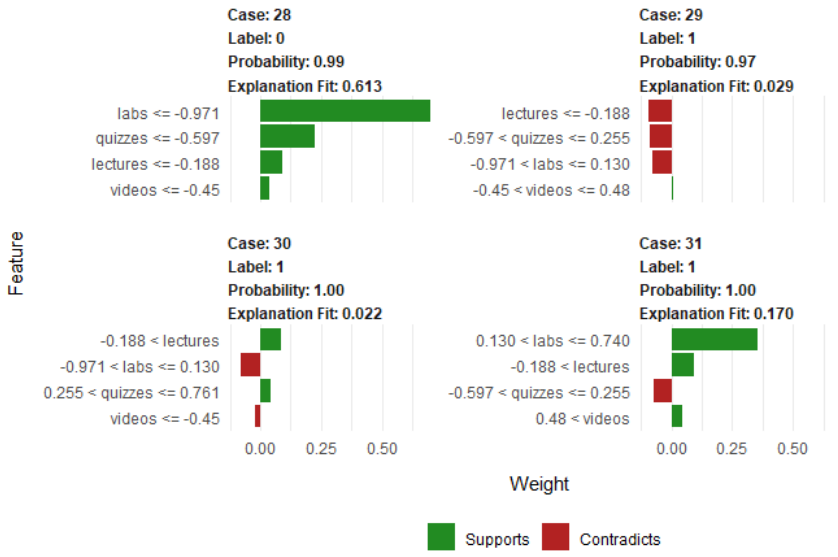

Figure 9. Feature plot. Every instance is marked with four labels: instance number (Case), outcome value (Label), predicted label probability (Probability), quality of the model used for explanation (Explanation Fit)

ACKNOWLEDGMENT

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General Solution Framework for Management and Monitoring of Cross-Platform Data Processes

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The purpose of this paper is a description of a proof-of-concept implementation for running and managing cross-platform data processes. The term "data process" in this context represents a variety of data management processes being executed by any of the common data integration tools and business intelligence processes ran through BI tools. Besides the common data management process workflow, custom data processing can be achieved by executing scenario-specific scripts, such as Big Data processing being achieved by running Spark or Hadoop jobs from inside the platform. The framework is implemented as a web application with a separate service, which handles job execution and scheduling. Besides that, the service is in charge of achieving parallelism, performance optimization and dependency management including the automatic discovery of different dependencies. The user interface offers monitoring of process execution through a graph representation of the execution plan or a regular table visualization. This paper explains the details of the developed concept and the architecture of our technology agnostic implementation.

I. INTRODUCTION

In a common data warehouse environment, there are numerous ETL (extract, transform, load) processes and other data processing tools and techniques that are hard to manage and control in a unified way. Typically, it requires multiple tools and a lot of tedious manual work, but automation and control of these processes can be of great importance to the company's data, and, by extension, its business development.

The main idea behind our solution is to implement a generic, scalable framework with two core functionalities:

- execution of data processing jobs
- monitoring and visualization of the processes

We describe the concept and its implementation by giving an overview of our solution architecture and main challenges, together with examples of job execution workflow management, monitoring and visualization.

Section II describes in more detail the problems we are addressing and gives an overview of our solution in that context. In Section III, we are describing our framework from the architecture and implementation points of view. Section IV goes into more detail on the job execution, dependency handling, and how parallel processes are managed and optimized to improve performance wherever possible. Finally, Section V describes the visualization component of the solution, i.e. visualization of the execution plan and monitoring of executed tasks through the application GUI (graphical user interface).

II. PROBLEM STATEMENT

Our solution is designed for running and monitoring cross-platform data processes. It is based on the assumption that multiple tools – databases, data integration tools, BI tools, Hadoop, etc. – are required to achieve a complete data management workflow. Implementation of this workflow with all its components is a complex process, with many potential complications [1]. The framework we present in this article is designed to address common difficulties, and to ease and automate typical functionalities such as:

- Running independent tasks in parallel – the framework automatically takes care of executing independent tasks in parallel mode, with consideration of system capacities.
- Automatically starting processes which have their prerequisites completed – prerequisites can be other jobs or source system status.
- Jobs can be started by the scheduler, event-triggered or started manually (with checking for prerequisites).
- Load on demand – load of a particular table can be initiated at any time in order to get the newest data for reporting. The framework has the ability to determine which tasks have to be executed in order to achieve this.
- Task execution monitoring, with corresponding statuses and statistics, is possible through the GUI.
- Check mechanisms for preventing faults during data load – e.g. source system readiness, prerequisites check, blocking of same task being executed twice, etc.
- Recoverable errors and automatic task restarting – the framework has the ability to automatically restart a task if it failed with a common recorded error.

The above mentioned functionalities in terms of our solution are described in more detail in Section III. We believe that our framework covers these points in a comprehensive way and builds a complete, general, and scalable solution to a typical data management workflow, with the ability to customize it and extend its functionalities as needed.

III. SOLUTION IMPLEMENTATION

The main logic of the application is implemented in a Node.js service named the Agent, which is a process that runs continuously having a primary function of checking if there are any tasks ready for execution. Since the tasks are linked in between themselves through a system of task dependencies, it is necessary to implement the readiness checking inside the solution itself. When a task is flagged as ready for execution, the Agent is also in charge of executing it.

The functionality of starting jobs of heterogeneous nature is achieved through a system of generic functions. General task processing logic, the propagation flow of parameters and managing of tasks is the same for any kind of job while they each have a task type specific solution at the end of the computing chain. Those specific solutions are developed to enable starting of a task on its befitting platform and their implementation depends on the technology where the actual processing is actually taking place (e.g. DataStage). This way the framework can support a potentially unlimited number of distinct job types.

Implemented solution currently has a staging area integrated, which is located between the data sources and the data targets, prior to the data processing tasks area. Staging area architecture can be designed in various ways depending on the specific usage of the solution, but most commonly is implemented in the form of tables in relational databases. Staging area tasks most often cover the functions of consolidation of data from multiple source systems, data standardization, metadata tagging, etc [2].

The solution has an implemented scheduler for running the mentioned staging area tasks while the Agent is in charge of running all upstream data layer tasks. All of the major data integration tools package scheduling capabilities into their environments but for this implementation the developers choose to manually code the job execution scheduler to be able to schedule any type of data processing task. While making a custom scheduler solution it was imperative to take into consideration the control over the relationships and dependencies between data processing tasks, recognition of data source readiness, real time architecture support, problem escalation notifications, etc [3].

Besides from running more common data process workflow tasks using the data integration tools such as IBM's DataStage or Informatica products, the developed solution offers custom data processing achievable by running scenario-specific scripts such as Big Data processing being achieved by running Spark or Hadoop jobs from inside the platform. In that case, Big Data processing e.g. Spark job is just a specific task that is executed through an SSH connection on the Spark server or cluster. Given that the Agent has access to Spark, the framework can run the job and receive information on its execution status and completion. Since the job is executed on the Spark cluster, all benefits of the parallel processing are leveraged – as they are available in the cluster implementation and configuration. In our framework, we imagine this as, not the core component of the DWH system, but an additional functionality used for specific data processing from external systems.

Furthermore, it is possible to use the framework for managing non-relational (NoSQL) database processes. The framework is designed to be technology-independent, which means that the actual processing is not a part of it – the framework only orchestrates these processes. In that context, big data processing like Spark job or NoSQL is just a specific task that the framework can manage and monitor, while the actual job configuration and resources used for it depend on the actual technology – Spark cluster, NoSQL database, etc.

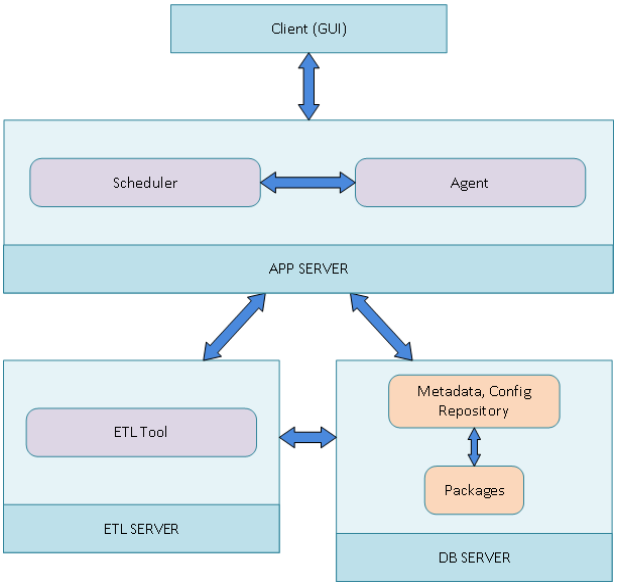

Figure 1. Architecture of the framework implementation

Fig.1 gives an overview of the architecture we implemented in our solution. Main logic of the application lies in the centre box; the Agent takes care of all task execution, dependency handling and optimization logic. There is also a scheduler implementation in charge of managing jobs that are run at specific scheduled time, either once, or periodically.

The Agent communicates with the configured database server and ETL server where the actual data processing is being executed. In our implementation, the database server is also the storage component of the solution. The framework is not technology-dependent; all standard relational databases can be used (Oracle, MS server, MySQL, MariaDB, PostgreSQL). However, we assume the database is relational, as the process orchestrating includes database procedures. The database server has metadata repository, stored procedures, and packages that are used by the Agent. ETL tools have their implementation logic, but our solution does not depend on it; all communication between servers and processes is implemented through socket messages.

The application offers a user interface developed using the Angular framework through which the user can control all data processing through a single set of displays and graphs. Through the interface, it is possible to monitor all static information about the used systems, schedule jobs, monitor task executions, graphically display dependencies, create task batches, etc.

Implemented solution also has an integrated notification system, which is used for forwarding success or failure messages to the application user through on-screen alerts, e-mail or SMS. This information (among other) is sent to the client also via socket messages and displayed in the application interface.

Alongside that, it provides mechanisms for recoverable errors handling in terms of restarting a certain task for a system-specified number of times. Each error comes with a database-stored code, which, if in the recoverable errors code list, triggers a repeated task execution. In case of a non-recoverable error, the failed task and all of its upstream tasks are halted until manual interference from the user. The mentioned way of error handling can be visualized on a scenario when a number of tasks is grouped into a batch. Inside the batch the user can monitor the execution flow of tasks and batch status is dependent of its consisting tasks. Fig.2 shows a batch whose first two tasks were executed successfully while the task number three failed and task number four is still running. The framework would try to rerun the task itself, if so specified inside the application configuration, and, if that repeated execution also failed, it would set the entire batch status as failed. The administrator would then have to figure out the reason behind the task's execution malfunction and fix it manually, after which he can rerun or reschedule the entire batch. The next batch run would continue its execution from where it failed, thus meaning it would only restart the mentioned malfunctioning task number three, as seen in Fig.3.

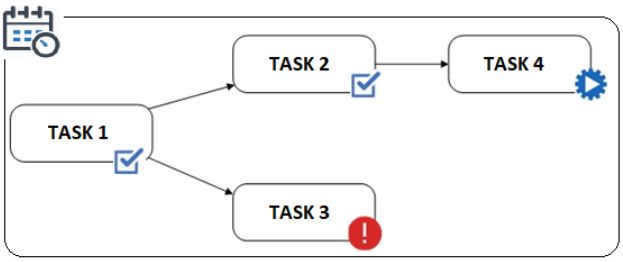

Figure 2. Task failure example

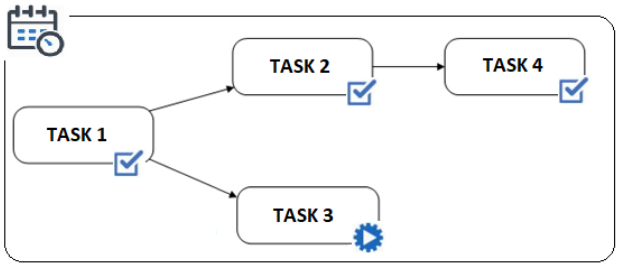

Figure 3. Batch restarting example

IV. DEPENDENCY DISCOVERY AND PARALLELISM OPTIMIZATION

The entire solution is designed to be able to run tasks in parallel depending on the weight factor value of a task. Each job execution is assigned a factor value describing its complexity and computing resources necessary for its successful completion. The factor value of each task is initially assigned before the task's first run. The initial value is given by the application's administrator when providing task definition data and it is estimated from the business point of view while taking into consideration prior knowledge of the size of data being modified by the task. Later on, the framework monitors the task's execution runs and, based on variable value scopes for information such as execution time length, recalculates the weight factor. This way of factor value calculation makes the weight variable admissible for task execution readiness check. The maximum value of the combined sum of these factors must not exceed the threshold set for the source system linked with the task in order to achieve optimized parallelism. If the execution of a new task would exceed the defined source system threshold, the framework will not start that task and will wait until this condition is fulfilled.

The execution optimization takes into consideration the equal representation of distinct weight factor levels to avoid scenarios in which multiple tasks with high computing costs, represented with higher weight factors, do not enter their long execution periods, and by doing so, do not permit the lower weight factor tasks to enter their execution phase. This kind of optimization is available through the creation of exclusion groups from within the application or through the initial import of data. Exclusion group represents a group of tasks, which are not to be executed at the same time. The idea behind the concept is to be able to group high weight factor tasks linked with the same source system. The weight factors serve as labels for recognition of tasks with high computing costs. Due to the business purpose of the framework, it is to be expected that there will be a great quantity of lower weight factor tasks throughout the framework's run cycle, therefore the scenario in which a high weight factor task's execution is blocked because of its associated exclusion group task at the same time when there are no other lower weight factor tasks for execution, is not likely to occur. Nevertheless, this exclusion principle is customizable and the user has the option of changing the tasks belonging to a specific group.

The solution also has in place check mechanisms for preventing faults during data load, the best examples being that the same task should not run at the same time or that tasks should not be able to be started if their prerequisites are not fulfilled. The user can manually change the computed order of task executions if the tasks are equally ready for execution looking from the dependency completion point of view.

While scheduling staging area tasks, the solution also has an integrated data source systems readiness check. There is a flag stored inside the application data for each known application source of data representing the ability of the source to start serving data to upstream layer tasks. The user can monitor these readiness flags directly from the application user interface.

Each task can be linked with a series of other tasks on whose completion it depends. The solution offers a task dependency management system through which those dependencies can be monitored, graphically displayed, imported into the application and modified at any time. The initial task dependency information grid is loaded through the interface by the user and it can be updated at any time. Through the application, the user can also use the automatic dependency discovery system in which the implementation

computes and draws out a graph of all tasks whose successful execution is a prerequisite for a specific task chosen by the user. Those computations are based on the initial dependency grid through which the solution algorithm can recursively iterate and fetch all necessary prerequisites in reverse.

Through the initial import of data in which the user imports the mentioned dependency grid, it is also possible to import information about collecting multiple task types into batches of tasks or purpose-specific process groups, which can both be selectively scheduled for executions and monitored in their own interface tabs from within the application.

V. PROCESS MONITORING AND VISUALIZATION

As discussed in Section III, from the implementation point of view, our solution consists of two main components – user interface and the Agent. The Agent (and other back-end processes) enable the execution and optimization of all data processes, while the application's simple and intuitive GUI allows users to monitor and manage all the processes.

Once all the data processes in the data warehouse environment are established and properly implemented, a major concern becomes monitoring of these processes; their statuses, data usage, resource usage, etc. There are ways to achieve this in individual tools [4]. However, we are proposing a unified way of monitoring all configured processes from one place, through a customized dashboard in the application GUI.

The GUI enables the user to configure multiple different data processing tools, and to create, edit and control the execution workflow of all the jobs in one place. The app receives information about the jobs' execution state, so that the user can see that information in a simple tabular format. That way the information about all the jobs from all configured data processing tools (different databases, data integration tools, BI tools, etc.) is gathered in one place and joined in one unified dashboard. The user can filter and sort them by time, specific tool, or other criteria, monitor task executions with corresponding statuses, audit data (history, start/end time, execution duration, etc.), and other details.

Besides the tables and forms for process management, there is also a graph visualization for each batch, which captures the batch workflow – tasks and their links (dependencies). The graph gives a direct insight into the details of the execution plan and its configuration. Tasks are represented as nodes in the graph, and task dependencies (prerequisites) as edges between them. Therefore, the graph captures an overall execution plan, but also the details of a specific node can be viewed by clicking on it.

Fig. 2 captures an example workflow with seven database stored procedures, four DataStage jobs, and a custom shell script. The application can potentially be expanded with specific job types – e.g. specialized database procedures, Cognos, Spark jobs, etc.

VI. CONCLUSION

Good data management system is a key foundation for any data-driven strategy and development. In this article, we summarize common functionalities and potential difficulties in management and monitoring of cross-platform data processes, and the way we address them in our solution.

Our framework is designed as a general scalable solution for running and monitoring of data processes run by multiple data processing tools. It provides an optimized way for parallel job execution, and automatic dependencies handling, as well as a simple GUI where the user can manage, monitor and visualize the execution workflows.

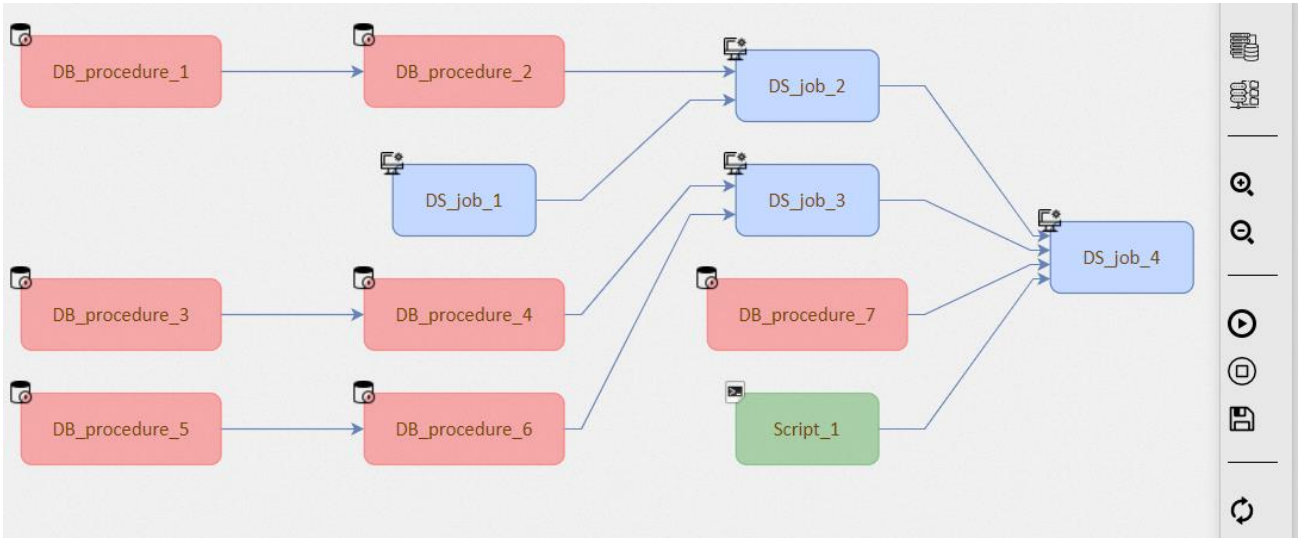

Figure 4. Workflow graph example

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Digital Transformation Case Studies Across Industries – Literature Review

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Abstract **- Digital transformation (DT) has been introduced in all industries for improving the way of running business. Industries have embraced technology to different extents, as not all technologies can be equally implemented, even in semantically similar processes. This can be explained by the fact that the hype cycle of emerging technologies differently impacts industries from the time a concrete technology has been discovered and introduced, to the time when technology reaches its full potential of use in real processes, or so-called maturity. This paper presents a literature review on Digital transformation papers, which use the case study method in their researches and/or compare digital transformation case studies across different industries. The purpose of the analysis of case studies is to bring some light to real digital transformation processes and their success in practice. Analysed papers are selected from the Web of Science database based on content, industry and number of papers within it.**

Keywords - digital transformation; literature review; case study; industries

I. INTRODUCTION

The turbulent and constantly changing market require companies to constantly innovate in products and/or services and also to innovate in business operations. At the same time, market conditions are subject to frequent changes, increasing competition affects the reduction of operating costs, and organizations are expected to react accordingly achieving thereby the most efficiency. At present, the market imposes digital transformation as a necessary, new stage of the company, that it must undergo to become/remain competitive on the market.

Digital transformation is a complex and demanding process that requires the engagement of all enterprise resources - human, technological, physical, organizational and financial. It marks the digitalization and its implementation throughout the organization with a special focus on people and business processes. DT is the transformation of an organization driven by digital technology, and it directly affects the change of organization's core, that is, the change of its business model. As such, organizations open up possibilities for new business opportunities, innovations in product and/or service creation and opportunities to acquire new knowledge. Although digital transformation is increasingly popular among companies, recent research suggests that individuals have much more transformation efforts than they expected. One of the important factors of a successful DT is certainly an adequate digital strategy, tailored to the corporate structure.

According to the mentioned, the transformation efficiency is seen in the following: dynamic strategy (subject to constant change), exploitation of all available resources (human, technological) and quantitative measurement of DT success (determining measurable and achievable goals) [1]. As not all businesses are equally focused on digital transformation, so it does not apply to all industries at the same time. Some industries have caught up with DT earlier, while for some this is a relatively new term. However, all of them are inclined to accept new technologies and new ways of realizing their business. This paper presents an overview of case studies by industry, i.e. how enterprise approaches the process of digital transformation.

II. METHODOLOGY

Research in this paper was driven by literature analysis based on scientific papers published in the database Web of Science (WOS). Papers were selected according to search of term „Digital Transformation“ in the title of papers. From research were excluded books and other materials that are not scientific journal or conference proceedings papers. Also, publishing period was reduced on time period from year 2000 till 2019 since papers earlier of year 2000 were mainly dealing with transformation from analogue to digital media. Analysis was made on December 2018 and derived a sample of 214 research papers. By content analysis of these papers, 88 papers were extracted by the use of a case study method [2] as sample of digital transformation process in real life.

III. RESEARCH RESULTS

According to preliminary results, mentioned 88 papers (41.1% of all 214 papers in WOS) were further analysed as a sample for 96 industrial use cases of digital transformation, due to the fact that some papers include case studies in more than one industry and some include more than one case study example. One part of case studies were general but industry dependant.

Figure 1 shows a grafical representation of top 10 research areas according to WOS in which these digital transformation case study papers were published.

This research has been conducted as part of the wider research in the project Development of innovative platform for digital transformation of enterprises (RDI) which is funded by European Union through the European Regional Development Fund (ERDF).



Figure 1. Top 10 research areas of papers with digital transformation case study

Figure 2 shows top ten countries or regions on the same sample of DT papers in the maner of the location where the paper's authors and case studies originate from.

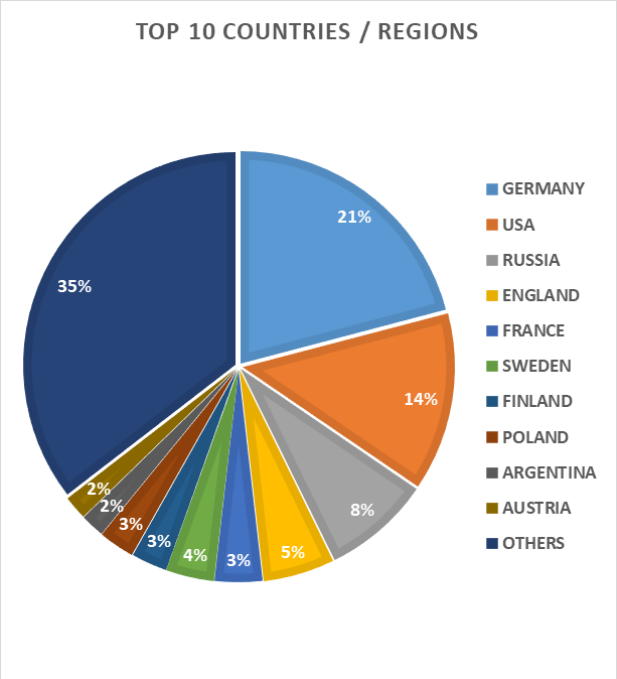

Figure 2. Top 10 countries or regions of papers with digital transformation case study

Figure 3 shows the graphical representation of case study researches in digital transformation according to industry to which they relate. Industry classification is done by NACE 2 [3]. As we could see in Figure 3 most case studies were made in information and communication industry and this is expected because DT is perceived as IT thing so most case studies are classified as information technology change in IT, telecom, computer and media industry. Second industry in this graph is manufacturing in general since the case studies show that digital transformation is present in manufacturing companies by implementation of Industry 4.0 technology and changing the way production is being run and product design is made. Third industry with most DT case studies is education, since the technology largely influence educational sector. After these industries in front, we could say that health care and medicine; energetic sector; wholesale and retail trade are next most researched industries with real life case studies. All other industries were present in just several case studies like defence industry; public administration; agriculture and forestry; transportation and administrative services. Industries with no case study was construction, real estate, accommodation and mining.



Figure 3. Papers with Digital Transformation Case Study per Industry

For more detailed insight into the first 6 most researched industries with DT case studies, we made a cross-industry analysis based on literature review of articles in these industries. For these selected industries, most representative case studies are described in next sections.

IV. DIGITAL TRANSFORMATION ACROSS INDUSTRIES

Below is an overview of case studies across six industries based on detailed literature review of papers from selected sample (see Figure 3): Information and Communication (J), Manufacturing (C), Education (P), Human Health and Social Work Activities (Q), Electricity, Gas, Steam and Air Conditioning Supply (D), Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles (G).

A. Information and Communication Industry

Case studies in IT industry are most common group of case study papers but it's challenging to separate what is the DT in IT industry and when it's just a case study made by IT people in some other industry.

Firstly, in this pool of papers we decided to describe papers in IT industry like case study of Fujitsu [4] where Fujitsu makes a presentation how they see future businesses in process of digital transformation based on cloud services and interconnected business model, or so called Composite Business. Similar, cloud based solutions based on interviews with 10 companies were made by authors in [5] describing the strategy of DT though the SaaS multicloud platform. Hess et al. [6] describes how CIOs and other senior executives face the challenge of coping with the opportunities and risks of digital transformation. In order to help managers to solve this issue more systematically, the article describes how three German media companies have successfully joined the digital transformation. Based on their experiences, a list of 11 strategic questions and possible answers is provided, and managers can use them as guidelines in formulating the strategy of digital transformation.

Several paper focus on media digital transformation [7], [8]. First is dealing with change in Arab news and compare 54 newspapers in hard (paper) and soft (online) web page format. Second paper is presenting research of challenges need to be overcome to digitally transform media group Haufe Digital with focus on digital leadership and characteristic of the people who lead such a project (digital transformation manager). More about how the chief digital officer needs to promote digital transformation in his company is described in [9] while the needed framework for assessing organizational readiness for DT is described by Sanchez in [10].

Last paper in this short review of IT industry shows challenges made from digital transformation in companies regarding infrastructures, integration and architecting during and after digital transformation [11]. Authors described examples of Tesla, Audi, Apple and Google in the article, posing thereby problems that are caused by the increase in the number of external integrations, solutions by using external infrastructure for integration and the consequences caused by the change of architecture.

B. Manufacturing Industry

In this industry several research case studies were made. First of them is from fashion industry [12] and describes what for and were in production processes new technology to improve business process in manufacturing of textile, clothes, shoes and accessories can be used, focusing on „smart factory“ with use of laser cutting, digital printing, production of 3D accessories of garments (buttons, zippers etc.) and 3D printing. Full integration off all modern technologies in the industry is still missing, in order to close the life-cycle of products and cutting down some “old-fashion process” with large share of expenses like pre-production and sampling which is slowing down the industry innovation cycle from idea to customer. To improve in this area fashion industry use virtualization as impressive virtual fashion shows and interoperability e.g. in RFID implementation in production and tracking product through the entire value chain from suppliers to retail. All these changes made it possible for large players such as H&M, Zara and similar to make catwalks trends in their shop in matter of just couple of weeks [12].

Next case study in manufacturing was describing DT in Case study of Husqvarna Group AB, one of the leading manufacturers of gardening tools and chainsaws. Case was set on enterprise opportunities of DT and its impact on enterprises architecture management since Husqvarna is in the DT process right now and they seemed mandatory for them to stay concurrent on global market [13].

In automotive industry case study research was made to see if digital transformation of production robots could be used to optimize their working speed to save power. To cite [14] “Today all robots in a body-in-white manufacturing run with a motion speed of 100%. But in fact the robots work together in teams, they interact. That means that not all robots have to work with full motion speed, because they have to wait for each other. These waiting times provide the opportunity to slow down non cycle time critical robots. The result of a slower motion is energy consumption reduction“. The digital connectivity of machines through the Internet generates the 4th industrial revolution. These "smart machines" are already transforming a wide range of sectors, from production and agriculture to healthcare and transportation as states [15]. Their study made research to visualize and analyse the trends in technological knowledge leading to inventions that lead to industrial digitization with a high impact on the value chain. Through the study of patents, they have observed how technological advances in industry 4.0 contribute to the creation of new inventions in the machine tool sector. [15].

As the last manufacturing DT case study we analysed an article [16] which is dealing with paper production. In this industry there is a risk of digitalization and reduction of paper usage done by users of digital content. Industry tries to find a new way of producing paper and use new digital technology in development of new fibber-based materials.

C. Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles Industry

In industry of wholesale and retail trade one research paper was dealing with e-commerce and on-line shopping in the Czech Republic [17] which revealed that online channels of sale are common and retailer or wholesaler that are not using them are not in trend. Statistic shows that the number of Internet shops is rising and only in Czech Republic there are 37.000 of it (2017). In the wholesale trade structural changes in added-value chain are present in last the 10-15 years. Digital transformation example on automotive industry parts production and design was presented in Zachmans framework as efficient data communication means, appearing in all product development phases as prerequisite for lean, agile and flexible collaboration; since parts suppliers are developing and producing parts for different OEM cars producers [18].

Additional research paper was found in usage of simulation games to teach students or production employees digital transformation in the automotive and online retail sector [19]. Both case studies are described in

the field of education, but their goal is improve manufacturing and sales industry.

D. Education Industry

The transformation of teaching methods is the result of the increasing representation of digital technology in teaching processes. Ithaka S+R (Strategies and Research) is an American non-profit organization that helps higher education institutions, publishing houses and libraries to successfully adapt new, digital, market demands. As such, Ithaka organizes conferences on the topic of digital library transformation resulting in the exchange of experiences and methods of digitalization of libraries. Furthermore, Ithaka explores the use of digital technology in education through online learning. It is considered in America as a way to attract students, but also to reduce the costs of higher education institutions. Online learning makes education more accessible at any time and everywhere, so MOOCs (Massive Open Online Courses) such as Coursera, Udacity, edX become more popular. They provide participants with personalized access and quick feedback on tasks, and they are active learning promoters too. Ithaka explores the field of online learning with the aim of presenting results to universities and implementing them in higher education institutions [20].

The real sector of Russia [21] demands more and more entrepreneurial and managerial skills. Challenge for Russia is the lack of a unique classification of competences in the educational and real environment. For this reason, a study of competences (taking into account business environment requirements) was conducted in Russia, where 2337 students of different years of study participated. The research has resulted with the following universal competencies: systemic critical thinking, development and implementation of projects, teamwork and leadership, communication, intercultural interaction, self-organization and self-development, life safety. The process of implementing universal and professional competencies in the Russian education system is a complex process, with a gap between education and professional standards. Russia's entry into the new digital world needs to be supported by the adequate knowledge of future experts that they have adopted from the education system and which are adapted to the needs of the market. The focus on the needs of society and the demands of the digital economy results in changes in the training of experts, and Russia has been approaching this process with exceptionally slow steps [21].

Education system in North Cyprus is characterized by a centralized management of education policy - primary, secondary and tertiary education. Education is compulsory to high school, and the system directs stakeholders to do research, handle scientific issues, and think critically. The Principals are responsible for the implementation of rules and regulations, and the Ministry of Education for coordination of school management, knowledge management, teacher motivation and control, coordination of learning activities and school activities, collaboration management and resources. Also, the Principal’s responsibility is to manage all resources and introduce new trends in education. Emphasis has been placed on the technological resources used by teachers in the educational process, and Cyprus DT of schools is considered as an important link to achieving higher quality education. Teachers implement technology, movies and the Internet in teaching processes, and emphasize the need to increase social activities and mobility. Northern Cyprus School Principals are aware of the importance of using digital technologies in the education process, although there are financial constraints for their adequate and complete application [22].

BME (Budapest University of Technology and Economics) focuses on differentiated management in classical teacher activities and the application of effective educational methods and procedures. Teacher training is partially conventional, related to knowledge, skills and attitudes, and partly related to the following teaching abilities: student personality development, student and community support, didactic professional training and professional knowledge, planning of the educational process, support, organization and control of learning, evaluation of educational processes and students, communication, professional co-operation and career identity, commitment and responsibility for professional development. BME regularly organizes trainings for teachers dealing with topics such as new theories of learning, atypical learning, lifelong learning approach, new results in ICT tools that support learning and education, online learning, and more. The University is implementing the project "E-learning Culture and Digital Content Development", which aims to influence the continuous development of quality and excellence of teachers, and within the project it is planned to develop digital curricula in English and Hungarian for 27 courses [23].

E. Human Health and Social Work Activities Industry

An increasing number of patients in the healthcare sector is increasing the workload of healthcare staff, as well as the development of telemedicine. As a solution to cost cutting and providing services to patients from remote areas, hospitals in Sweden (in a survey called Clinic A and Clinic B) have started video sessions with their overweighed patients. Video visits included several meetings aimed to change the lifestyle of patients. Both clinics have chosen existing patients or relatives for video visits. During the video visit, the following advantages or limitations have been reported: technological (time and space flexibility, connection issue, waiting) and environmental benefits and constraints (non-adequate patient or physician environment). It can be concluded that the introduction of video visits influences the creation of new ways of working, new work tasks in the use of technology, and a new division of labour is also present [24].

The authors of [25] present a systematic analysis of worldwide companies in the health sector using first Forbes data, from whose sample, based on the keywords related to digitalization of health care, they identified 100 leading companies, and using second CBinsights database, from which they identified the 100 most successful start-ups. In order to carry out the analysis and evaluation of the companies, a commission of 10

members was set up, from the field of medicine, pharmacy and economics. The analysis was based on the following criteria: value of the buyer's offer (patient engagement, prevention, treatment…), identification of key processes and resources, profit. By observing different health sector stakeholders (life science, technology, start-up companies), it has been found that start-up companies are investing a lot of effort in addressing patient needs, exploring new market segments, transforming business models, and investing in transformational efforts. On the other hand, longer-term companies rely on innovations that support their existing business models [25].

Next case study describes Center-Edge digital transformation of Kaiser Permanent, a US healthcare provider, where the term Center represents the company (supply chain, business systems, technology), while Edge represents the customers, communities and ecosystems that are connected to the Center digitally. Kaiser Center-Edge transformation aims to create a new strategic value through improving patient services, enabling easier communication between Center and Edge. Transformation is based on three organizational configurations: Value Chains, Value Shops and Value Networks. Kaiser has implemented the KP HealthConnect system that enables: availability of medical documentation in the digital version (for healthcare staff and patients), access via mobile devices, electronic communication of staff and patients, review of laboratory results, recipe management, scheduling meetings with doctors, providing health care to distance, personalized health care, easy decision making based on available data. KP has increased the Center's efficiency by reducing costs and delivering high-quality health care [26]. In America, there is a belief that the rural population in the 1990s was in a disadvantageous position with regard to urban health care. Namely, in rural areas, due to the reduced economy and population aging, there were a number of endangered rural hospitals with decreased number of physicians employed. Health care costs have risen, new technology is introduced, and the hospitals are becoming more expensive to work. At the same time, hospitals become weak in generating revenue, so the tendency of their closure increases. However, with the emergence of digital transformation and health telemedicine, the situation for rural areas changes to the better. The era of using interactive video for distant patients begins, technology investment increases, e-health platform is introduced. Doctors in the villages have access to materials for continuous education, medical documentation is available at any location, data is digitally collected and costs are reduced. All listed is available to the rural population based on the existing Internet connection [27].

F. Electricity, Gas, Steam and Air Conditioning Supply Industry

Collecting natural gas is a demanding process that encompasses a wide range of activities, such as pipeline operations and maintenance, gas processing installations, dehydration and treating installations, condensate storage and sales, etc. Many companies continue to manage the condensate business on paper and spreadsheets, but not company eSimulation. eSimulation Inc. is a company which undertook in late 2013 to help improve their efficiency by helping the operator transform its management from paper and spreadsheets to specialized digital applications. For this purpose, software to improve the working flow of condensate was developed with the aim to identify and quantify benefits of cloud-based, rigorous material-balance application, which is the foundation for the condensate inventory management system (CIMS). Fast development and deployment of the CIMS allowed simpler workflow (minimizing unnecessary data for working groups, losses become visible and documented, deviations were explained, CIMS is easy to check and control, etc.) using the cloud-based web interface and SQL database [28].

In today's business world, information technology (IT) is an important strategic factor, a source of competitive advantage and an important link in the transition to a digital economy. Its role is not just the execution of business processes but also the redesign of the business processes. One of Russia's largest oil and gas companies has noted the previously mentioned importance of IT. It sees digital transformation as a new business opportunity, an opportunity to enter new markets, and create new business models. The company has enough resources to implement the transformation and transformation is within the competence of the IT department (whose task is to analyse the situation and define changes in practice, methodologies and IT systems) [29].

Oil and natural gas managers are faced with the pressure of cost reductions - the market is turbulent and needs advice on: (i) the manner of digitalization; (ii) the necessary organizational changes; (iii) who is responsible for conducting digitization; (iv) the role of the Chief Information Officer (CIO) in the implementation of the Digital Strategy. The article [30] analyses the example of Encana Company and explains how to cut costs on the turbid gas market, with the implementation of digital technologies. Investments in DT for Encana are actually investments in digital technology, equipment and some complex processes (exploration, gas extraction, production, transportation, warehousing, distribution and marketing). Digital transformation is seen as an aid in effectively responding to price variability and reducing production costs by requiring unconventional natural gas sources. There are three phases in Encana (digitization for automation, metering and analysis) through which the company has developed two applications to help them control costs and agility, and also help strengthen the relationship with contractors and service providers - Digital Oil Platform (DOP) and Electronic Lease Purchase Report (eLPR). In the process of digital transformation, Encana places emphasis on its employees. Consequently, the CIO is launching a knowledge management program that seeks to provide staff expertise and generate business intelligence. All employees start business training and the company has defined the knowledge that the CIO and the CEO must possess to contribute to the success of the business and the successful implementation of the digital transformation.

V. Conclusion

This paper provides an overview of case study articles on the topic of DT and their relevance in different industries. A more detailed analysis shows that the DT process is permeated in a multitude of industries, but industries do not accept the transformation at the same time and to the same level of implementation and use.

Companies are applying digital technologies for different purposes: to integrate business processes, create new business opportunities, innovate products, reduce costs and make new business models. However, companies should have a strategic approach to the process of DT in order to create better a market position and stay concurrent on the global market. In all analysed case studies, DT is seen as a new approach, recognized as a future way to improve business and to answer the challenges of the future.

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A project managment system for time planning and resources allocation

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Abstract - **When comes to the efficient management and planning of a company's resources and workload many modern businesses are facing a serious problem, which can be the cause for their failure. Lack of planning is certain to result in shortages, reduced effectiveness and delays.**

This paper presents two types of analyses - an overview of existing solutions and an organization survey. Several Enterprise Resource Planning systems are reviewed and their positives and negatives are compared and rated by a set of criteria. The survey of the work processes of a small organization among with interviews with employees gives an insight of the problems and needs of a small-to-medium size businesses. The two sets of research complete the functional requirements for a project management system that can allocate resources more effectively. A web-based solution is proposed and is viewed through the prism of the whole business process and not just as an independent unit, although the presented application can be either a stand-alone system or a module of an ERP system with the project management being an operative module. Experimentally the project management system is implemented in the surveyed company replacing an existing PMS systems, the results of an additional survey are presented and analyzed as well.

Keywords - ***project management, work efficiency, ERP System, workload, time management, time diagrams, business management***

I. INTRODUCTION

In order to have an accomplished and satisfactory done project every company has to have a good project management strategy, a strong team and the tools needed for the execution and development of the said project.

Many companies these days are facing managing problems and are struggling to plan their resources effectively. Up to 75% of a company's projects can fail because of problems with managing or no planning at all.

In times of highly evolving technologies and businesses, Project Management (PM) practices and techniques are constantly changing and improving. The Traditional Project Management emphasizes on the claim there should be only one project at time [4] but seeing the change of PM in the last 25 years that there are more software solutions for project planning and control [8] that statement is outdated and unsuited for modern businesses. While the traditional PM has all the needed actions – scheduling, planning and tracking a project, it lacks the ability to overview the so-called collaborative projects. According to Romano, Chen and Nunamaker [5] collaboration will be essential for the success of the project.

In times of highly evolving technologies and projects that are more complex the most important role is the one of the project manager [1]. PM can be described as "a special way of organizing, planning and controlling to create defined changes or products with predictable cost, time and quantity" [8]. Therefore, the project manager is responsible for the planning, execution, control and completion of every project. He has the key role in every team and has to be able to predict risks and problems before their appearance so that tasks in the team are evenly planned and distributed among the members.

According to Macedo, Marihno and Santos [6] it's easy to believe that when risks are managed the uncertainties of a project are also managed and with that the role of the project manager is complete. Despite being close in meaning, these concepts are different and their understanding is essential for the success of the project. A study from [9] states that various project management approaches does not consider the uncertainties that exists in projects.

This paper presents an overview of a small company working in the field of web and graphic design. The company uses a set of tools that can be viewed and analyzed. The study is thoroughly decomposed and considered when compiling a list with functional requirements needed for the efficient and effective work of the company. Based on the list with requirements a web-based solution of a Project Management Software is proposed in section 3.

The web-based application has the sole purpose of easing the daily tasks of the managers and the teams and make the communication with clients and developers easier. It has the goal to minimize the number of uncertainties that can fail the project.

Particular attention is paid to the process of starting a new project, that proved to be difficult and hard to achieve in the company. The proposed solution contains several modules and every module is independent and can be tracked and managed individually and as whole project. The application is viewed through the prism of the whole business process and not just as an independent unit although the system can be either a stand-alone application or a module of an ERP system with the project management module as an operative module.

The top three questions when starting a project are "How was before?", "How it will be?" and "How it can be done better?",

The research gave answers to the first question; the analyses gave a basic idea of what was needed. The planning and structuring of the presented application showed gave a clearer view of the work processes and the workflow. The potential problematic units were considered and the answers to the third question were given.

II. RESEARCH

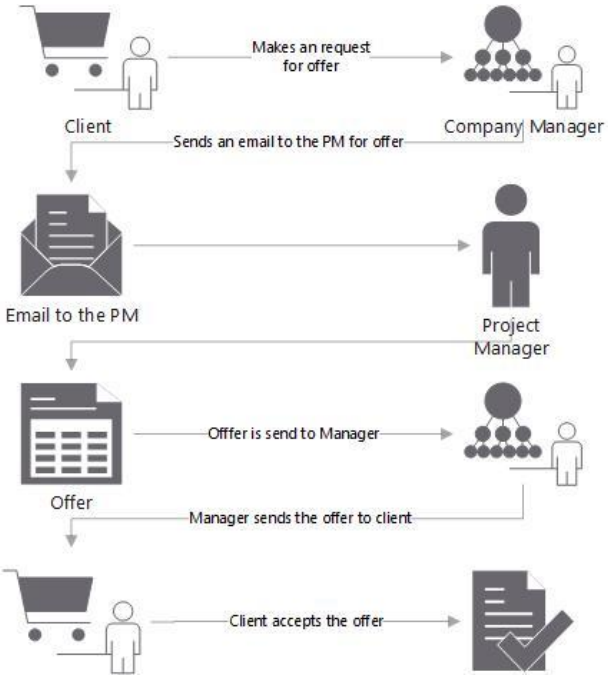
A. *Overview of an existing company*

To understand better the problems with which every company is struggling a research of a small company was made. The company is working in the field of graphic and web design, which made her acceptable choice for analyses and examination.

The steps of the study included an observation of the work, interviews with the employees and the management, overview of the company's policies and rules as well as being acquainted with the company's documentation and used software.

The process of making an offer by a request from a client is shown on fig.1.

FIG 1 PROCESS OF MAKING AN OFFER



Every project has some preliminary actions that need to be done in order to start the project. Every request to the company was made by phone or email from a client to the executive manager of the company. After that the manager has to send an email to the project manager with some brief details about the request. Based on these brief instructions the project manager has to conclude an offer, which will be then email to the executive, and he will send it to the client. In the process of overviewing the company and it's internal workings that whole process proved to be too difficult and time-consuming.

If the client approves the offer, the project is starting and a number of meetings between the client and the project manager are held in order to develop a clear and sufficient assignment for the project.

Once the assignment for the project exists, the PM can start planning and scheduling the tasks between the team members.

The company used a set of tools, which were used for scheduling, planning and controlling a project. Some of them included:

- An Excel template for offers - every project manager had to copy the template in the clients' file, fill it and send it to them.
- A traditional web-based system for project tracking. A roughly 10 % of the system capabilities were used due to its difficult and hard to navigate interface. The most needed functionality – the gantt diagram – was not used because the software can build a gantt diagram for one project while the managers wanted to see the status of all projects at once, a further confirmation to the theory that today's projects are complex and collaborative [8].
- Excel templates for tracking the work progress of every employee, also used for calculating the salary of every employee based on the work done.
- Gantt diagram for tasks allocation also made as an Excel sheet. Every morning the project manager will update the gantt diagram according to the statuses given by the team members.

Based on the observations made and the interviews held with the employees the most critical problems were collected and divided to tables. These tables are based on the theoretical approach to managing uncertainties in software projects (MUSP), presented by Marinho [7] but are modified for the purposes of the research.

Table 1 describes the technological issues that the employees are facing in their everyday work.

Problem	***Cost***
Time-consuming and difficult process of making an offer	PM2
Defragmented information and lack of centralized data storage policy	EM2
Lack of informatin about the project' status	PM2
Lack of information about the project' requirements	EM3
No information about the work load of every employee	PM1
Confusion among the team members about the current tasks	EM2
Difficult reporting process	PM2
Impossible calculation of the salaries	PM3

Problem	*Cost*
Lack of transparency about the formation of the salary	EM3
No quality control	PM3
Difficult planning of future tasks and projects	PM3
Delay of project delivery	PM3
Too much spreadsheets for maintenance	EM1
Lack of financial incomes	PM3

Every problem has a corresponding Problem Cost (PC) that contains two-letter identificator about the party that is most concerned about the problem and a numeric value that represents the level of the problem – 1 being a problem that the company can work with and being a problem that is critical for the company' future.

The interviews with the employees showed another problem with the process of making an offer – in many cases they were given very little information about the project and were unable to understand the task they were given. That turned out to be a repeatable problem as they declared that even when a project was being developed they have difficulties in understanding what their daily tasks are.

The Project Managers wanted to know what tasks are the team members currently working on but with the system of spreadsheets that was impossible. Therefore the process of planning and scheduling new tasks and projects was complex and in many cases unpredictable. The managers could start planning the next project only after the current ones were near the end of the development process. And combined with the constant delay of product delivery that always reflected on the financial incomes of the company.

III. Results and Analysis

The emerging problems in the company has led the managers to believe that a new approach is needed in order to achieve cost-effective resources allocation, shorter execution time and higher revenues.

A common cause of delay is the requirement of the client the project to be finished by a certain time, within a budget while achieving specific performance levels [2]. That relationship can be represented as the follows:

$$C = f(P, T, S) \quad (1)$$

Equation (1) shows the cost as a function of performance, time and scope.

Increasing of even one of parameters of the equation will cause the increasing of the others. For example, increasing the scope of the project will lead to increasing of the resources, which in turn will increase the cost [3].

These three components are in the basis of the compiled list of functional requirements collected from the study.

A. Functional Requirements

From the overview of a small organization is obvious that a project management system has to meet basic requirements in order to be efficient and fit for work.

- The systems has to offer easy management of the work processes, reporting and controlling the activity of the employees
- It should provide a way of quality control over the finished projects by reducing the mistakes, optimizing the work hours and prioritizing the tasks
- All input and output data should be centralized and monitored
- The system has to provide a comfortable working environment for team members such as easy access to needed resources, reliable application and intuitive design.
- The application has to provide a way for control and self-control of the employees
- Customer relationship is important factor when building a strong and successful business. In order to have satisfied customers every company has to offer accurate updates and reports to their clients. The system has to have the option for easy reporting or even giving clients access to their files.
- The problem with time-consuming offering has to be eliminated and for that, the application has to offer faster and more efficient way for making offers and processing of clients' requests.
- The need for detailed reports of operational and financial character is mandatory.
- Receiving a quality report for the complete project based on a set of questions regarding the way the project has been done is also a requirement the company wanted.
- The system has to give quick and apprehensible view of the current projects in order for better planning and organizing of current tasks
- The most important requirement is the time sustainability – it should be able to evolve according to the needs of the company while the company itself evolves and not stopping it.

B. A Project Management System

Based on the collected data from the process of company overview, the researches made for methods of uncertainty management [7, 10, 11] and the compiled list of functional requirements a software for project management and resources allocation is proposed.

The architecture of the proposed solution is a three-tier architecture, which gives the possibility of adding more modules to it and expanding it to a complete ERP system. The final goal is for the company to have own

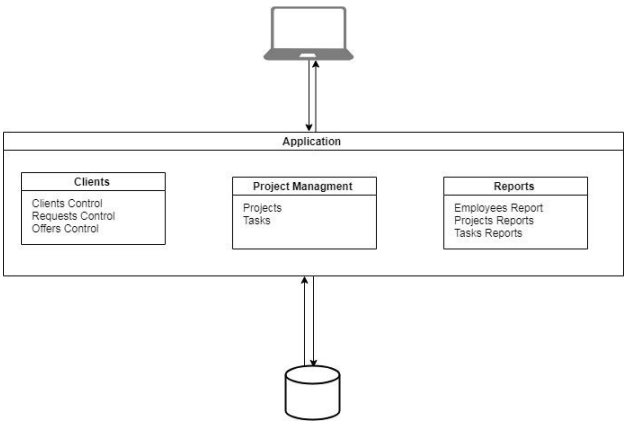
ERP system that can handle all of the business processes of the company.

The ERP system will contain operative and basic modules. The basic modules are the ones that contains all the needed information with which the operational modules will work with.

The current paper considers only the project management part of the whole system and fig. 2 shows the basic modules that the PMS application has. These modules are also operative modules for other applications – accounting, production, etc.

The module for the clients' information consist of requests sub-module and offers sub-modules. These two units operates with clients data and therefore are placed inside the Clients module. The flexibility of this structure allows more modules to be added to the architecture without damaging the current application. Adding a module for accounting will result in better control and reducing the number of operation needed for the issuance of accounting documents. Adding other modules will complete and expand the system, making it more functional, efficient and useful.

FIG 2 ARCHITECTURE OF WEB-BASED SOLUTION



To overcome the problems, which were stated by the employees of the company, the proposed solution intends to speed up the process of offering a project by centralizing the input data and showing it in real-time to the interested parties. That will minimize the time lost in writing unnecessary emails and possibilities of wrongly passed information.

Even though the modules in the software are independent, they are in constant synchronization and work as whole system. That gives the opportunity to managers to track the current projects and their phases and also the ability to plan new ones.

C. Implementation

After the initial development of the proposed system, it was implemented in stages in the observed company. It replaced the old management tool and a lot of the Excel spreadsheets used by the employees and management. The results were visible in the first week of the implementation.

Educating and showing the system to the employees was done in a very short time as the design of the application made possible the adaptation to it easier for everyone working with it. The managers were satisfied with the easy access to the needed files and documents.

The employees had the tasks planned in advance and all the projects and tasks were visible in one gantt diagram showing the current load of the company as whole making the planning of new projects and deadlines more accurate and predictable.

The time for processing a new request and making an offer was reduced to 8 minutes reducing in turn the number of the rejected orders from clients.

The decision for a web-based solution was made on the basis of the nature of the company's work. The company was developing web-based solutions itself and because of that it allowed its employees remote work hours. The new project management system gave access to much needed information to everyone with no restrictions to geographical location, devices or network. Many of the employees were satisfied and relieved because of it.

IV. CONCLUSION AND RECOMENDATIONS

This paper studied the problems in a small company working in the field of web development and design services. The study of the company was made with an observation of the work process and familiarization with the tools used by the company. A series of interviews with the company employees were held and a set of problems were defined and analyzed.

In a result a project management software was proposed that can work effectively as a stand-alone program or as a key component of an ERP system, although as a part of a system it will lead to better results such as less time for administrative work by managers, easier and quicker access to needed information and reduced costs. The benefits if using a planning tool can be easily observed and measured. Having a well-thought, solid and working plan will undoubtedly lead to more well-completed projects and increasing of the business profits. The proposed solution in this paper is for small to medium business but it can be transformed and expanded to suit the needs of every business regardless of its size, number of employees and projects aspects.

The proposed solution can be further developed and expanded to suit the needs of the business and the company.

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Influence of Digital Transformation Drivers on Business Model creation

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***Abstract* - Digital transformation (DT) can be seen as an approach which assumes a radical change of doing business, driven highly by todays necessity to change and adapt to the digital age. This change is mostly made by creating new business models, which define the way how an organization provides value to the customers.**

In this paper we define and analyse the drivers of DT and explore their influence on the creation of new business models.

The drivers of DT define ideas for organizational innovations, and they can arise from trends in the organizational environment or from innovation ideas within the organization itself. Either way, the desire to change can be classified as customer driven - when the change is a result of an adoption to new customer needs, technology driven - when a new technology has become a standard within the industry the business acts in or organizational development driven, when the need for digital improvement of work is defined as a strategic goal that has to be achieved.

Keywords – digital transformation; drivers of digital transformation; business model

I. INTRODUCTION

Digital transformation (DT) is a concept that changes the way how businesses do they work today and as a research field, it experienced an explosion on new approaches, frameworks and case studies, that are supposed to guide and help businesses to digitally transform their work and/or the results of it. A bibliographic analysis on articles and conference papers referenced in the Web of Science database, based on the keywords "Digital transformation" in the document title, was conducted in March 2018 and resulted with 107 hits, and again in December 2018, resulting with 216 hits. This significant increase in number of works in six months shows the relevance of DT as a novelty in digital technologies implementation approaches.

Many studies show that IT-enabled process orientation in organisations can address challenges such as fast changing customer needs, international competition, or technological change. This development leads to innovation potentials which are increasingly discussed under the concept of digitalization [1].

Organizations are expected to timely manage and understand how digital transformation will influence their work. Hence "Digital transformation" includes the use of digital technologies to fundamentally redefine working processes [2], customer needs, products, services and whole industries are changed, being encouraged by digital transformation. Creation of new or change of existing business models is the first step for helping organizations to better define and understand their transformation.

A business model is the blueprint of a company that describes what benefits are provided to customers and partners. A business model answers the question of how the provided benefits flow back into the company in the form of revenue. The created value enables a differentiation from competitors, the consolidation of customer relationships, and the achievement of a competitive advantage [3].

Business models are usually defined through organizational, technological and market (customer) aspects, so in order to know where to start in the creation process, it is important to identify which drivers can be the initiators of change.

This paper first clarifies what DT of an organization is and how business model creation can help in starting the change. In the second part, a classification of DT drivers is done, and suggestions are given on how an enterprise can develop its business model, after the main driver of digital transformation has been identified.

II. DIGITAL TRANSFORMATION DEFINITION

Digital transformation is the result of cultural and organizational changes required for the interconnected use of new digital technologies to make significant improvements such as improving user experience, rationalization of business operations and innovation of products/services and business models [3].

In Table 1 we present some definitions of DT, which all show that DT is not only about technology, but it requires changes mostly related to business concepts within an organization.

TABLE 1. DEFINITION OF DT

Autors	Definition DT
Schallmo, D., Williams, C.A.,	"DT involves companies, business models, processes, relationships, products, etc."

This research has been conducted as part of the wider research in the project Development of innovative platform for digital transformation of enterprises (RDI) which is funded by European Union through the European Regional Development Fund (ERDF).

Boardman, L. [4]	
Clohessy, T., Acton, T., Morgan, L. [5]	"DT is concerned with the changes digital technologies can bring about in a company's business model, which result in changed products or organisational structures or automation of processes"
Brown, A., Fishenden, J., Thompson, M. [3]	DT encompasses "everything from the cultural and organizational changes required to the related use of new digital technologies in order to enable major improvements"
Nandico, O.F. [6]	DT is a change of an "enterprise with the intention to provide a new or significantly enhanced offering to its customers, where this new offering or enhancement is based on information technology as key enabler or even part of the offering"
Kokkinakos, P., Markaki, O., Koussouris, S., Psarras, J. [7]	DT is "the realignment of, or new investment in, technology and business models to more effectively engage digital customers at every touchpoint in the customer experience lifecycle
Corejova, T., Rovnanova, A., Genzorova, T., Valica, M. [8]	DT "represents an organizational change induced and associated with the use of digital technologies and business models in order to improve performance.
Roedder, N., Dauer, D., Laubis, K., Karaenke, P., Weinhardt, C. [9]	DT "enables new business models that rely on automated decision making based on data analytics. In addition to entirely new business models, existing industry can provide new services to customers and improve internal processes based on data analytics, prediction, and decision support"
Betchoo, N.K. [10]	DT is described as the "profound and accelerating transformation of business activities, processes, competencies and models to fully leverage the changes and opportunities of digital technologies and their impact across society in a strategic and prioritised way"

III. BUSINESS MODELS IN THE CONTEXT OF DT

Organizations that want to survive in today's challenging market conditions have to change and adapt their way of doing business. The process of sorting out and shutting down of those organizations, that fail to adapt faster than the technologies and the environment change is also known under the term of Digital Darwinizm [11]. The changes are an inevitable consequence of exponential development of technologies, digitalization of all parts of the value creation process and great potentials of connecting everything [12].

Business models are the fundament of organizations, and the can represent the current and the future state. They are simplified and structurally similar illustrations of all or selected aspects of the company's resource transformation and its exchange relationships with other market participants [13].

Digital transformation in business models refers to some elements or whole business models [14]. Thereby, technologies have a significant impact on the achievement of organizational strategic goals aimed on needs of all stakeholders in the value chain. From a practice perspective, ICT service providers should continue to focus on business model experimentation as a means for harmonizing their organisation's strategies with the disruptive and/or innovative digital transformation [5].

Furthermore, it is important to mention that business models of all industries change. Many products or services will remain the same or similar, however their position in the value chain will be completely (disrupted) or partially changed in terms of the digital level.

Business model canvas [15] is the most used and cited business model framework. Business model canvas is not only used for creating a business model, it is also used for managing and improving of each of the nine business model elements that it contains. The elements are divided into four parts: customers, supply, infrastructure and finance. The customer part includes relationships with customers, customer segments and channels and is directed towards customer definition and understanding. Key partners, activities and resources refer to crucial organisational elements. Additional value refers to innovations that make the service or the product better for the customers, using the possibilities new technologies can provide. The finance part includes the analysis of the costs and the revenue streams that the transformation brings.

Grgurevic [16] groups the nine elements of Business model canvas differently. The Business model option (BMO) matrix, shown in Figure 1, consists of 3 dimensions. The Operational model dimension deals with elements that are defining the internal business structure, the Commercial model dimension gathers the customer related elements and the Value proposition defines the product or the service.

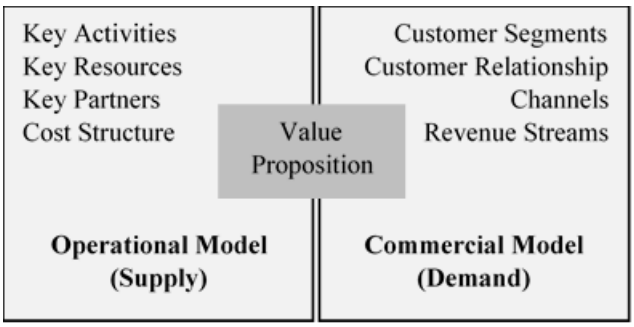

FIGURE 1. BMO-MATRIX [STRATEGIZER]

The three dimensions are equally important in defining the new way of work and are dependent on each other. Still, it is necessary to start with one of them. Digital transformation of processes and business models is an innovation activity and it is identified as important to understand the motivation and underlying drivers of it [17].

IV. DRIVERS OF DT

The term "driver" is defined in the Oxford dictionary [18] as "a factor which causes a particular phenomenon to happen or develop". The drivers of DT can be defined as influent factors or ideas for digital organizational innovations. They can arise from trends in the organizational environment or from innovation ideas within the organization itself.

Trends within the environment influence and push organizations to start DT. These trends can be analysed by

creating a strategic landscape map (shown in Figure 2.) [19], that may help organizations „to identify and understand the current strategic landscape in relation to the current technology/legal trends, customer trends, competitor trends and the economic environment trends“.



FIGURE 2. STRATEGIC LANDSCAPE MAP [DIGITRANS]

The technology trends are defined by new conditions within the industry, where a technology that is considered to be an emerging or new within one industry can be already widely in use by another, while legal trends create a framework that every organization has to adapt to. Customer trends show changes on expectations towards products and services, generating a need to manage „customer engagement“, „customer networks“ and „customer experience“ [20]. Competitor trends give an insight on what other organizations within the same industry are working on while the ongoing economic environment defines the buying habits and practices of consumers.

Ideas for organizational innovations can arise from the mentioned trends in the organizational environment but can also be defined within the organization itself. As stated by Andresson et al. [21] the dramatic increase of importance of ideas and creativity in value creation processes is showing the need for investments in human capital, machinery and infrastructure. The three mentioned resources are identified as very important ingredients, as well as ideas of where and how to use them as key factors for developing the businesses.

Whatever the initiator for a new idea is, from the practical experience of the authors of this paper, the drive for DT can come from:

- the wish to adopt to new customer needs, so it is customer driven
- new possibilities emerging technologies have/give, so it is technology driven or
- intentions to improve the way how work is being done, so it is organizational development driven.

Customer driven DT is initiated by the influence of customers of products or services, based on their new needs or desires. It is important to identify how the product or service, as an element that is the starting point for innovation activities, meets customer demands. For that reason, companies are conducting innovation activities of products or services to redesign the product or service and create an added value for all participants [22]. The Digital Revolution has significantly changed behaviour of customers and their requirements. It is a fact that customers are curious and thrilled by new technologies and that they are attracted by new innovations. That motivates companies to understand their customers and involve them in development and improvement of existing products. The importance of customer drivers is recognized by Kumar Betchoo [10] whereby consumer convenience, customization and mass-customization are emphasized as drivers of DT.

Technology driven DT is related to changes and opportunities induced by digital technologies [10], which may be a response to challenges initiated by the influence of rapid change in purchasing habits, international competition and technological changes [1]. These drivers include the SMACI concept of digital transformation, namely Social Media, Mobility, Analytics, Cloud and Internet of Things [10]. Other technological drivers of DT are Sensors, On-demand computing, Mobile computing and Blockchain [9].

Organisational development driven DT starts with ideas for organizational innovations [22], with the goal of increasing profitability, reduce costs and achieve efficiency. In this case, innovations have a stronger impact on the company's internal focus [22] and changes are initiated by organizational drivers, meaning they are linked to people, processes, strategies, structure and dynamics of competition, thereby facilitating production, commercialization or transfer of products and services to customers [8].

V. INFLUENCE OF DT DRIVERS ON THE CREATION OF BUSINESS MODELS

Identification of the driver that initiates the digital change is the first step in DT, and it can help the organization to make the decision on where to start in the business model creation.

An autonomous vacuum cleaner is an example where a new digitally improved product was made as an answer to a new customer need for more time, better functionality and more comfort in use, so it is customer driven DT. Sensors on things are supposed to gather data and connect everything, which opens new possibilities for products and services use coming from the technology itself, representing a technology driven DT. A fully automated warehouse management system uses robots to replace human workforce, due their lack on the labour market and organizational thrive to increase efficiency of work, so it is organisational development driven.

All three examples show ideas for digital improvement but are motivated through different driver type. The influence of the different DT driver types on Business model dimension of the BMO-Matrix, described in Chapter III, is shown in Figure 3.

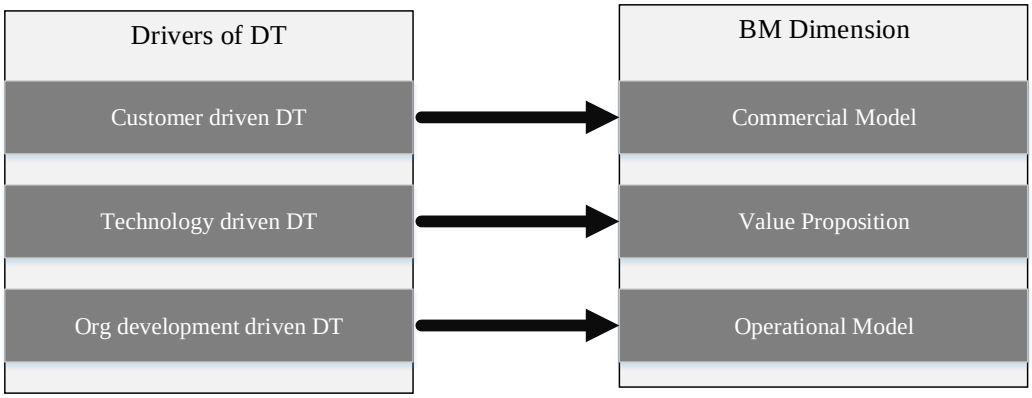

FIGURE 3. INFLUENCE OF DT DRIVERS ON BMO – MATRIX DIMENSIONS

If the company recognises the driver to be a response to new customer needs or demands, the creation of the new business model should start within the commercial model. If the change is initiated by a technology driver, then the first part of the business model to be created is the value proposition. The third driver group, organizational development drivers, pushes the organization to start with the operational model part of the business model.

For each Business model dimension, specific methods can be used for identifying the Business model elements:

- In the Commercial Model, the emphasis is on the methods for customer identification and description. The customer experience research started in the 1960s, through the creation of Customer buying behaviour process models, was continued in the 1970s by Customer satisfaction and loyalty assessing and evaluating, 1980s by identifying the specific context and elements of the customer experience and creating the customer journey, 1990s by relationship marketing, 2000s with Customer relationship management, 2000s till 2010 by Customer centricity and customer focus and 2010s with Customer engagement [lemon]. Customer journey is one of the mostly used method nowadays, allowing the organization to lead the customer through the service delivery process with an emphasis on sequence of events that characterize the it [23].

- The Value proposition starts with the product or service enrichment or with a whole new output and is defined by the technology that is used for it. The emerging technologies of the so called 4th Industrial Revolution [24] can be used separately or combined with each other and the only way that they can bring improvement to the company's performance, is if they are applied in the right places [2].

- Operational model can be assessed using methods that help identifying strengths and capabilities within the organization that will enable the transformation. Also, using a competence analysis [19] a better understanding of the competences, resources and skills that the organization possesses can be identified, as well as on which of them should be further build on to generate sustainable competitive advantages.

VI. CONCLUSION

Digital transformation is a concept that is experiencing an exponential growth trend, both in research as well as in real life use. Business models are supposed to create an illustration of the desired change, seen from organizational, customer and value creation perspective. Thereby, DT can be initiated by different driver's types, so the creation of a business model can also start by defining elements in different dimensions first.

Customer driven DT is initiated by customer needs, so commercial model elements like customer segments, channels and relationships are identified first. Technology driven DT starts with new possibilities technology offers, and that puts the value proposition creation at the beginning of business model creation process. Organizational development driven DT starts with initiatives and innovation ideas from inside of the company, so first key resources, activities and partners are defined. The suggested approach helps organisations to determine where to set accent at the beginning of the process of business model creation, but do not reduce the scope of work that has to be done in total. Digital transformation includes changes of all aspects of work, so consequently, also all business model parts need to be defined. It is important to notice that customers' habits, products, services and approaches within organizations are changing fast, so adapting to the new conditions becomes business' key factor of success. The incentive is to innovate the business model and adjust the way of doing business to the new digital environment, in order to survive in the global marketplace.

Each of the drivers can also be broken down into more detailed elements of influence and their translation into business related concepts could be described on the meta-model level. Depending on which influence element (or combination of several of them) is selected for DT, the digital change within the DT dimension can be further analyzed and initiated. The extent of their influence is also important in our further investigation in terms of projecting potential benefits and resource allocation planning.

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Automated decision-making with DMN: from decision trees to decision tables

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***Abstract* - Recent advances in artificial intelligence, especially the subfield of machine learning, is commonly cited as one of the driving forces for digital transformation and innovative business models. Ongoing research is focusing on embedding solutions based on machine learning into business processes which are commonly modelled using the BPMN standard. The Object Management Group has recently adopted the Decision Model and Notation standard. By using the Decision Model and Notation (DMN) it is possible to replace multiple decision points embedded in business processes. The purpose of this research is to provide a method to derive DMN decision tables from the corresponding machine learning model generated by the decision tree classifier. The development is conducted using the Python machine learning library scikit-learn and Camunda Modeler. This approach facilitates and automates the process of converting machine learning models into DMN tables.**

Keywords* - *Business Process Management (BPM); Decision Model and Notation (DMN); decision trees

I. INTRODUCTION

Business process management (BPM) tools have been extensively used for digital transformation within companies: recourse orchestration, work routing and automation of routine manual tasks are just some examples of business/IT alignment that enable companies to work more efficiently. As business process management (BPM) systems become more advanced, there is a shift from pre-defined process models to intelligent systems that support and automate processes. Modern BPM systems are general-purpose application development platforms that allow integration of other technologies through e.g. RESTful API calls. These innovative and augmented processes usually include artificial intelligence applications, powered by machine learning algorithms. Technologies that are being integrated into modern BPM systems include business rules, predictive analytics, machine learning and robotic process automation (RPA), Internet of Things (IoT), process mining algorithms etc.

Advances in machine learning algorithms include image recognition systems, recommender systems and natural language processing automation tasks. As business processes are generally great candidates for automation, combining BPM systems and machine learning together can take automation to another level. By connecting machine learning applications to existing BPM tools and feeding process data to machine learning applications, companies could decrease the user tasks even more, while at the same time also deliver a better product to market.

The content of this paper is structured as follows. Section II presents selected relevant literature and establishes the theoretical framework for the development of the proposed method. Section III details the conceptual modelling process and the results of the development process. The method is presented and described in detail. Finally, section IV includes the summary of the results, guidelines for further actions, limitations of the study and concluding remarks.

II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The DMN model is primarily designed for business people who are modeling business decisions. Its central construct is the decision table. Relevant objects in DMN tables are business knowledge models that relate to implementation and sources of knowledge that serve for documentation. DMN tables are based on the FEEL (Friendly Enough Expression Language) language, a standard DMN language. FEEL language has the following characteristics [1]: a) side-effect free; b) simple data model with numbers, dates, strings, lists, and contexts; c) simple syntax designed for a wide audience; d) three-valued logic (true, false, null) based on Structured Query Language (SQL) and Predictive Model Markup Language (PMML). The elements of the DMN decision table are [1]: Decision, Business Knowledge Model, Input Data, Knowledge Source and Decision Service.

The purpose of DMN is to provide constructs that are needed to model decisions, so that organizational decision-making can be readily depicted in diagrams, accurately defined by business analysts, and (optionally) automated [2]. When using a DMN table, it is desirable to understand clearly the business objective and specific business rules to avoid storing large amounts of data. The DMN decision table contains columns and rows that indicate the input/output logic and rules.

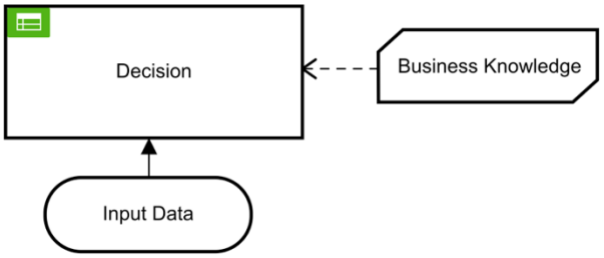

Figure 1. Basic elements of a decision model [2]

The basic elements and the structure of a decision model are shown in Figure 1. In this case, the decision is obtained using the logic of the business knowledge model that is derived from the input values.

Due to the increasing use of DMN decision tables in the business world, there is a growing need for analysis of these tables [2]. Rules for defining task analysis over this tables and a general approach for analysis and processing of decision tables based on geometric interpretation is proposed [3]. The authors provide a solution to simplify the DMN tables by merging the rules when they have the same expression and conclude that the variant with a single permutation is sufficient for practical application. The complexity of the Decision Model and Notation was assessed, and the results were compared with previous studies for other modelling notations, such as Unified Modeling Language (UML) activity diagrams, Business Process Model & Notation (BPMN), and Case Management Model & Notation (CMMN) [4]. The authors note that the complexity of the process models decreases as the process is reduced to its essence, i.e. without hard-coding the decision logic within the process. It is also suggested that employing DMN in organizational decision making might be specifically useful in a setting where business rules change frequently and where decisions have high risk for the operations [5].

The decision tree is a recursive graphical algorithm that uses the branching method to illustrate the possible out-come of a decision. It works on a Boolean algorithm principle divide and conquer. It divides data into smaller subcategories and if those unambiguous algorithms cease to work and we get the result. However, if subcategories are not uniquely determined, then the algorithm is the next subcategory of the other attributes as long as it does not get a sub-category that is uniquely determined. Using the decision tree, we get new data that we can use to build a DMN table.

Applications based on machine learning algorithms and other intelligent systems that integrate DMN decision tables with BPM systems can be developed in various ways. One approach is to integrate machine learning applications with microservice architecture, then use it as an external service in BPM systems through signal events (with BPMN represented as the triangles in enclosed circles). A dynamic decision-making framework for BPM is proposed as an extension for BPMS [6]. It aims at guiding the actions and decisions of the BPMS, thus, automatically proposing decisions that have a behavioral character. With this approach a Bayesian network is derived automatically from an event log and a decision model in DMN is based on historic and current process execution data. A user-friendly graphical user interface that allows for interactive decision enactment on the modelled decisions is proposed [7]. The authors proposed a system for translation of DMN to an extension of first-order logic.

The DMN decision modeling process structure shown in Figure 2 includes two activities addressed by the method proposed in this paper: formulate decision logic (usually a part of the business domain) and create decision services (usually part of the IT domain). The design-time approach taken in our case provides a clear advantage over a runtime approach when using decision trees, rules or linear models that can be produced transparently, represented statically by a decision service and made available to all stakeholders, both in the business and IT domain. Recent studies [8] show that such approach not only provides an explanation for any outcome, but also an understanding of how the decision is made in general, irrespective of any specific input data.

While this approach is not suitable for a broad range of applications, it is very convenient in the way that it takes into account existing DMN standards already included in many BPM systems (e.g. Camunda BPM, Goldman Sacks jDMN, Oracle Process Cloud, Red Hat Drools). This facilitates its implementation and further development and customization to specific needs and scenarios.

We argue that design-time approach may not be suitable in settings where Neural Networks, Support Vector Machines (SVM) or Bayesian networks are used. In such cases, a runtime approach would be preferred.

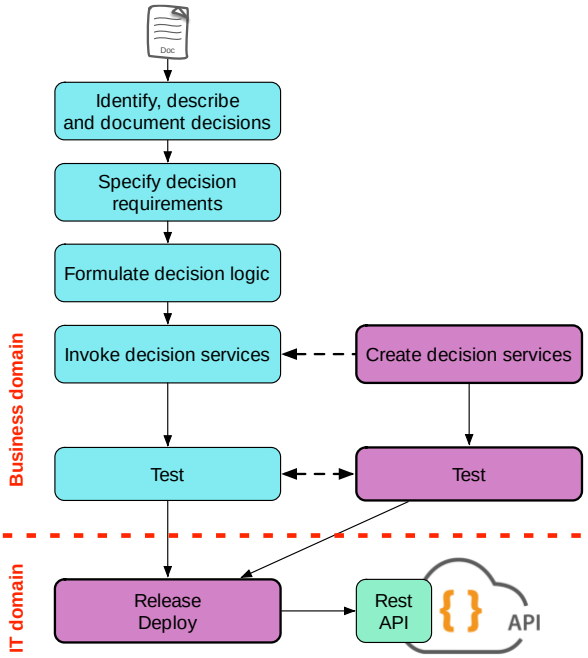

Figure 2. DMN decision modeling process

III. RESEARCH METHOD, DEVELOPMENT PROCESS AND RESULTS ANALYSIS

The development process goal is to create a method that enables the conversion of the decision tree model generated by Python-based machine learning algorithm into a DMN based decision table XML artifact that can be imported into various BPM platforms and used within BPMN process models.

The Python programming language and Camunda modeler were the tools chosen for implementing our solution. Python is an interpreted, object-oriented, high-level programming language with dynamic semantics while Camunda modeler is a desktop application (developed in JavaScript) for modeling BPMN and DMN diagrams which are stored in XML (Extensible Markup Language) format. Scikit-learn, a well-documented and widely popular open source machine learning library, and ElementTreeXML, a simple and efficient API for parsing and creating XML data, are the main libraries used in our script. Other Python libraries used in the development process include: Numpy and Pandas (used for reading csv files), deafultdict class from module collections, random and string (used for creating simple id generator), Graphviz (used for visualization of the decision tree classifier) and Progress (from which we used class Bar to create a simple progress bar).

The script we developed is divided into two classes, the base class (xmlDmn) consisting of functions needed for generating DMN tables and derived class (clfDmn) which contains the machine learning model.

A. Machine learning model development

A clfDmn object is created to which two mandatory parameters are passed: a csv file (our training data) and a dmn file (file that contains the table we want to edit).

The constructor is called and starts processing the csv file by creating and splitting the data frame into needed parts and after the data is ready, the machine learning algorithm (DecisionTreeClassifier) is started. The core function in this class is generateTableFromClf shown in Figure 3. This function first extracts information from the classifier: leaf Ids, decision path, thresholds, features, left and right children.

In the next step, a list of features (featuresForDiagram) is prepared, that will be used for creating the columns in the decision table and for the dictionary (inputOutput), because we have to ensure that the order of features are the same. Next follows the cleaning of the table (clearDecisionTable()), generating new table columns (generateTableColumns()) and the looping over leafs is started. From every leaf the class name and all samples in it (samplesInNode) is collected, but only the first one (sampleId) is used. For that sample, its decision path is tracked and looped over it. By doing that, all features, thresholds and threshold signs (<= or >) from all nodes are extracted, after which the filled dictionary is sent to generate the rules in the table (generateTableRows()). In the end of the function a new file is created, in which all changes made to existing table are written (writeTree()).

```
def generateTableFromClf(self):
    featureNames = [self.dfFeature[i] for i in self.clf.tree_.feature]
    leafIds = self.clf.apply(self.dfData)
    leftChildren = self.clf.tree_.children_left
    rightChildren = self.clf.tree_.children_right
    decPath = self.clf.decision_path(self.dfData)
    threshold = self.clf.tree_.threshold

    featuresForDiagram = list(self.dfFeature)
    featuresForDiagram.append(self.dfClassColumn)

    self.clearDecisionTable()
    self.generateTableColumns(featuresForDiagram)

    bar = IncrementalBar("Processing",suffix='%(percent)d%%', max = len(set(leafIds)))
    for i in set(leafIds):
        samplesInNode = decPath.getcol(i).copy()
        rows,cols = samplesInNode.nonzero()[0]
        sampleId = rows[0]
        nodeIndex = decPath.indices[decPath.indptr[sampleId]:decPath.indptr[sampleId+1]]
        className = self.clf.classes_[np.argmax(self.clf.tree_.value[i])]
        inputOutput = defaultdict(dict)
        for value in featuresForDiagram[:-1]:
                inputOutput[className][value] = {}
        for index, nodeId in enumerate(nodeIndex):
            nodeFeature = featureNames[nodeIndex[index-1]]
            nodeThreshold = threshold[nodeIndex[index-1]]
            if nodeId in set(leftChildren):
                inputOutput[className][nodeFeature]["<="] = nodeThreshold
            if nodeId in set(rightChildren):
                inputOutput[className][nodeFeature][">"] = nodeThreshold
        self.generateTableRows(inputOutput.items())
        bar.next()
    bar.finish()
    self.writeTree()
```

Figure 3. generateTableFromClf function from clfDmn class

```
def generateTableColumns(self,names):
    outputName = names[-1]
    inputNames = names[:-1]
    for name in inputNames:
        newInput = et.SubElement(self.decisionTableElement, "{%s}input"%(self.namespace), attrib= {"id": self.idGen("input_")})
        newInputExpression = et.SubElement(newInput, "{%s}inputExpression"%(self.namespace), attrib={"id": self.idGen("inputExpression_"),"typeRef":"double"})
        newText = et.SubElement(newInputExpression, "{%s}text"%(self.namespace))
        newText.text = name
    et.SubElement(self.decisionTableElement, "{%s}output"%(self.namespace), attrib={"id": self.idGen("output_"),"name": outputName,"typeRef":"string"})

def generateTableRows(self, mlDict):
    for k, v in mlDict:
        newRule = et.SubElement(self.decisionTableElement, "{%s}rule"%(self.namespace), attrib={"id":self.idGen("DecisionRule_")})
        for keyValues in v:
            tSignList = list(v[keyValues].keys())
            if len(v[keyValues]) == 0:
                self.createRuleCell(newRule)
            if len(v[keyValues]) == 1:
                self.createRuleCell(newRule).text = "{} {:.4f}".format(tSignList[0],v[keyValues][tSignList[0]])
            if len(v[keyValues]) == 2:
                if tSignList[0] == "<=":
                    if v[keyValues][tSignList[0]] > v[keyValues][tSignList[1]]:
                        self.createRuleCell(newRule).text = "]{:.4f}..{:.4f}]".format(v[keyValues][tSignList[1]],v[keyValues][tSignList[0]])
                    else:
                        self.createRuleCell(newRule)
                if tSignList[0] == ">":
                    if v[keyValues][tSignList[0]] < v[keyValues][tSignList[1]]:
                        self.createRuleCell(newRule).text = "]{:.4f}..{:.4f}]".format(v[keyValues][tSignList[0]],v[keyValues][tSignList[1]])
                    else:
                        self.createRuleCell(newRule)
        newOutEntry = et.SubElement(newRule, "{%s}outputEntry"%(self.namespace), attrib={"id":self.idGen("LiteralExpression_")})
        newOutText = et.SubElement(newOutEntry, "{%s}text"%(self.namespace))
        newOutText.text = str(k)
```

Figure 4. generateTableColumns and generateTableRows functions from xmlDmn class

B. DMN tables implementation

When clfDmn object is created xmlDmn constructor gets triggered and starts parsing the mandatory parameter (dmn file) using ElementTreeXML library. Two main functions of class xmlDmn are shown in Figure 4. Both functions are called from generateTableFromClf (see Figure 3). GenerateTableColumns loops over inputNames (sliced list of featuresForDiagram containing only input features) creating a new xml element for each element in the list and at the end the output element is created. At the moment, types from input and output elements are hardcoded. GenerateTableRows loops over dictionary which has specific structure {Class Name : { Feature : {Threshold Sign : Threshold }}}. For each Class Name (variable k in Figure 4) the function creates a new rule after which it loops over all features (variable keyValues in Figure 4) and collects threshold signs (<= or >) in list (tSignList). Depending on the number of signs in the list we decide to create an empty cell (number of signs = 0), comparison cell (number of signs = 1) or range cell (number of signs = 1). We complete our new business rule with the output element at the end, which contains the class name.

C. Discussion

As we can observe from Figure 5 that every sample in a leaf (node without children) took the same specific path from the root (main node) e.g. node 4 (preorder tree traversal, root node is 0) has 43 samples of class Iris-versicolor. We can conclude that every single sample in that node has "Petal width > 0.8, Petal length <= 4.75 and Petal width <= 1.65". This knowledge can be extracted from the decision tree and it can be used to create a DMN decision table as we have shown with our script.

Every rule (row) in Figure 5 represents one leaf of the decision tree. By observing Figure 4 we can notice that some cells are left empty which meaning that feature is irrelevant for classification. Furthermore we can notice ranges like "]0.8000..1.6500]" which means that feature "Petal width" needs to be in range 0.8 to 1.65, excluding 0.8 and including 1.65.

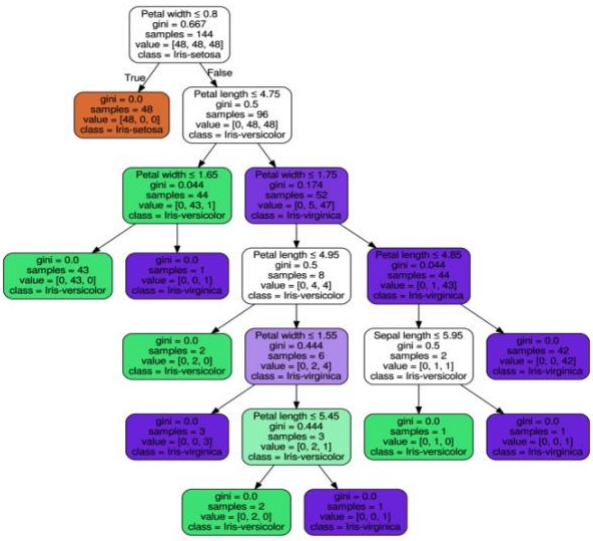

Figure 5. Decision tree visualized with Graphviz module

IV. CONCLUSION

As BPM systems collect and store detailed process information, paired with machine learning, process data can improve decision making by identifying patterns as the process advances through the workflow, thus automating user tasks that would take significant time (e.g. sales forecasting, demand planning).

The benefits of applying DMN to model business decisions can be summarized as a list that includes: (1) improved speed and faster project cycles, (2) increased participation of business stakeholders, (3) visualization through graphical logic that can reveal hidden relationships, (4) flexibility, transparency and auditability and (5) ease of deployment through REST calls. Benefits also include improved efficiency, both in terms of worker hours and end-to-end cycle time for a transaction, improved quality and compliance due to standardized processes and decisions. All of these contribute to improved customer satisfaction, increased job satisfaction by automating unskilled and semi-skilled tasks that are non-value-added overhead in most workers' workload.

First Decision

`Decision_13nychf`

U	Input +			Output +	
	Petal lenght	Sepal lenght	Petal width	Class	
	double	double	double	string	Annotation
1	-	-	<= 0.8000	"Iris-setosa"	-
2	<= 4.7500	-	]0.8000..1.6500]	"Iris-versicolor"	-
3	<= 4.7500	-	> 1.6500	"Iris-virginica"	-
4	]4.7500..4.9500]	-	]0.8000..1.7500]	"Iris-versicolor"	-
5	> 4.9500	-	]0.8000..1.7500]	"Iris-virginica"	-
6	]4.9500..5.4500]	-	]1.5500..1.7500]	"Iris-versicolor"	-
7	> 5.4500	-	]1.5500..1.7500]	"Iris-virginica"	-
8	]4.7500..4.8500]	<= 5.9500	> 1.7500	"Iris-versicolor"	-
9	]4.7500..4.8500]	> 5.9500	> 1.7500	"Iris-virginica"	-
10	> 4.8500	-	> 1.7500	"Iris-virginica"	-
+	-	-	-	-	-

Figure 6. Decision table created from extracted decision path of every leaf

In this paper we presented a method that creates DMN decision tables from a decision tree model. The proposed method automates the process of converting decision tree models (generated by the decision tree classifier) to DMN decision tables, which can be used alongside BPMN process models within various BPM systems.

The main limitation of the presented method is that relevant tasks have many attributes which can be successfully handled by machine learning algorithms but their presentation in the decision table may be a bottleneck. Future work will focus on extending the method to other machine learning algorithms.

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Hidden costs of ERP Implementation

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Abstract: - It's well known that ERP Implementation requires, above all, time and money. It can be said globally that these two elements represent a cumulative effect of many critical success factors (CSFs) of ERP implementation. Without diminishing the importance of time, the cost component of ERP implementation may be significantly increased by the hidden costs of implementation, which in the phase of supply and contracting are not seen as separate items. This paper presents the research on hidden costs of ERP implementation in small and medium-sized (SME) manufacturing companies in Croatia.

Key words – SME, Hidden Costs, ERP Implementation

I. INTRODUCTION

ERP is an acronym, whereby E is Enterprise with emphasis on the integrity of business system, R is Resources representing all resources of a company: human, material, financial, information, organizational, respectively all resources at disposal in a company, while P is Planning, whereby the focus is on providing all resources and their best allocation for the achievement of objectives (in accordance criteria of efficiency, flexibility and growth of business system [1]. For the same, or very closely similar concept, certain other terms are also often used, such as Enterprise Information Systems, Enterprise Wide Systems (EWS) or Enterprise Systems (ES).

The term ERP system cannot be easily defined, especially taking into consideration different views of possible stakeholders, as quoted by al-Mashari and others [2]. Boersma and Kingma [3] within such point of view indicate that there is no generally accepted definition of ERP. Klaus and others [4] after quoting a dozen of definitions of ERP by various authors, also express a dilemma regarding the possibility and exact definition of ERP.

However, notwithstanding the quoted dilemmas, there are many of those who tried to define ERP. Hence, ERP systems are highly technically multifunctional information systems designed for increasing organizational performance and competitiveness by a more efficient organization of business processes through eliminating work and data duplication [5]. It must be mentioned ERP definition from APICS (American Production and Inventory Control Society) should be quoted, i.e. ERP is a framework for organizing, defining and standardising business processes necessary to effectively plan and control an organization so the organization can use its internal knowledge to seek external advantages [6].

The term SME (small and medium enterprises) means micro, medium and small enterprises.

In 2017 small and medium-sized enterprises had a share of od 99,7% in Croatian economy. Compared to the previous year, in 2017 there was an increase in the number of micro and small enterprises by 4,9% and an increase in the number of medium-sized enterprises by 3,9%. Micro, small and medium-sized enterprises employ almost three-quarters (73,2%) of all employed persons in business entities in Croatia in 2017. Within the sector, micro enterprises employ 27,5% of all employed persons in business entities. The number of employed persons in micro enterprises in 2017 compared to 2016 grew by 4,3%, in small enterprises by 3,1%, in medium-sized enterprises by 4,5%, and in large enterprises by 2,3%. In 2017 the share of micro, small and medium-sized enterprises in total revenue achieved in Croatia amounted 59,6%, which is slightly lower in relation to the previous year 2016. However, when it comes to revenues, changes are somewhat higher: total revenue of micro enterprises in 2017 grew by 8,4%, small enterprises by 7,9%, medium-sized enterprises by 4,7%, and large enterprises by 7,6% in relation to the year 2016 [7].

The definition of micro, small and medium-sized enterprises in Croatia is aligned with the definition of the European Commission [8]:

- Micro enterprises:
  - less than or 10 persons employed and
  - annual turnover and balance sheet up to or equalling 2 million Euro,
- Small enterprises:
  - 11 to 50 persons employed and
  - annual turnover and balance sheet up to or equaling10 million Euro,
- Medium-sized enterprises:
  - 51 to 250 persons employed and
  - annual turnover up to or equalling 50 million Euro, and annual balance sheet up to or equalling 43 million Euro.

II. HIDDEN COSTS OF ERP IMPLEMENTATION LITERATURE REVIEW

ERP implementation is a cost demanding undertaking for every organization. Thus Domm and Milis [9] made a survey in four small and medium-sized enterprises in Belgium, and that in terms of costs for hardware,

software, for consultants, for the team participating in the implementation and for training users. Data aren't fully comparable because there are more significant deviations between companies but, in general, the price of software does not exceed 30% of total costs, the costs of hardware are approximately 10% while the largest items are consultants with close to 40%.

Sudzina and Johansson [10] compared ERP implementation costs in Denmark, Slovakia and Slovenia. Costs of software licenses are from 43% for small enterprises, 45% for medium-sized up to 33,5% for large enterprises. Implementation and modifications programming costs are approximately 40%.

Due to the large number of elements of costs structure of ERP system implementation and application, Elragal and Hadara [11] developed a model for the assessment of ERP implementation costs, providing several benefits for both scientists and practitioners. The quoted model of cost structure is shown in Figure 1.

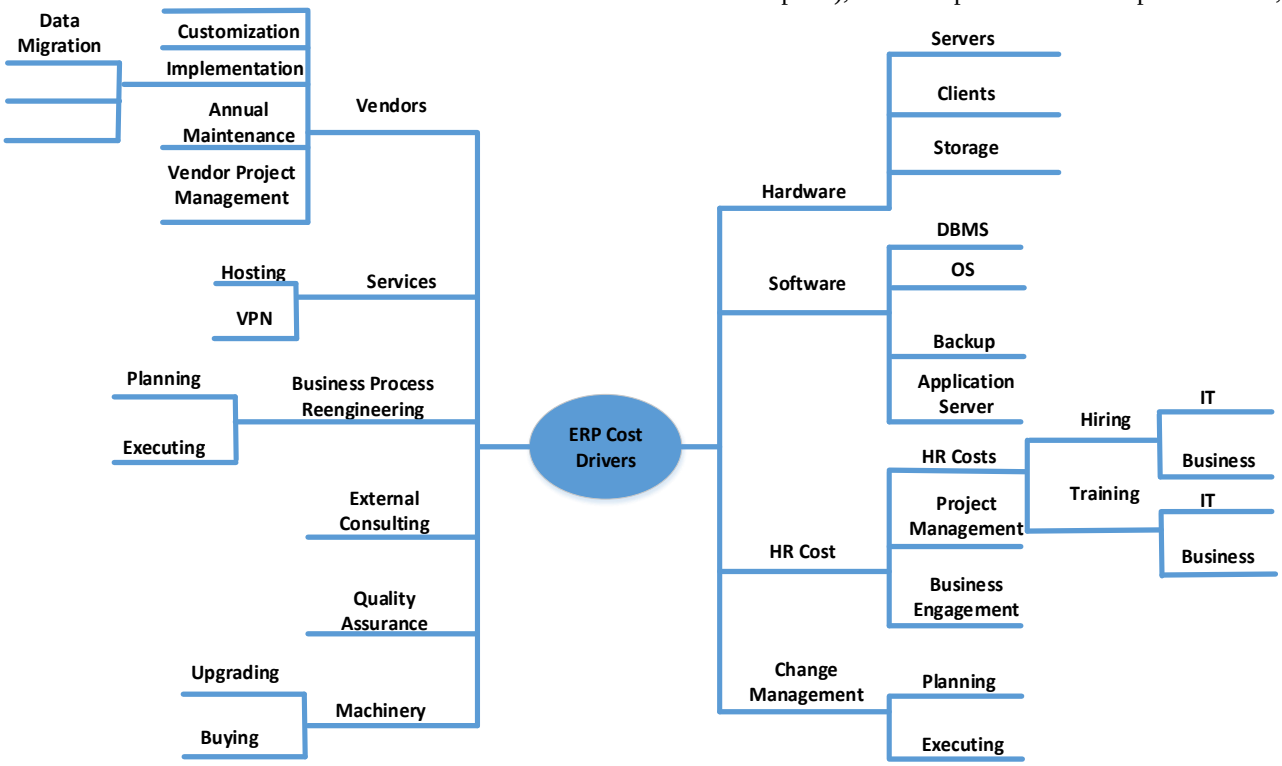

Figure 1 Cost structure model

Haddara [12], prompted by the problem of costs assessment and management, made a survey in small and medium-sized enterprises of Egypt on the quoted model, based on percent participation of the shown factors.

Mahadevan and others [13] explored costs in 111 SME enterprises in Malesia from two aspects. The first part were costs from three standpoints, company, people and implementation. The other aspect was the research of influence of every single factor on other factors. It was established that the software cost is not the key cost.

Based on literature [14], [15], [16], [17], [18] and [19] it is possible to conclude that, when acquiring a new ERP software, hence not a transition from the old ERP solution, four summary costs should be expected:

- software licence,
- maintenance cost (on annual basis)
- hardware infrastructure and
- implementation cost.

The first three elements are "relatively" clear and visible already in the implementation plan. However, the fourth summary cost is the largest "unknown" area and the relatively most difficult to assess. Realistically, practitioners with 100 and more implementations of a software solution have problems to define the costs because every project of implementation has a series of elements which vary from environment to environment. The cost of implementation consists of a series of elements, among which the most significant are as follows: number of users (the same influences the software price), time period for implementation, requirement for customization or reconfiguration of the software solution, which level of the financial part of ERP solution is implemented, whether it is required to implement certain other solutions as well (Distribution, Supply Chain Management, Customer Relationship Management....) within ERP solution, whether there is a requirement for additional reports in relation to the existing ones, quantity of data conversion, quantity of training future users, etc.

If all quoted potential costs are taken into account when planning the project of ERP solution implementation, how is it possible to talk about hidden costs of implementation, respectively, what is their definition? There is no simple definition for this term. In the available literature [20], [21], [22], [23], [24], [25] and [26] we can find other terms for the quoted term such as:

unexpected costs, budget overrun, unplanned costs, etc. It is common to say that budget overrun is related to insufficiently proper planning during the development of the implementation project which, as an integral part, includes the completeness of received bids from suppliers and consultants respectively external managers of implementation.

What are the generators of hidden costs of implementation? Based on the quoted literature, we can speak about the following constituent elements:

- **Trainings,** are highly dependent on the practice of those conducting the implementation, regardless whether they are external consultants or in-house consultants. Users are practicing a new set of procedures for carrying out business activities whereby lack of understanding occurs in the training process,
- **Integration and Testing,** means testing between new modules of ERP solution and other software that exist in the company,
- **Customization,** should be, in entirety, the included cost at the beginning of the implementation project. However, during the implementation process it is very often concluded that it is required to procure new modules for supporting the totality of business processes,
- **Data Conversion,** is usually a cost that should be reckoned with when planning implementation costs. This refers to the transfer of usable master data, those from sales, procurement, etc. Of course, the emphasis is on automated data conversion which, in the majority of cases, includes additional programming,
- **Data Analysis,** in terms of users, is the worst part of implementation. A series of data in the previous software solution is of questionable accuracy. This process means the control of transferred data (or prepared for conversion) exactly by those who are using these data and who know most about the same.
- **Consultants,** the implementation plan should provide that every business function has an advanced user who will be the internal consultant for everybody else. In these cases an external consultant is needed only in new inflection points, if the same occur, or with significant novelties in the execution of business functions in modules,
- **Replacement of the best from the implementation team.** Very often the best from the implementation team, after completed implementation, go to those who are at the beginning of such process. These are usually project manager or heads of individual business functions from the implementation team.
- **Activities of the implementation team in post-implementation phase.** It is necessary to think about this phase when planning the implementation process, especially when establishing the implementation team. If the implementation team consists of the best representatives of business functions, there is a high probability that in the post implementation period they will be able to continue to configure as advanced users and to perform business functions in the same way as before the implementation of the ERP solution. Otherwise new persons will have to occupy these positions,
- **Expectations of return on investment.** One of the most often asked questions during the implementation project is the time of return of invested funds. There is a series of answers [26] and the starting point should be the eason for entering into the implementation project, and
- **Maintenance.** Every software solution requires periodical maintenance, regardless whether it is the issue fix the bugs or functional-technical improvements in order to maintain the system at the latest versions. Thereby it is required to adjust the users' documentation and to implement new functionalities.

III. RESEARCH METHODOLOGY

Based on research of available literature, a ranking list of hidden costs of ERP solution implementation was drawn up, which occurred in the same. In total, there were 15 hidden costs. Some of the factors appeared as sub-factors in other factors. After analysing these factors, we opted for all costs which could be unambiguously defined and for which, after consultations, we believed that the users could recognize the same respectively for which they might have relevant accounting records. In this way the questionnaire had 8 hidden costs of implementation which had to be ranked according to a scale ranging from did not influence (1), influenced (2), strongly influenced (3) the totality of costs of the implementation project. The reason for selecting this kind of scale lies mainly in the assessment methodology of Panorama Consulting in terms of budget for implementing the ERP solution. According to the report from 2017, and for year 2016, budget movements in terms of implementation had the following distribution [27]:

- within budget, 26% of companies surveyed,
- budget overrun below 25%, 56% of companies surveyed, and
- budget overrun by more than 25%, 18 percent of companies surveyed.

Budget overrun for 2017 amounting 64% indicates a reduction in cost overruns [28].

Reports of Panorama Consulting in the part of budget for ERP solution implementation, for the past five years, show a similar distribution, although amounts differ.

The questions referred to the totality of the implementation process, respectively to the entire lifetime of the implementation (with post implementation time).

The questions were sent by e-mail to 120 manufacturing companies in Croatia in which during 2012 a research of Critical Success Factors (CSFs) of the project of ERP implementation was conducted. At the same time a programme was made on the web which the users could complete and its appearance was identical to that in the world document. Opting for the word document and returning the completed document by e-mail was the result of experience from previous research. Based on the above, we asked two research questions:

- to which extent are hidden costs of ERP implementation recognized in Croatian companies and
- what is the ranking list of the most influential hidden costs of ERP Implementation.

Questionnaires were sent in early April 2018. The time period till the end of June was set for returning the completed questionnaires. In that period we received merely 9 responses so we included an interview in the research methodology, and the same was conducted during September and October 2018. It should be noted that, on this occasion, personal acquaintance was a key factor for a more or less relevant number of returned questionnaires.

The companies have implemented the following ERP solutions: SAP, Pantheon, MS Dynamics (Navision), EXACT Max and Point.

IV. Analysis and Interpretation

Of the 120 companies to which requests for completing the questionnaire were sent, 13 companies no longer exist. After performed interviews, responses were received from 43 companies which is 35,8% of contacted ones, respectively 40% of active companies. The interview was not conducted in 17 companies in which there were significant changes in terms of employed persons (departure of CEOs, project managers or advanced users) and thus personal acquaintance was not a factor for completing the questionnaire. Hence, potentially we had available 90 manufacturing companies, 47 companies did not complete the questionnaire for one of the following reasons:

- Monitoring of additional-hidden costs was not envisaged by the project implementation plan,
- Additional-hidden costs in relation to the implementation plan were monitored on a single summative account, and it was not possible to make the distribution per questionnaire,
- Monitoring of additional-hidden costs was interrupted for some reason after a certain period of time, so there is no continuity in the collection of costs and
- Certain companies, even after repeated requests, did not complete the questionnaire.

The quoted would be the response to the first research question.

TABLE I: OVERVIEW OF HIDDEN COSTS OF ERP IMPLEMENTATION (1-DID NOT INFLUENCE, 2-INFLUENCED, 3-STRONGLY INFLUENCED)

Hidden Cost of ERP Implementation	**1-did not influence**	**2-influenced**	**3-strongly influenced**
Training	16	13	14
Integration and Testing	15	16	12
Customization	15	16	12
Data Conversion	5	9	29
Data Analysis	5	14	24
Consultants	7	10	26
Post Implementation	21	14	8
Maintenance	21	14	8
Sum	102	110	132
Percentage (%)	**30**	**32**	**38**

Based on the obtained results, it can be concluded that in 30% of cases hidden costs did not have an influence on budget overrun. In 32% budget overrun was at the level of up to 25% and in 38% of cases budget overrun exceeded 25%.

In accordance with these results, the ranking list of hidden costs strongly influencing budget overrun is as follows:

- Data Conversion 22%,
- Consultants 20%,
- Data Analysis 18%
- Training 11%,
- Integration and Testing 9%,
- Customization 9%,
- Post Implementation 6% and
- Maintenance 5%.

It should be noted that the first four hidden costs of ERP implementation account for 71%, which means that in preparing the plan of ERP implementation project they should be given special attention.

If the values of hidden costs relating to the totality of budget overrun are summed up, the following ranking list is obtained:

- Data Conversion 16%,
- Data Analysis 16%,
- Consultants 15%,
- Integration and Testing 12%,
- Customization 12%,
- Training 11%,
- Maintenance 10% and
- Post Implementation 9%.

In this case, too, the first three hidden costs are the ones most strongly influencing budget overrun: Data Conversion, Data Analysis and Consultations. As noted above, this suggests that in the project of ERP

implementation these are the costs that should be given special attention.

This would be the response to the second research question.

V. CONCLUSION

One of the most frequent questions in the phase of analysing the received bids for the totality of ERP solution implementation, in addition to duration, is the amount of budget overrun. The vagueness of responses from potential contractors and implementers (consultants) deepens the already huge doubt. What are the reasons that the quoted stakeholders of the totality of the implementation process do not provide straight answers. Certainly not ignorance. One of the important factors is certainly the correctness of the same. If they present all costs, and at the same time the other bidders fail to do so, they can potentially lose the job. One of the factors is also a certain unwillingness of future users, during implementation, to accept in full all suggestions of implementers. Thus, when launching the system, ignorance and disorientation will occur, which will surely result in cost overrun. Here we primarily refer to the analysis of existing data and conversion of the same to the new system. It's an arduous and boring work, provided the same are known.

Future research should have a background in data which today are relatively hard to obtain. Some users, for various reasons, do not want to "see" the truth when it comes to the structure of cost overrun in ERP implementation. Once it is the fear of the core implementation team that accurate registering of cost overrun will point to their inability to manage the implementation process before other stakeholders. On another occasion it is the same fear of senior management before the Supervisory Board, and thus costs are recorded on some other basis. External consultants fear the registration of these costs in a similar way. Although when talking to external consultants, and within preparation for this research, we came to the conclusion that they are familiar with many of these data.

And finally, the actual registration of hidden costs of ERP implementation, should be the goal of all stakeholders for, inter alia, reducing or eliminating one of the key taboos of ERP implementation.

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PAPERS

Workflow for development and integration of digital content for holographic displays

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***Abstract* - Virtual Reality (VR) and Augmented Reality (AR) have gained a lot of popularity in the last decade, but the holographic technology and the holographic displays remain, as one would say, "the holy grail" of three-dimensional content. The holographic technology and the holographic displays have evolved tremendously during the past several years. They are significantly different compared to the aforementioned VR and AR technologies, and are widely considered the ultimate display technology. There are plethora of 360 degrees head mounted displays (HMD) that fill almost all of the cues, by which we recognize depth. However, they cannot be called true holographic display, as they do not have real depth and require eye focus change. The true holographic technology utilizes light diffraction to create virtual 3D images of specific objects and does not require any form of special 3D glasses or HMD for the viewer. Even though holographic displays are not so common in the present, in the near future they will most likely be everywhere around us. One of the key issues for this technology is the lack of suitable digital content for it.**

Resolving the aforementioned issue requires in-depth study and adaptation of the available methods for 3D reconstruction and for creation of 3D digital content, so that this content can be integrated into the available technologies for holographic displays. Section II of this paper gives a brief overview of the two most widely known methods for creation of 3D digital content – 3D modelling and 3D scanning. Section III of the paper presents the current state of the holographic technology and the types of displays, which are currently available for it. In Section IV, the authors present a workflow for integration of 3D digital content into holographic displays. The workflow is explained in two subsections – the first one presents the basic steps to create a holographic effect using single video source, while the second subsection tackles issues, which are related to purely computer generated video files.

Keywords - 3D Modelling, Digital content, Holographic display, Photogrammetry

I. INTRODUCTION

Holographic projection is an emerging technology that is going to change how we perceive the world around us. It is a promising technology, which could affect all areas of our lives – education, science, medicine, healthcare, business and others. Before we dive into the workflow for creation and integration of digital content for this technology, we have to clarify what exactly a hologram is. Holograms are three-dimensional projections of images, which are formed by the interference of laser light beam or other coherent light source. The holographic effect was first invented by Hungarian-British electrical engineer and physicist Dennis Gabor in 1947 [1], however the first actual hologram was released in 1964 following the creation of the laser. One advantage of the holographic technology, over the aforementioned VR and AR technologies, is that in most of the cases, the user does not need any special 3D glasses or head mounted displays (HDM) to view the three dimensional image. This key feature is what makes the holographic technology the ultimate display technology [2].

In the recent years, the holographic technologies have advanced tremendously and have led to the appearance of different types of displays. Probably, the most widely known one is the volumetric display. This type of display provides the 3D visual representation of the objects, as opposed to the planar images of the traditional displays. A typical example, which is also used in this paper, is the reflection pyramid. This display type reflect a simple 2D image, which is being projected from a screen that is mounted either above or under the pyramid (Fig. 1). Another more advanced volumetric display uses ultra-high-speed digital light engine and volumetric rendering engine. The object, that is being rendered, is sliced into hundreds of horizontal cross-sections (depending on the resolution), before being projected synchronously onto a specialized high-speed reciprocating screen. A different type of holographic display involves the use of HMD with build-in holographic computers. A typical example can be given with the Microsoft HoloLens [3], although this device is considered more as mixed-reality glasses and not as a holographic display.

The focus of this paper is to present a complete workflow for development of digital content and for its integration and visualisation in holographic displays. The creation of digital content could be achieved in myriad of different ways – from using simple photographs and videos to the creation of more realistic three-dimensional contents by modelling of the object or by using digitalization technologies, like photogrammetry.

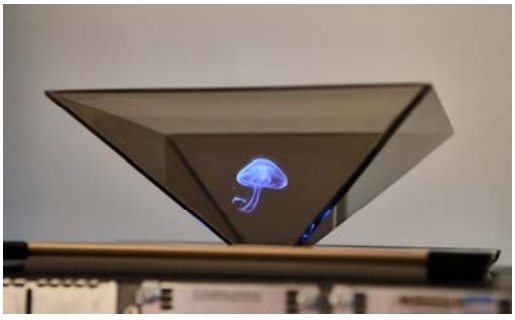

Figure 1. Simple volumetric holographic display – inverted reflection pyramid with an underlying tablet as image source

The digital 3D modelling represents the process for development of the mathematical representations of objects or scenes (real or fiction) using 3D software. Some of the well-known software products with such capabilities are 3DS Max, Maya, Blender, etc. Another way to create 3D models of objects or of whole scenes is to use the principles of photogrammetry. Photogrammetry is the process for making measurements and for extracting the exact position of every surface point from multiple overlapping photographs. Photogrammetry is not a new technology, but lately it has gained a lot of popularity, because of the excessive need of 3D digital content. Regardless of the technology that is being used, following the creation of an object or a scene, the content has to be prepared and integrated into the holographic displays. There are plenty of holographic displays available on the market. Our main objective is to build a three or four-sided holographic pyramid at minimum cost. Those type of holographic displays differ from the traditional displays, because instead of using light scattering to achieve the holographic effect, they are using a regular computer monitor, TV or a screen to display the digital content. The holographic effect is achieved by building a three or four (depending on the pyramid) high definition videos with specific offset from each other and combine them into a single video file [4]. In this way, the presented video achieves a holographic effect, as it "floats in the air". Additionally, we are going to present the workflow for designing three or four-sided holographic pyramid.

II. COMPARISON OF THE METHODS FOR DEVELOPMENT OF 3D DIGITAL CONTENT

As previously mentioned, the creation of the 3D digital content for the holographic displays can be achieved in two ways – by modelling the object using 3D modelling software, such as Maya, Blender, 3DS Max, etc., or by reconstructing the object using the principles of the photogrammetry. In this section of the paper, we will make a brief overview of both approaches for development of 3D content and their pros and cons.

A. Development of 3D content using software modelling

The development of 3D content, by modelling of the objects, is the creation of the mathematical representations of the surfaces of the objects with the help of specialized 3D modelling software products [5]. The creation of the models could be achieved in many different ways, all of which depend on the perception of the artist who develops the models. The final models fall into two main categories – solid models and shells. The solid models provide information about the volume of the objects, while the shells define only their boundaries. Objects, which were developed using both approaches, could look very similar or the same, but they have different purposes and use areas. For example, the solid objects could be found in areas like engineering, medical industry and others, while the shell objects are typically used in the cinematographic and game industries. Another area, where the shell objects are used, is in the holographic projections and displays. The holographic representations (models) of the desired objects does not have to be solid for couple of reasons. Firstly, the end users does not have to see the inside of the objects (unless it is specifically required, e.g. for section cuts, etc.) and secondly, the rendering of solid objects is quite difficult and requires more hardware resources, thus leads to increase of the overall costs of the production.

There are three main methods for representation of the three-dimensional models:

- Polygonal modelling – this is an approach for modelling of objects by the linking of 3D points in space (called vertices) into polygons. Any surface that consist of three or more connected vertices is called a polygon. Most of the objects that we encounter today are made using this method of modelling, because it is more flexibility and provides faster rendering times. The one area, that polygonal modelling falls short, is the representation of curved surfaces. Because polygons are planar objects, the approximation of curved surfaces could be only done by using a large number of polygons;
- Curve modelling – in this modelling approach, the object is constructed by curves that are defined by weighted control points;
- Digital sculpting (3D sculpting) – this is a method that includes, as the name suggests, sculpting of an object by pulling, smoothing, grabbing, pinching or manipulating the object in any way similar to the real-life sculpting.

B. Development of 3D content using photogrammetry

Photogrammetry is the process for measuring and extracting the exact position of every surface point from multiple overlapping photographs. Photogrammetry is not a new technology, but lately it has gained a lot of popularity, because of the excessive need of 3D digital content. The process involves the taking of multiple overlapping photos of an object from different positions and subsequently the processing of these photos, using specialized software products, such as Agisoft Photoscan or Pix4D Mapper [6, 7]. Another way to create a digital model of the real-world object is to use 3D scanner. The 3D scanning technology is faster and the widely available commercial scanners can achieve better results than the aforementioned approach. However, both methods rely on the photogrammetry principles, which use triangulation techniques in order to reconstruct the model. Triangulation itself refers to the process, which determines the location of a point in the 3D space by being projected onto two or more images (Fig. 2).

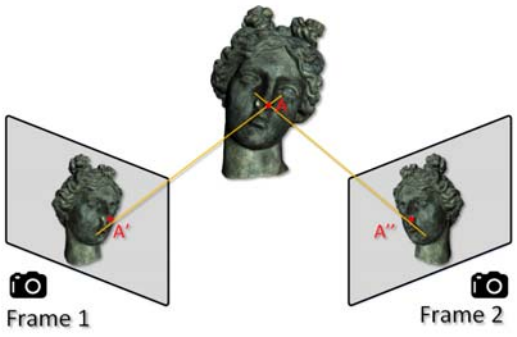

Figure 2. Extraction of a point from two overlapping photos

The image above represents the epipolar geometry of a pair of stereo cameras on the pinhole model. The point *A* (a 3D point) in 3D space is projected onto the respective images along the yellow lines, which go through the focal points of the cameras, resulting in the two corresponding image points *A'* and *A''*. If *A'* and *A''* are given and the geometry of the two camera positions are known, the two projected lines (yellow ones) can be determined and they must intersect in point *A* (the 3D point). Using basic linear algebra, that intersection point can be determined in a straightforward way. This is the ideal case of the triangulation principle being implemented. In practice, some factors influence the process of determining the exact position of the 3D points in space. Such factors includes geometric distortion (from the camera lenses), light dispersion and others.

III. BASIC PRINCIPLES OF HOLOGRAPHIC PYRAMIDS

Nowadays, three and four sided reflection pyramids are commonly used to create holographic effects in order to enhance the viewer perception of a particular scene. Even though that there are some differences in the content creation processes for the three and for the four-sided pyramid, they both rely on the Pepper's ghost effect. Discovered by the English scientist John Henry Pepper in 1862, this effect provides a way to present virtual objects and items in a scene, as if they were actually there. The basic principle of the effect is illustrated in Fig. 3.

The holographic effect, illustrated in the figure above, could be described as follows – the original image is projected towards the reflective surface (e.g. Plexiglas) at an angle of 45 degrees and the virtual image of the original object appears as a hologram. The user or the audience is located on the other side of the reflective surface and observes the hologram and not the original (projected) image. During the design of the pyramid, it is important to say that the distance between the original image and the reflective surface should be equal to the distance between the surface and the virtual image (the hologram).

The design of a three or of a four-sided pyramid is typically the same with the only difference that the fourth side of the three-sided pyramid is completely flat and the observer cannot look through it. Fig. 4 and 5 show the top view of both of these types of pyramids.

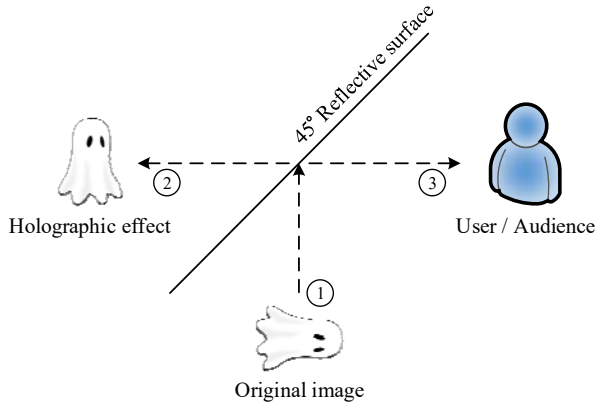

Figure 3. Illustration of Pepper's ghost effect (Holographic effect)

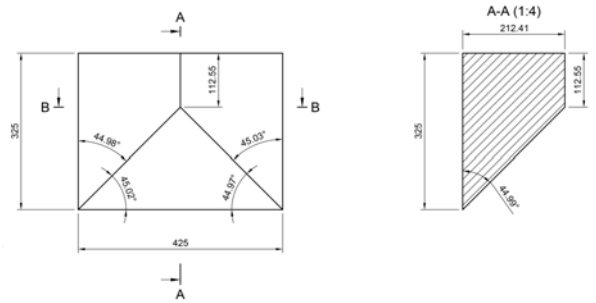

Figure 4. Top view of a three sided holographic pyramid

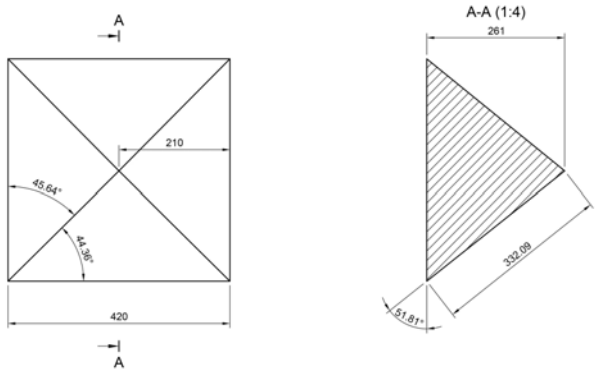

Figure 5. Top view of a four sided holographic pyramid

As seen from the figures above, each holographic pyramid has its unique features, mainly their dimensions. The main difference between the pyramids is that the four sided pyramid has four identical sides in the form of trapezoids, while the three sided pyramid consist of one rectangular triangle (front side) and two rectangular trapezoids (left and right side). Both pyramids can be reduced or enlarged in size, depending on the type of display that is going to be used – phone, tablet, TV, etc. The size change is possible, as long as the right proportions and dimensions are kept as shown in the figures above.

IV. A WORKFLOW FOR CREATION AND INTEGRATION OF DIGITAL CONTENT IN HOLOGRAPHIC DISPLAYS

So far, we have gone through the process of how to create digital 3D models by the means of modern 3D modelling software. We also discussed how to digitalize objects using photogrammetry and with the help of a photo camera. In this section, we will discuss the process that involves the integration of the aforementioned models or scenes into the holographic displays. This section is divided into two subsections – the first one will cover the process of designing a holographic scene using single video file, while the second one will cover the same process, but when using multiple video files.

A. Design of a holographic scene using single video file

In the previous section, we have covered the basic principles of the holographic effect. In this section, we will be using that effect to design and create a video suitable for both the three-sided and the four-sided pyramid.

As already illustrated in Fig. 3, the holographic effect could be achieved by the projection of an object or image on a reflective surface at an angle of 45 degrees. The law of reflection states that the incident ray, the reflected ray and the normal to the reflective surface are all situated in the same plane. The law also states that the angle of the incident ray to the normal is equal to the angle of the reflected ray. When an object is projected onto a reflective surface, it reflects the incoming light with the same angle as the incident rays and projects the image to the user (audience). In this way, the user observes a virtual representation of the real object.

The holographic effect, depicted in Fig. 3, represents just a single projection of a particular object. Achieving a holographic effect on a three or four-sided pyramid requires three, respectively four videos to be combined into one. The final video would project the same object (image) onto the pyramid, but each image is going to be phase shifted at 90 degrees from the previous one. Fig. 6 and 7 depicts how such a video would look like.



Figure 6. Holographic content for a three sided pyramid



Figure 7. Holographic content for a four sided pyramid

The method presented in this section gives a basic overview on how to create a holographic scene using a single video. However, this method cannot produce true holographic scenes and is to be avoided.

B. Design of a holographic scene using software for 3D animation and rendering

As already mentioned in the previous section, a single video file does not create a true holographic effect. That is because the video that is being used is the same and the user observes the same images from all sides of the pyramid. Creating a true holographic effect, requires the object or the scene to be captured from all sides and all individual video clips to be combined later on. In the final render of the video, which is doing to be projected onto the pyramid, the user will see the different sides of the object, depending on where he or she stands. It may not be obvious at first, but the most important thing when creating a true holographic effect is the synchronization of the individual video clips. The most widely known and basic way to synchronize individual video clips is to capture a scene using multiple camera setups and to trigger all cameras at the same time. Even though this method is quite effective and does not require a lot of post processing it has one big disadvantage – it is expensive. Capturing a single scene, for example, would require four digital cameras with a remote trigger feature, a green screen studio and a very good lighting setup.

Another less expensive approach to create a true holographic effect is to use 3D software like Blender, 3DS Max, Maya [8, 9 and 10] and others. These software platforms could be used to create the required 3D scene and capture it with the help of virtual cameras. It has to be noted that the true holographic effect could be achieved if the 3D scene is captured simultaneously with four virtual cameras or if the camera gets shifted at 90 degrees with respect to the object and four individual clips are produced – one from the front, one from the back and one for each side (left and right). In this section, we will cover all of the necessary steps that are required to capture such a video and integrate it in a holographic display.

The first step of the process is to select the object (item) that is going to be displayed in the pyramid. Following this, the method that is going to be used to extract the 3D model of the object has to be selected. The object could be virtually anything that could be digitalized by utilizing one of the methods mentioned in the previous sections. In our case, we have chosen a sculpture that representing the head of Aphrodite (Fig. 8), an object that was selected for digitalization during the implementation Project ARCHIVE [11]. All of the figures associated with that model (Fig. 6-14) are also obtained during the implementation of the same project and are considered own work. The three dimensional model of the object was obtained using a professional 3D scanner – Artec Eva [12]. There are diverse types of 3D scanners, which are categorized mainly based on their range and the scanning technology. The scanner, which was used by us, is using structured light for scanning. This type of scanners work by emitting a known pattern of light (often grid or bars) on the surface of the object. Based on the distortion of the light at the edges of the surface, the scanner software can extract the depth and the surface information of the object.

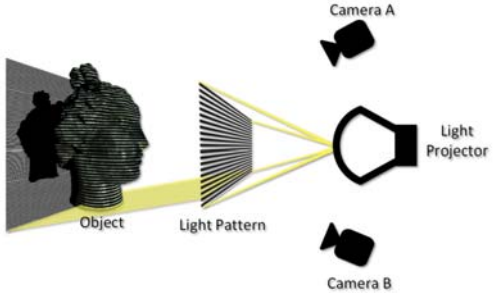

Figure 8. Working principle of the structured-light scanner

Fig. 8 represents the working principle of a basic structured light scanner. The scanner consists of a camera or cameras and a projector. The measurement principle of the structured light scanners is based on detecting the deformation of the pattern of light projected onto the surface of the scanned object. A camera, which is slightly offset from the projector, records the shape of the line at the angle and the distance to every point on the line is computed by a complex algorithm with a technique similar to triangulation. The displacement of the stripes allows for an exact retrieval of the 3D coordinates of any surface detail. In addition, the camera also extracts the colour information of every pixel and based on that the texture of the model could be build up later on.

The actual scanning process consists of walking around the object and collecting all of the required surface scans. The number of scan strongly depends on the level of details that are required for the particular object. However, in a case where multiple scans are needed all of them have to have at least 10-20 percent overlapping. The overlapping of the scans generates more reference points, which are needed for the alignment and the reconstruction of the actual model. After acquiring all necessary scans, they have to be processed and the model will be reconstructed. The implementation of these two stages differ and depend on the scanner that is being used to scan the object and are not covered in this paper.

At the end of the reconstruction stage three output files are generated – a solid untextured 3D model (.obj format), a material file (.mtl) and a texture file (.jpg). The OBJ, also known as Wavefront, is an open file format mainly used in 3D applications that describes the geometry of the surface of the object, as well as its texture. The material file describes how textures are applied to the object and includes the names of the texture files, as well as the 3D positioning of the textures. The texture file contains information about the texture itself. Visual representation of the mapping of the texture on the model is depicted in Fig. 9.

After the selection of the object for digitalization and after acquiring its 3D model it is time to move to the next step – capturing the video of the object and its integration in the holographic display. Capturing a video of a particular object could be achieved by the means of almost any professional 3D software (Blender, Maya, 3D Studio Max and others). In order to achieve our objective and to minimize the overall cost of the process, we are going to use the Blender software [8]. Blender is a free and open source software that includes all necessary features to create a working 3D animation and render it afterwards. In the next few paragraphs, we will go over the process of importing, animating, rendering and exporting the final video file that is going to be integrated into the holographic display.

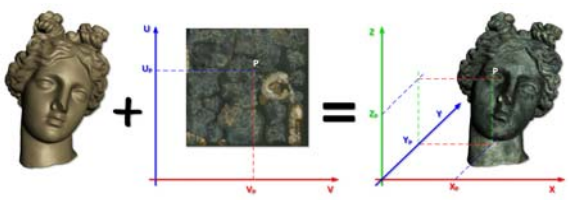

Figure 9. Mapping of the UV texture onto the 3D model

The first step in the process is to import the digitalized 3D model and correctly orient it in the 3D workspace. This is a necessary step, because the animation of the scene is strongly dependent on the correct orientation of the object (Fig. 10).

The next step is to prepare the workspace for the capturing of the animation of the object and the creation of the animation itself. The preparation of the workspace might include many things, such as other 3D objects, lighting, virtual cameras, green screens and other, but for the purpose of this articles we are going to include just a virtual camera, some lighting and a green screen. The green screen is an essential part, because it does not match any natural colours and the object can be easily separated from the background in the post-processing stage. Fig. 11 depicts how the 3D workspace would look like with the aforementioned actors.

After the preparation of the 3D workspace (orientation of the virtual camera, lighting and others.), it is time to create and capture the animation itself. Blender has a powerful engine for animations that has evolved a lot over time. For the purpose of this paper, we are going to make a simple rotating animation of the Head of Aphrodite that is going to be later projected in the holographic display. The animation itself consist of two rotational key frames – one at the start and one at the end of the animation. The object rotation is done by the difference between the two key frames.

At the first key frame, the object is situated in front of the camera at 0 degrees, while at the second frame the object is rotated in 360 degrees along the Z-axis. The default behaviour of the animation engine of Blender is to start the animation slowly, speed it up at the middle and slow it down again at the end. That is because the default key interpolation mode is set to use the Bezier curve [13]. In order to make the animation as smooth as possible, the interpolation mode of the animation has to be set to linear (Fig. 12).

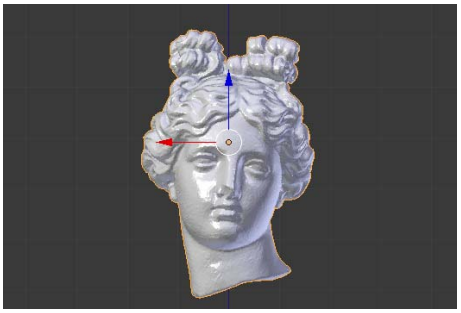

Figure 10. Orientation of an object in the Blender's 3D workspace

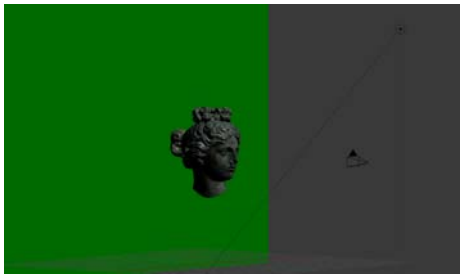

Figure 11. Final view of the 3D workspace before the animation of the scene

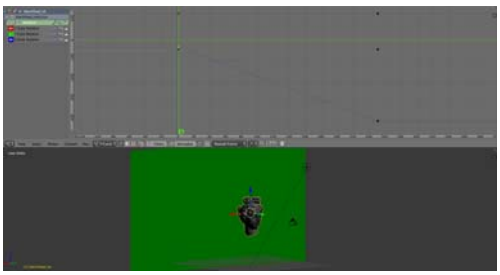

Figure 12. Setting animation's interpolation mode to linear

The duration of the final animation depends on the number of key frames between the first and the second rotational key frames. In our case, we have set the second rotational key frame to number 250 and we have rendered the final animation at 25 frames per second (fps) for a total of 10 seconds of animation. Fig. 13 summarizes the final render times, which were achieved with the CPU or the GPU of the computer used for the animation rendering.

As already mentioned, the true holographic effect comes from the fact that the object is either being captured simultaneously from four different sides or is being captured from one side, but the camera is rotated at 90 degrees for each of the four videos. After capturing and rendering the four individual videos, they have to be combined and exported as a single video file (Fig. 14). This can be done using software products like Adobe Premiere, Final Cut, Sony Vegas and others.

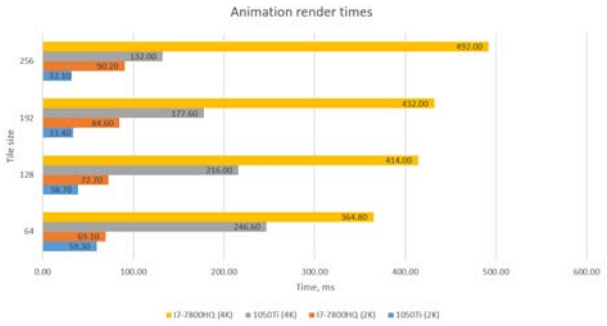

Figure 13. Animation render times for 2K and 4K resolution



Figure 14. True holographic effect for a four sided pyramid

V. Conclusions

The holographic displays are considered as a novel technology that has a promising future ahead of it. They are seen as the ultimate viewing technology, because of the possibility to create a true holographic effect, something that the VR and the AR technologies are not capable of achieving. Another benefit of the holographic displays is the fact that they do not require the user or the audience to wear any special head mounted displays or goggles in order to observe a three dimensional object or the scene. The issue with every new technology is the lack of content and support for it. This paper presented a workflow for creation of digital content for holographic displays by using modern software products for 3D modelling and animation. Software products, like Blender for example, provide the possibility for modelling, rendering and capturing of 3D animations, which can be integrated with ease in the holographic displays. We have discussed and analysed the process for creation of a basic 3D scene in the aforementioned software, as well as how to animate and capture an object. In addition to that, this paper gives a brief overview of the two main technologies for development of 3D models – by using 3D modelling software and by using photogrammetry.

Acknowledgments

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Use of Hierarchical Clusters Analysis in Identification of Obstacles to Introduction of e-Commerce in European Countries

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***Abstract*— e-Commerce has become extensively used across the globe with the purpose to simplify the process of communication between sellers and buyers. The objective of the paper is to investigate to what extent European companies use e-Commerce and what are the obstacles that they encounter. The analysis will be conducted by means of hierarchical cluster analysis. Results indicate that European countries can be divided into groups with similar characteristics regarding e-Commerce usage. On the other side, the intensity of e-Commerce usage in European countries is not linearly related to the level of economic development, measured by GDP and GDP change. In addition, companies in those countries which are leading by the usage of e-Commerce also perceive that the level of barriers towards e-Commerce is the highest. A possible conclusion is that companies which do not use e-Commerce stick to the old business model, and they do not perceive barriers as important simply because they are just not trying as hard as they could.**

Keywords- e-Commerce, Development, Cluster Analysis, Hierarchical Cluster Analysis, Barriers

I. INTRODUCTION

E-Commerce provides many benefits, e.g., sellers can offer lower prices while buyers can overcome geographical and time barriers with the support of the Internet and information and communication technologies (ICTs) [1,2]. Grandon et al. [3] stress that usage and application of e-commerce infrastructure allow sellers to target tight geographically dispersed market segments, while the buyers can take advantage of approaching worldwide markets, with the broader supply of goods and services offered by the various suppliers at lower prices.

Expansion of e-Commerce started during the 1990s with the increasing growth and usage of the Internet. The United Kingdom was the leading European country regarding ICTs usage and growth in online markets [4]. In the last few years, the United Kingdom has more than double the size of the e-Commerce market than the next leading European country on that same market [5]

Many authors in their research named elements which impact the e-Commerce utilization. Alnemr (2010) highlighted that perceived reputation and trust in enterprises have a strong influence on e-Commerce usage [6]. Guang Qu (2015) also identified trust as a key factor in promoting e-Commerce [7]. Rodríguez-Ardura (2008) and his colleagues emphasized that providing secure communication and transaction via Internet has a significant influence on the results of commercial activity and attraction of new clients [8].

In a way to clarify the elements that could impact on e-Commerce usage, our work is focused on two research contributions. Firstly, we aspire to illustrate resemblances and disparities among European countries in relation to their level of e-Commerce utilization. Secondly, we examine the possible positive relationship between the level of e-Commerce utilization and economic, and what is the possible role of perceived barriers in e-Commerce in that relationship. In the first phase, the hierarchical cluster analysis is used to group European countries into homogenous groups using the Eurostat database for 2016, according to their practice of e-Commerce utilization. In the second phase, identified clusters are evaluated by the average level of economic development measured in terms of GDP per capita and GDP change, as well as the level of perceived e-Commerce obstacles.

The paper is organized in the following manner. The first chapter provides an introduction. In the second chapter, the methodology is presented. Results of the cluster analysis and the Kolmogorov-Smirnov tests are described in the third chapter. Finally, a discussion and conclusion end the paper.

II. METHODOLOGY

A. Quantifying e-Commerce in Europe

In order to investigate the e-Commerce usage as well as perceived barriers related to e-Commerce adoption, we used Eurostat database for the year 2016, with the focus to 29 European countries (EU countries, Luxembourg, Norway

and Macedonia). Luxembourg was excluded since exploratory analysis indicates that it is an outlier according to a number of indicators related both to e-Commerce and measurement of economic development. We did not include other European countries since the data was missing for the observed period and variables of our focus.

The following measurements of the expansion of e-Commerce in Europe are used for the enterprises (including all enterprises, without financial sector (10 persons employed or more):

- ECOM1 - Received orders via any online channel
- ECOM2 - Selling online (at least 1% of turnover)
- ECOM3 - Selling via a website or apps - B2C
- ECOM4 - Selling via a website or apps - B2B&B2G
- ECOM5 - B2C web sales are 10% + of web sales
- ECOM6 - B2C web sales are 1%+ of the web sales
- ECOM7 - Receiving orders via a website or apps
- ECOM8 - Receiving orders via EDI-type messages

The following measurements of the barriers of e-Commerce in Europe are used for the enterprises (including all enterprises, without financial sector (10 persons employed or more):

- OBST1-The enterprise's goods or services are not suitable
- OBST2-Problems related to logistics (shipping of goods or delivery of services)
- OBST3-Problems related to payments
- OBST4-Problems related to ICT security or data protection
- OBST5-Problems related to the legal framework
- OBST6-The costs of introducing web sales too high compared to the benefits

B. *Hierarchical cluster analysis and Kolmogorov-Smirnov test*

Cluster analysis is a method often used for the identification of similar groups of statistical units, which are homogenous within the group and heterogeneous against other groups. There are two main groups of cluster analysis: partitioned clustering and hierarchical clustering [9]. Hierarchical clustering produces a hierarchy of cases or variables using one of the proximity measures which is calculated for each pair of statistical units in the data set.

For the purpose of our research, we used a divisive hierarchical clustering, which groups the statistical units into nested groups, starting with all statistical units in one group, and then divide them with the application of "top-down" method [10,11]. Identified groups are compared using the Kolmogorov-Smirnov test in order to investigate if the differences between the level of economic development and perceived obstacles for e-Commerce are statistically significant [12].

The following methodology is used in the paper. In the first phase, we apply hierarchical cluster analysis with the goal of identification of homogenous groups of European countries according to their usage of e-Commerce, for the year 2016, using Ward-method and Squared Euclidean Distance. In the second phase, we apply non-parametric Kolmogorov-Smirnov test to contract the clusters identified in the first phase according to i) their GDP per capita & GDP change in %, and (ii) their perceptions regarding the barriers in e-Commerce.

III. RESULTS

A. *e-Commerce indicators*

Table 1 portrays the descriptive statistics of the overall sample related to e-commerce usage indicators and obstacles for e-Commerce as perceived by the enterprises including all enterprises, without financial sector (10 persons employed or more).

TABLE I. DESCRIPTIVE STATISTICS OF E-COMMERCE USAGE INDICATORS AND OBSTACLES FOR SELECTED EUROPEAN COUNTRIES

	Cluster				
	Mean (St.Dev)	Median	Min(Max)	Kurtosis	Skewness
E-Commerce Indicators (2016)					
ECOM1	19.2 (7.0)	20.0	7.0 (30.0)	-1.044	-0.194
ECOM2	16.9 (7.4)	17.0	3.0 (30.0)	-0.789	0.044
ECOM3	12.2 (4.3)	12.0	4.0 (22.0)	-0.232	0.056
ECOM4	11.0 (4.2)	11.0	4.0 (18.0)	-1.046	-0.044
ECOM5	10.6 (4.6)	10.0	2.0 (22.0)	0.153	0.371
ECOM6	11.6 (4.2)	11.0	4.0 (22.0)	0.116	0.264
ECOM7	15.8 (5.5)	16.0	6.0 (25.0)	-1.008	-0.129
ECOM8	6.1 (3.2)	6.0	1.0 (15.0)	0.833	0.786
E-Commerce Obstacles (2016)					
OBST1	3.2 (2.0)	3.0	1.0 (8.0)	-0.052	0.866
OBST2	2.0 (1.2)	2.0	0.0 (4.0)	-1.079	0.450
OBST3	1.9 (1.0)	2.0	1.0 (4.0)	-0.601	0.714
OBST4	1.3 (0.8)	1.0	0.0 (3.0)	0.230	0.439
OBST5	1.2 (0.8)	1.0	0.0 (3.0)	0.010	0.427
OBST6	2.1 (1.4)	2.0	0.0 (5.0)	-0.425	0.608

Source: Author's research based on Eurostat data (2016); EU28, excluding Luxemburg; Norway, Macedonia

The highest number of enterprises has positively affirmed the e-commerce indicator ECOM1, which indicates that 19.2% of enterprises in the overall sample of European countries have received orders via any online channel in the year 2016. On the other side, only 6.1% of enterprises

received orders via EDI-type messages in the overall sample of European countries in 2016 (ECOM8). E-Commerce obstacles were rarely perceived among enterprises in selected European countries. The highest is OBST1 (average 3.2%), and the lowest is OBST5 (average 1.2%).

B. The position of South-Eastern European countries

South-Eastern European (SEE) countries included in this analysis are Bulgaria, Macedonia, Romania, Croatia, Slovenia, Cyprus, and Greece. SEE countries are compared according to e-commerce indicators and obstacles related to e-commerce indicators (Figure 1 and Figure 2). The highest e-commerce indicator in both samples is ECOM1, with an average of 12.71% of SEE countries, and 21.23% in EU+Norway countries. The same trend is present for other indicators of both e-Commerce usage and perceived obstacles related to e-Commerce in two observed groups of countries.

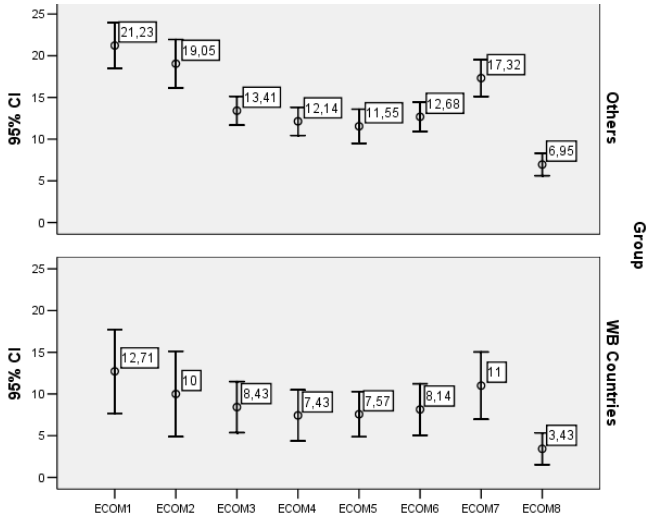

Figure 1. Means and 95% intervals of e-Commerce indicators; 2016

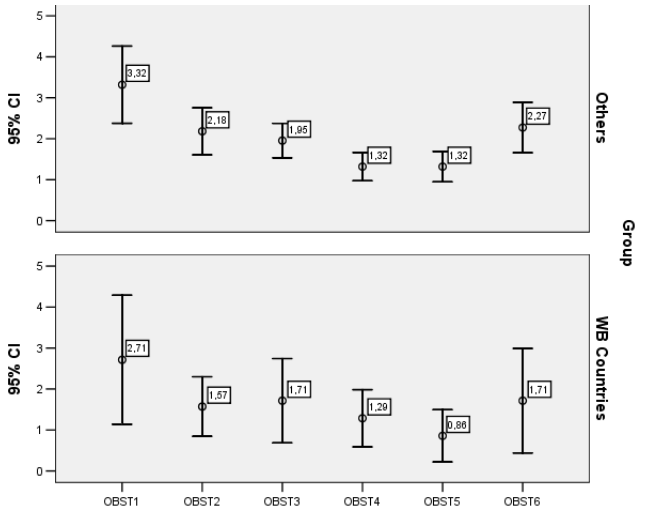

Figure 2. Means and 95% intervals of e-Commerce obstacles; 2016

C. Hierarchical cluster analysis results

Hierarchical cluster analysis revealed five clusters as optimum, as indicated in Dendogram in Figure 3. Table II presents countries grouped per clusters, and SEE countries are present in C2, C4, and C5 clusters.

TABLE II. EUROPEAN COUNTRIES ACCORDING TO CLUSTERS BASED ON DIFFERENT FORMS OF E-COMMERCE USAGE; 2016

C	European countries
C1	Belgium, Finland, Lithuania, Malta, Netherlands, UK
C2	**Bulgaria**, Italy, Latvia, **Macedonia**, **Romania**
C3	Czech Republic, Denmark, Germany, Ireland, Norway, Sweden
C4	Austria, **Croatia**, Estonia, France, Portugal, **Slovenia**, Spain
C5	**Cyprus**, **Greece**, Hungary, Poland, Slovakia

Source: Author's research based on Eurostat data (2016)

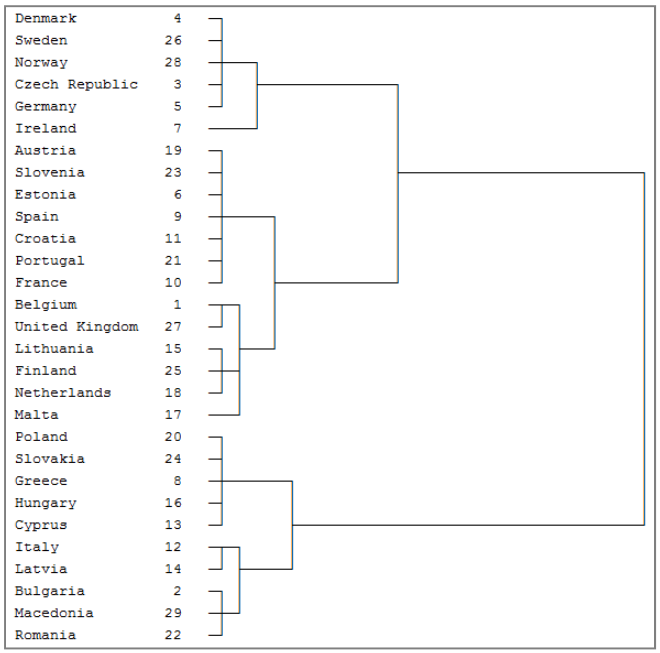

Figure 3. Chosen European countries arranged into specific clusters based on different forms of e-Commerce usage; 2016

Table III represents descriptive statistics of the e-Commerce usage indicators according to clusters. The overall ranking of clusters according to the e-Commerce indicators is as follows: Cluster 3, Cluster 1, Cluster 4, Cluster 5, and Cluster 2. Cluster 3 has the highest average value of all e-Commerce indicators likely because of the highest number of most developed countries in this cluster. Countries in Cluster 2 are those with the lowest average

values of all e-Commerce indicators which are due to the highest number of developing countries in this cluster.

TABLE III. DESCRIPTIVE STATISTICS OF THE E-COMMERCE USAGE INDICATORS ACROSS CLUSTERS (% OF ENTERPRISES)

	Cluster				
	1	*2*	*3*	*4*	*5*
ECOM1	23.0 (2.2)	8.8 (1.8)	**28.3 (1.0)**	19.6 (1.1)	13.4 (1.5)
ECOM2	19.3 (2.7)	6.2 (2.2)	**27.5 (1.4)**	17.0 (2.1)	11.6 (1.1)
ECOM3	15.3 (1.9)	5.8 (1.3)	**17.2 (2.6)**	11.4 (0.8)	10.0 (1.6)
ECOM4	14.2 (1.6)	5.0 (1.2)	**16.0 (1.8)**	10.6 (1.3)	7.8 (0.8)
ECOM5	12.2 (3.7)	5.4 (1.3)	**16.5 (3.1)**	10.4 (0.5)	7.0 (3.0)
ECOM6	13.8 (2.5)	5.4 (1.3)	**17.0 (2.6)**	11.0 (0.6)	9.4 (1.1)
ECOM7	19.5 (1.4)	7.6 (1.3)	**22.8 (1.7)**	15.4 (1.0)	11.6 (1.1)
ECOM8	6.2 (1.8)	2.4 (0.9)	**10.5 (2.7)**	6.6 (1.0)	3.8 (1.5)

Source: Author's research based on Eurostat data (2016)
Note: Means and standard deviations (in parentheses) are provided; bold letters indicate the highest average value

Cluster 1 consists of six countries: Belgium, Finland, Lithuania, Malta, Netherlands, and the United Kingdom, and it includes several highly developed European countries, e.g., Finland and the United Kingdom.

Cluster 2 consists of five countries: Bulgaria, Italy, Latvia, Macedonia, and Romania, and countries represented in this cluster are developing, such as Bulgaria, Macedonia, and Romania, or were hit hard by the economic crises, such as Italy and Latvia.

Cluster 3 consists of six countries: Czech Republic, Denmark, Germany, Ireland, Norway, and Sweden, including highly developed European countries, e.g., Germany, Norway, and Sweden.

Cluster 4 consists of seven countries: Austria, Croatia, Estonia, France, Portugal, Slovenia, and Spain, which contains both developing countries (Croatia), and highly developed countries (e.g., France).

Cluster 5 consists of five countries: Cyprus, Greece, Hungary, Poland, and Slovakia, which all struggle hardly through the period of economic crises, but recovered.

Figure 4 presents the European map according to countries grouped into specific clusters based on e-Commerce usage in 2016. It can be concluded that countries within Cluster 1, Cluster 2, Cluster 3, Cluster 4 or Cluster 5 are somewhat similar regarding socio-economic development and regarding the geographic position. In all five clusters developed and developing European countries can be found. SEE countries can be found in cluster 2, 4 and 5. However, they are similar to their level of e-Commerce usage by the enterprises.

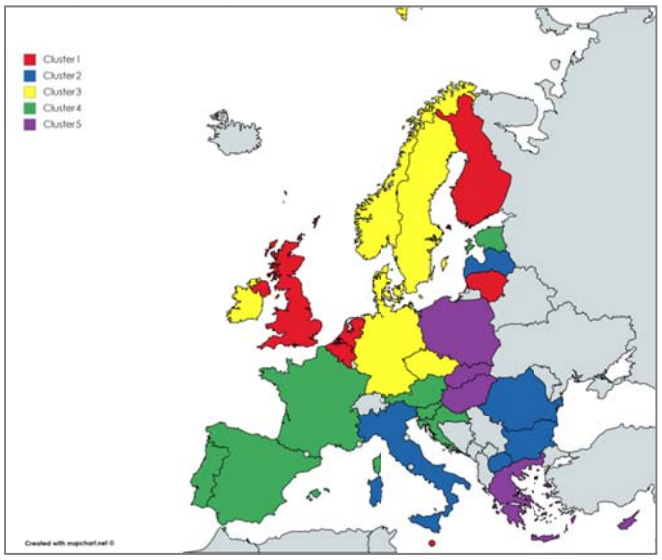

Figure 4. European map according to countries grouped into specific clusters based on e-Commerce usage; 2016

D. Comparison of clusters according to economic development and e-Commerce obstacles

In this chapter, the outcomes of the Kolmogorov-Smirnov tests are displayed (Table IV).

TABLE IV. AVERAGE VALUES OF ECONOMIC DEVELOPMENT INDICATORS ACROSS CLUSTERS & RESULTS OF KOLMOGOROV-SMIRNOV TEST

	Cluster					Chi-square (p-value)
	1	*2*	*3*	*4*	*5*	
Economic Development						
GDPpc 2016 (in 000 EUR)	34,9 (12,1)	13,3 (10,2)	**49,6 (18,2)**	25,5 (11,3)	16,6 (4,5)	15,612 (0,004***)
GDP chng %	1,0 (5,2)	**4,8 (2,6)**	0,9 (3,1)	2,7 (1,2)	1,0 (1,7)	8,814 (0,085*)

Source: Author's based on Eurostat (2013) and World Bank data (2016)

Note: Means and standard deviations (in parentheses) are provided; bold letters indicate the highest average value; *** 1%, ** 5%, * 10% significance

In order to evaluate the connection between e-Commerce usage and the level of economic development of investigated elected European countries in 2016, we have calculated the average values of GDP per capita and GDP change in % in 2016 in comparison with 2015 (Table IV).

Cluster 3, which was the most developed according to the level of usage of different e-Commerce indicators, was also the leading according to the average value of GDP per capita (49,600 EUR), which is the result of grouping the

most developed European countries (Germany, Norway, and Sweden) into this cluster.

On the other side, the average GDP per capita was the lowest in Cluster 2 (13,300 EUR), which was also the lowest according to the level of e-Commerce indicators. The same relationship is present for the GDP change in %. Kolmogorov-Smirnov test indicates that found differences not statistically significant, which indicates a strong relationship between the level of economic development and level of e-Commerce utilization in observed European countries.

In order to evaluate the connection between e-Commerce usage barriers towards e-Commerce of selected European countries in 2016, calculated average values for the barriers in e-Commerce of each cluster are displayed in Table V.

It could be expected that those clusters that are leading in the utilization of e-Commerce would have the lowest perception of the importance of e-Commerce obstacles among their enterprises, and vice versa.

TABLE V. AVERAGE VALUES OF PERCEIVED E-COMMERCE OBSTACLES ACROSS CLUSTERS & RESULTS OF KOLMOGOROV-SMIRNOV TEST

	Cluster					**Chi-square (p-value)**
	1	***2***	***3***	***4***	***5***	
Obstacles to e-Commerce						
OBST1	4,5 (1,4)	1,4 (0,9)	**5,0 (2,3)**	2,6 (1,7)	2,0 (0,7)	15,345 (0,004***)
OBST2	**3,3 (0,8)**	1,0 (0,1)	3,0 (0,9)	1,4 (0,8)	1,2 (0,8)	19,057 (0,001***)
OBST3	2,5 (0,8)	1,0 (0,1)	**2,7 (0,8)**	1,7 (1,1)	1,4 (0,5)	13,482 (0,009***)
OBST4	**1,8** (1,0)	1,0 (0,7)	1,7 (0,5)	1,1 (0,7)	0,8 (0,4)	7,330 (0,119)
OBST5	**1,8** (1,0)	0,6 (0,5)	1,5 (0,5)	0,9 (0,7)	1,2 (0,8)	7,851 (0,097*)
OBST6	**3,2** (1,2)	1,0 (0,7)	3,0 (1,5)	2,0 (1,2)	1,2 (0,8)	12,110 (0,017**)

Source: Author's based on Eurostat (2013) and World Bank data (2016)

Note: Means and standard deviations (in parentheses) are provided; bold letters indicate the highest average value; *** 1%, ** 5%, * 10% significance

However, our results indicate that the highest average values of several obstacles (*OBST1* and *OBST3*) are present in Cluster 3, which is also leading to e-Commerce utilization. The highest average values of other obstacles (*OBST2*, *OBST4*, *OBST5,* and *OBST6)* are present in Cluster 1, which was the second best according to e-Commerce utilization; closely following Cluster 1.

Kolmogorov-Smirnov test revealed that differences among clusters are statistically significant for the following barriers: (i) *OBST5* is statistically significant at 10%, (ii) *OBST6* is statistically significant at 5%, (iii) and indicators *OBST1*, *OBST2*, *OBST3* and *GDP per capita* are statistically significant at 1%.

IV. CONCLUSIONS

Various changes have been induced by the development of ICTs, with e-Commerce as one of those with the strongest overall impact on business and society. e-Commerce has been recognized as one of the new venues towards the increase in competitiveness [13].

The goals of our research were: (i) to investigate if European countries could be grouped into homogenous groups using hierarchical cluster analysis; (ii) to investigate if there is a relationship between the level of economic development, e-Commerce utilization and barriers. In order to attain these goals, we used the data on e-Commerce utilization and barriers and GDP per capita and GDP change in % for the year 2016 from Eurostat database, for countries: (i) EU28 countries, excluding Luxembourg; (ii) non-EU countries: Netherlands and Macedonia.

The results of our research indicate that European countries can be grouped into five clusters, based on the level of e-Commerce utilization, using hierarchical cluster analysis with the application of Ward-method. Five clusters of European countries were compared according to their level of economic development measured in GDP per capita and GDP change in %, using the Kolmogorov-Smirnov test. Result revealed that differences among clusters are statistically significant for *GDP per capita, GDP change %*. Therefore, we conclude that the level of e-Commerce utilization in European countries related to their level of economic development, thus reinforcing already present digital divide [14]. Additionally, five clusters of European countries were compared according to their level of perceived e-Commerce barriers. Counter-intuitive results revealed that those clusters that have a higher level of e-Commerce utilization at the same time encounter the high level of e-Commerce barriers, with statistically significant Kolmogorov-Smirnov test. Therefore, barriers emerge for those countries that are strongly pursuing e-Commerce as a venue towards competitiveness.

Our results indicate that the development of ICTs is not evenly distributed across countries, and is often interrelated with overall economic development, which indicates that different levels of e-Commerce in various countries are the results of the different levels of economic development. This indicates that countries which are lagging behind in overall ICTs development, are also lagging behind in the development of e-Commerce. Since e-Commerce is one of the main drivers of economic growth in knowledge economies, those countries that are behind in e-Commerce development are likely to lag even more in the future period compared to their developed counterparts. Since different

phenomena of e-Commerce (e.g., social media) have a strong impact to its success, future research should focus on new trends in e-Commerce, such as social media [15, 16], and new phenomenon such as group-buying websites [17].

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Cost-effective transition to Wi-Fi 5 standard in Small Office / Home Office (SOHO) environment

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***Abstract* – Wireless connectivity has become a de-facto standard in daily computer use, both in small office/home office environment and in large business organisations. The beginnings of wireless connectivity started with the 802.11a and b standard, which enabled a theoretical data rate of 54 and 11 Mbit/s. The umbrella organisation Wi-Fi Alliance has decided to use a simplified naming scheme for wireless standards, so the currently widespread standard 802.11n (aggregate rate up to 600 Mbit/s) will now be named Wi-Fi 4, and the standard 802.11ac (aggregate rate up to 7 Gbit/s[1]) will be called Wi-Fi 5. In addition, Wi-Fi 6 or 802.11ax is in course of preparation and will enable theoretical rates of up to 10 Gbit/s. The answer to the question of whether there is a rationale for switching to Wi-Fi 5 will be provided by measuring the performance of Wi-Fi 4 and Wi-Fi 5 standards according to the following criteria: Wi-Fi signal strength in 2.4 and 5 GHz frequency bands, average throughput – data rate (transmitting and receiving data), maximum throughput and playback of 4K video content in a simulated SOHO environment. Performance ratio (performance per price) is also calculated.**

Keywords – Wi-Fi 5, SOHO, cost-effective, transition

I. INTRODUCTION

The introduction and implementation of IEEE 802.11a and b standards for wireless communication undoubtedly announced the expansion of wireless connectivity, not only for computers, but also for peripherals, laptops, tablets, TVs, etc. Initial data rates were relatively modest (802.11b / 11 Mbit/s) in comparison with the present 802.11ac (aggregate rate up to 7 Gbit/s) and the forthcoming 802.11ax standard, which enable aggregate data rates of up to 11 Gbit/s. The development of wireless connectivity technologies according to the 802.11x standard introduced some new and some improved old technologies that facilitate faster and more enjoyable operation. The umbrella organisation Wi-Fi Alliance is responsible for promoting and certifying the 802.11x wireless network standard and, as announced in 2018 [1], Wi-Fi 802.11ax will be referred to as Wi-Fi 6. Accordingly, older standards will be called Wi-Fi 5 (802.11ac) and Wi-Fi 4 (802.11n). New Wi-Fi standards most commonly and most quickly find their way in small office/home office (SOHO[2]) environments, since these environments tend to upgrade or change their active network equipment for wireless communication more often than large enterprise environments. The reasons for this are a simpler network infrastructure and a smaller number of devices. Depending on the needs within a business environment, wireless access must provide necessary speed and availability for seamless operation. Here it should be noted that different standards behave differently in the same environment. The Wi-Fi 4 standard can also use the 5 GHz frequency band with 24 channels. Wireless network transfer rate is a product of multiplication of bandwidth, number of spatial streams and number of data bits of the subcarrier. The main scope of the paper is to test Wi-Fi 4 and Wi-Fi 5 standards by performance measuring in SOHO environment and to see is it enough to change Wi-Fi router only to get significant Wi-Fi network performance improvements of the newer standard. Performance ratio (performance per price) is also calculated.

Following the introduction, Chapter I describes the SOHO environment, Chapter III provides the overview of the current Wi-Fi standards, namely Wi-Fi 4 and Wi-Fi 5, Chapter IV describes the testing methodology, Chapter V shows the results measured in a simulated environment. Chapter VI contains final considerations.

II. HELP SOHO ENVIRONMENT

A. Abbreviations and Acronyms

A SOHO (Small Office/Home Office) usually consists of a small number of people (typically up to 10), employed within an organisation, and primarily relies on the use of local area network (LAN) and Internet access. In addition, local area networks in a SOHO environment can also include support for Voice over IP (VoIP) and other network devices [2]. Wireless SOHO routers usually belong to a so-called "home category", which results in a less expensive device, but also in proportionally lower performance. Routers operate in an infrastructure mode, which consists of at least one access point or router

[1] With eight 160MHz and 256-QAM channels each of which are capable of 866.7 Mbps.

[2] SOHO – Small Office Home Office concept. Category of up to 10 employees

TABLE I. SOME SOHO CATEGORY ROUTER MODELS [4].

Model	Cisco RV110 Wireless-N	TPLINK Archer C20	ZyXel MWR102	Netgear N900 WNDR (4500)
Wireless standard support	802.11 n	802.11 n and 802.11 ac	802.11 n	802.11 n and 802.11 ac
Spatial stream config. support	-	1:1	-	3:3
Price[1]	$ 176.63	$ 55.00	$ 80.00	$ 392.00

connected to a wired network infrastructure or a series of wireless terminals [3]. SOHO environment can be classified as less demanding in the context of using the latest technologies and devices. Table 1 provides the overview of some router models in the SOHO category. It can be noticed that the price[3] range of SOHO models can vary significantly, depending on the characteristics of the device and additional features, as well on the supported Wi-Fi standard. When a SOHO environment requires serving of a large number of users (for example, over 10), an adequate model should be chosen that can support this without any noticeable loss in performance.

III. IEEE 802.11X STANDARD

IEEE 802.11x is a general name for a group of standards to which Wireless Local Area Networks (WLAN) belong, developed by the 11th group of the international organisation IEEE 802 [5].

A. IEEE 802.11n Standard (Wi-Fi 4)

The 802.11n standard has been commercially available since 2007[4] and has introduced significant improvements in data rates (up to 600 Mbit/s) and in range, amounting to250 meters as the crow flies, inversely proportional to obstacles. In the physical layer architecture, Multiple Input Multiple Output – MIMO (downlink [5]) Orthogonal Frequency Division Multiplexing – OFDM technology and the possibility to use the 5 GHz frequency band are used for

TABLE II. SOME BASIC SPECIFICATION FOR THE IEEE 802.11N STANDARD. SOURCE: HTTPS://WWW.WI-FI.ORG/DISCOVER-WI-FI/WI-FI-CERTIFIED-N

IEEE 802.11N MAIN FEATURES	
PARAMETER	**IEEE 802.11N STANDARD**
Maximum data rate (Mbit/s)	600
RF Band (GHz)	2.4 or 5
Modulation formats	CCK, DSSS, OFDM, 64-QAM
Number of spatial streams	1 to 4
Channel width (MHz)	20 or 40
MIMO configuration	SU and MU-MIMO Up to 4 x 4 : 4 (40 MHz)

[3] Prices on eBay at 31 January 2019.

[4] The development of 802.11n standard began in 2003 and the first draft was published in 2005 [4]

TABLE II. SPATIAL STREAM SPEEDS ON THE 802.11N STANDARD. SOURCE: HTTPS://COMMUNITY.ARUBANETWORKS.COM

	Antennas (Tx*Rx)	Spatial Streams	Maximum Link Speed	Band Support
Single Stream	1 x 1	1	72 Mbps	2.4
Dual Stream	1 x 2	2	150 Mbps	2.4
Dual Stream	2 x 2	2	150 Mbps	2.4
Dual Stream	2 x 3	2	150 Mbps	2.4
Dual Stream	2 x 2	2	300 Mbps	2.4 & 5
Dual Stream	2 x 3	2	300 Mbps	2.4 & 5
Multi Stream	3 x 3	3	450 Mbps	2.4 & 5

the first time. MU-MIMO enables simultaneous communication between a wireless router and several devices, in full speed. Table 2 shows basic specifications of the IEEE 802.11n standard. MIMO-OFDM technology enables an increase in the range and performance (data rate) compared to the previous 802.11b/g standard. It uses multiple spatial streams, multiple antennas for receiving and transmitting signals and channel widths of 20 – 40 MHz [7]. Possible configurations of spatial channels are shown in Table 3.

Major improvements of the Wi-Fi 5 standard include the use of the following technologies:

- The Implementation of MIMO-OFDM
- Introduction of MU-MIMO technology
- MIMO Power Save
- Channel bonding – increasing throughput by combining adjacent channels
- Wider channel bandwidth

B. IEEE 802.11ac standard (Wi-Fi 5)

The 802.11ac standard was published in 2013 and was assigned a designation Wi-Fi 5 by Wi-Fi Alliance. This standard uses exclusively the 5 GHz frequency band and introduces the technology for further expanding the channel width from 40 to 80 and 160 MHz[6]. The application of Multiuser – Multiple Input Multiple Output (MU-MIMO)

TABLE IV. BASIC SPECIFICATION FOR THE IEEE 802.11AC STANDARD.SOURCE: HTTPS://WWW.WI-FI.ORG/DISCOVER-WI-FI/WI-FI-CERTIFIED-AC

IEEE 802.11AC GIGABIT WI-FI FEATURES	
PARAMETER	**DETAILS**
RF Band (GHz)	5.8 GHz
Max data rate (Gbit/s)	6.93 Gbps
Channel width (MHz) – Transmission bandwidth	20, 40, & 80 MHz 160 & 80 + 80 MHz optional
Modulation formats	BPSK, QPSK, 16-QAM, 64-QAM 256-QAM
MIMO	SU and MU-MIMO
Number of spatial streams	2 to 8
Beamforming	Optional

[5] MIMO technology in the 802.11n standard is limited to downlink

[6] Two 80 MHz channels bond into a single 160 MHz channel.

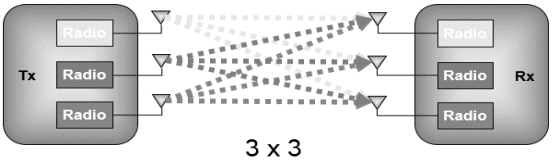

Figure 1. Graphic view of 3x3 spatial stream configuration. Source: http://www.multicap.be/en/technology/mimo-and-spatial-streams

technology in data transfer (download/downlink) enabled simultaneous multiple transfers between an access point (AP) and the client [8]. On the other hand, Wi-Fi 5 has a limitation of MU-MIMO technology to maximum 4 devices, which must be MU-MIMO compatible. The number of spatial streams has increased to 8 in comparison to the n standard. A special feature of Wi-Fi 5 is the introduction of beamforming[7] technology that enables the focusing of RF signals towards the device, enabling it to use the maximum throughput, i.e. the maximum theoretical throughput of 6.93 Mbps (866 MB/s). [8] Beamforming technology uses multiple antennas to transmit the exacts same signal to the device [9]. Table 4 shows basic characteristics of the Wi-Fi 5 standard.

As shown in Figure 1, spatial streams in configuration 3x3 imply 3 transmit antennas and 3 receive antennas, as in the example: 3 x 433 Mbit/s = 1299 Mbit/s. The additional number 3 in the example 3 x 3:3 stands for the number of spatial streams. Data rate is proportional to the number of spatial streams.

IV. Testing Methodology

Testing was conducted in simulated conditions, in a room representing an office of 70 m2, separated by a 20 cm thick solid brick wall and, in part, 11 cm thick drywall (knauf). Ground plan of the testing environment is shown in Figure 2. In this space, measure points (designated as M1, M2, M3, M4 and M5) were defined, from which clients connected to the router[9] previously placed in the main room (M1). A portable hard drive was also connected to the wireless router through an USB interface, and it served as a data warehouse in which a 2 GB video file was stored. The network was simultaneously accessed by 4 devices: a laptop, a mobile phone, a tablet and a desktop computer. In the simulated SOHO environment, signal strength was measured in 2.4 and 5 GHz frequency bands using the application **Wi-Fi Analyzer**[10]. The application **NetIO**[11] measured the response time of ICMP (ms) and throughput speed of the network via TCP and UDP protocols using various different packet sizes. Measurement data included Wi-Fi 4 and Wi-Fi 5 standards. Measurement tables show the measured values.

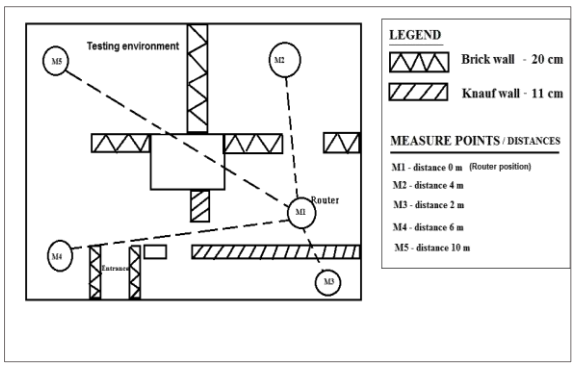

Figure 2. Tested SOHO environment. Room positions, measure points and distances. Source: author

The test point M1 represented the set up wireless router to which clients in different rooms of the simulated SOHO environment connected. Even though this is not shown in the ground plan, measurements were also carried out on the lower floor (measure point Lower floor in Figures 3, 4, 5 and 6). The distance of measure points from the starting point M1, where the router was primarily placed, is shown in the legend in Figure 2. Performance ratio has been calculated using tested speed results and device price.

V. Measurement Results

Measurements were performed in the simulated SOHO environment as shown in Figure 2, and the measurement

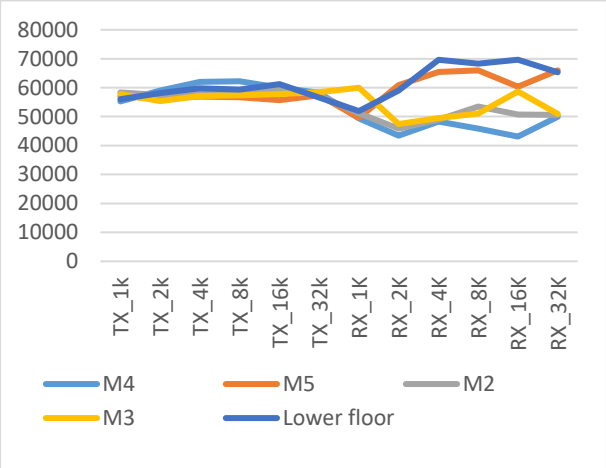

Figure 3. NetIO: 2.4 GHz, 802.11n standard throughput speed in Kbytes/s according to measure points. Source: author

results can be seen in Figures 3, 4, 5 and 6.

The average throughput speed of Wi-Fi 4 (transmit-TX/receive-RX) is given in Figure 3 and Figure 4. It can be concluded that the Wi-Fi 4 standard on 2.4 GHz at an average rate of 58000 Kbit/s (RX) and 55000 (TX) does not show any reduction in throughput from the measure point on the ground floor, which once again proves that the Wi-

[7] Beamforming means that the router determines where devices – laptop, smartphone, tablet, or whatever else – are located and projects a stronger signal in that specific direction. Beamforming uses multiple antennas to transmit the same signal.

[8] Higher than the throughput of SATA 3 interface for storage subsystems [10]

[9] The model of SOHO category router used in the test was TPLINK Archer C20.

[10] http://wifianalyzer.mobi (accessed 13.1.2019.)

[11] https://web.ars.de/netio/ (accessed 13.1.2019.)

Fi 4 standard offers a larger range, with relatively stable throughput speed.

TABLE V. ONE FILE COPY; AVERAGE COPY SPEED; 2 GB SIZE AND PERFORMANCE RATIO PER PRICE; SOURCE: AUTHORS

Average copy speed (USB HDD) – one file copy – 2 GB size – 10 meters distance (M5)[1]									
M	Wi-Fi standard	20 MHz Channel width (average)	40 MHz Channel width (average)	80 MHz Channel width (average)	Average ping response (ms) (average)	Signal strength (dbm)	Router price **Archer C20**	Performance ratio (MB/s per price)	Difference in % regards to Wi-fi 4
1	802.11n (Wi-Fi 4)	3.5 MB/s	8.2 MB/s **with delay	**Not applicable**	9.2	-57	55,00 USD	0,11	22,00%
2	802.11n @ 5 GHz	6.5 MB/s	8.7 MB/s	**Not applicable**	9.1	-53	55,00 USD	0,14	6,00%
3	802.11ac (Wi-Fi 5)	6.1 MB/s	8.9 MB/s	9 MB/s	9.4	-52	55,00 USD	0,15	

Measurement data for the Wi-Fi 5 standard obtained in the simulated environment are shown in Figure 5. As expected, throughput speed was higher than the one achieved by the Wi-Fi 4 standard, from 98000 Kbit/s to 102000 Kbit/s (12.2 MB/s – 12.7 MB/s), and this can be attributed to technical specifications of the Wi-Fi 5 standard, using a greater channel width for data transfer (20 or 40 MHz versus 80 or 160 MHz). The average ping response was 9.4 ms. According to Figure 5 and the diagram shown, data transfer is more uniform, without any significant oscillations, as opposed to the Wi-Fi 4 standard. This can be attributed to the 5 GHz frequency band which is "clearer" and less under the influence of interference.

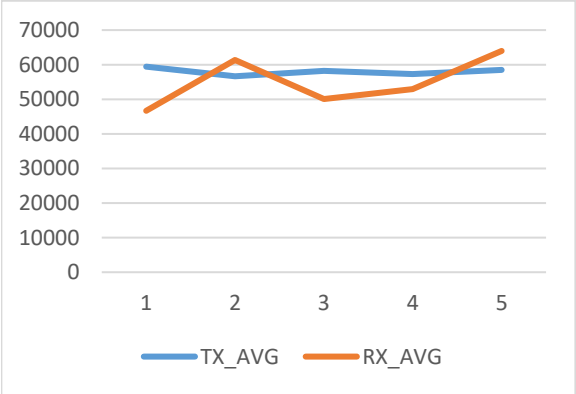

Figure 4. NetIO: 2.4 GHz, 802.11n; average throughput speed in Kbytes/s. 20 MHz channel width. Source: authors

On the other hand, while Wi-Fi 4 achieved relatively uniform throughput at the measure point Lower floor, Wi-Fi 5 showed the reduction in throughput of almost 50%, which can be seen in Figure 6. The reason for this lies in technical specifications of the Wi-Fi 5 standard, which has shorter range than Wi-Fi 4 in the 5 GHz frequency band. Table 5 shows average copy speed values for a single 2 GB video file. Measurements were performed on both the Wi-Fi 4 and the Wi-Fi 5 standard. Wi-Fi 4 standard also operated in the 5 GHz frequency band. Results obtained show that the greatest difference in copy speed was due to the channel width, but also to the used frequency band of 5 GHz versus 2.4 GHz. In the measurement under number 1 in Table 5, a delay in copying was observed, which can be attributed to interference.[12] Upon switching to the 5 GHz frequency spectrum, the delay did not occur and a stable data transfer was achieved. In the testing environment, the copy speed from the portable USB drive connected to the

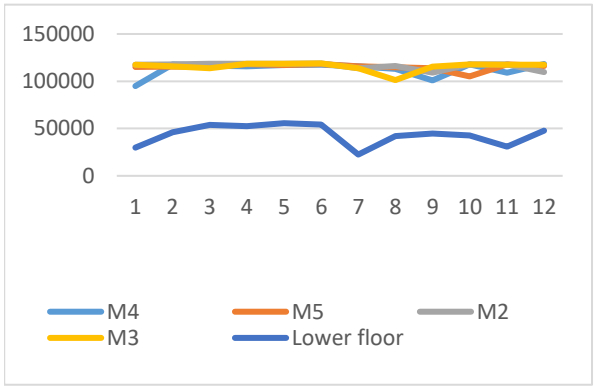

Figure 5. NetIO: 5 GHz, 802.11ac standard throughput speed in Kbyte/s according to measure points. 80 MHz channel width. Source: authors

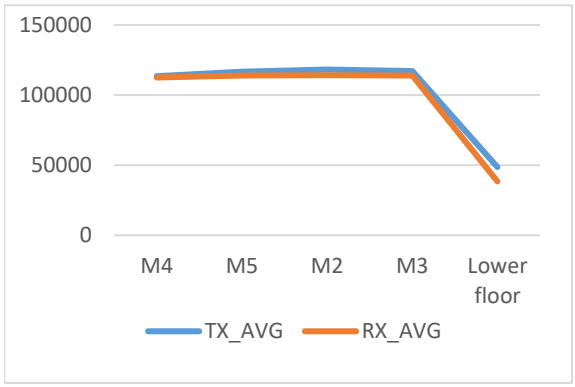

Figure 6. NetIO: 5 GHz, 802.11ac throughput speed in Kbyte/s according to measure points. 80 MHz channel width. Source: authors

[12] Measuring throughput speed at point M5 of the simulated environment. 10 m distance from the router through two walls

router, besides the throughput of the chosen Wi-Fi standard, depended on the speed of router hardware, speed of USB interface and speed of USB portable drive. The configuration of test router of SOHO class TPLINK Archer C20 and the test computer equipped with a wireless network adapter Intel AC3165[13] did not include multiple spatial streams, but the configuration was 1:1.1 (Figure 1).

The choice of a device supporting multiple spatial streams would yield better performance, but its price could exceed the SOHO class. For this reason, the most affordable device was chosen for the test, which can be found in the majority of SOHO environments.

Measurement results of the old Wi-Fi 4 standard and the new Wi-Fi 5 standard have shown that to fully utilize the throughput speed advantages of Wi-Fi 5, it is necessary to have the accompanying hardware supporting it, which entails additional financial investments. The major difference in speed was noticed when using a smaller channel width of 20 MHz and a larger channel width of 80 MHz, where the Wi-Fi 4 standard achieved 7 MB/s on average, and Wi-Fi 5 achieved 12.7 MB/s. On the other hand, when channel width was changed to 40 MHz, the Wi-Fi 4 standard achieved better performance. In addition, operation in the 5 GHz frequency band includes less interference, and operation in a higher frequency entails larger throughput [11].

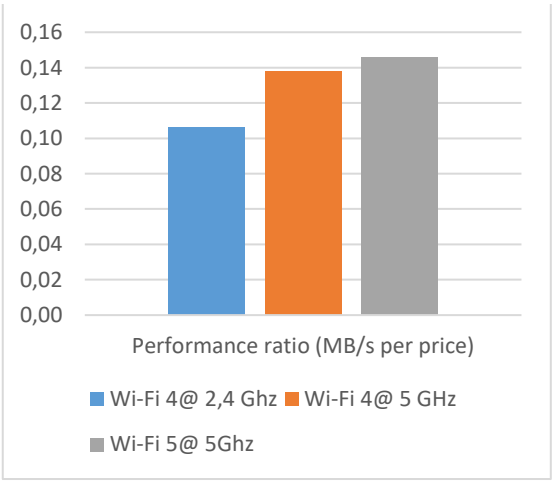

Figure 7. Performance ratios; MB/s per price. Source: authors

According to the analysis of measurement results of both wireless network standards in the simulated SOHO environment, the use of SOHO (lower-price) routers did not result in any significant change in the throughput speed in the daily work, as shown in Table 5. Since only a small number of users (4 users simultaneously) accessed the network, there was no network congestion or reduction in performance in either test. According to the test results, the Wi-Fi 4 standard enabled enjoyable operation, same as Wi-Fi 5. To realize the full potential of the Wi-Fi 5 standard, it is necessary to upgrade not only the router, but also the client hardware. This especially refers to the use of wireless network adapters for laptops or desktop computers that require network adapters supporting several spatial streams to realize the full potential of the Wi-Fi 5 standard. On the other hand, the newer Wi-Fi 5 standard offers new technologies such as beamforming and multiple spatial channels for achieving higher throughput, as well as the possibility to serve a larger number of devices (clients) without any reduction in performance.

There is no significant price difference between some SOHO category Wi-Fi routers according to Wi-Fi 4 and Wi-Fi 5 standards and both can be bought for pretty less than 100 $[14]. For using all Wi-Fi 5 benefits users have to invest to other hardware like appropriate Wi-Fi card which supports more spatial streams, higher MU-MIMO support or bought other new hardware that support newer standard which will take extra costs (cost of device). Performance measuring of both tested standards are comparable in most cases in SOHO test environment because of using testing hardware (laptop, mobile phone etc.) that is not supporting additional benefits and features of the newer standard. Improvement of using Wi-Fi 5 standard instead of Wi-Fi 4 in testing environment is insignificant (only 6%) using the same access devices. In this testing case additional financial investments of complete transition to newer standard are not advisable just because of insignificant performance benefits. Performance ratios and price are shown in Figure 7. Even though the Wi-Fi 5 standard is in theory basically 3 times faster [12] and offers affordable hardware such as the tested TPLINK Archer C20 which costs $ 55, financial investments within the SOHO environment are not cost-effective since any significant improvement would require replacement of the entire wireless network hardware.

VI. Conclusion

Though the new 802.11ax standard is in course of preparation, which according to Wi-Fi Alliance will be called Wi-Fi 6, currently the most widespread standards in common use are Wi-Fi 4 and Wi-Fi 5. All new generations of Wi-Fi standards offer high data rate (high throughput), operation in the 5 GHz frequency band (less interference) and larger data channel widths (up to 160 MHz). They also introduce new technologies such as beamforming and offer the possibility to use multiple spatial streams in various configurations. However, is a changeover to a newer standard, with better specifications, really necessary? Support of a newer wireless standard does not necessarily mean that the performance will be twice as good. The achieved data rates on the tested SOHO router in the testing environment showed little difference in speed in its daily use, but also some shortcomings of the 5 GHz band with respect to its range.

Sharing of wireless connection in a SOHO environment should not negatively affect the data rate given the relatively small number of users. SOHO environment is not as demanding as an enterprise solution due to a small number of users, and the Wi-Fi 4 standard enables just sufficient transfer rates for the SOHO environment, with

[13] Wireless network adapter of Intel AC3165, used in the simulated environment, is limited due to hardware constraints to one receive antenna and one transmit antenna – 1x1 stream

[14] Situation at price market on February 2019.

the possibility to use the 5 GHz spectrum, which shows more resistance to interference nearby. Investments into infrastructure for the purpose of benefiting from the features of a newer Wi-Fi standard will be proportionally followed by the price, and performance benefits in the SOHO environment do not justify such an investment. Wi-Fi Alliance announced the introduction of the Wi-Fi 6 standard (IEEE 802.11ax), which will operate in the frequency band of 1 – 5 GHz, including 2.4 GHz. Major improvements will be MU-MIMO support for download/upload, spatial frequency reuse, 1024 quadrature amplitude modulation – QAM [13]. For future research, it is recommended to compare Wi-Fi 5 and Wi-Fi 6 standards, i.e. to analyse the advantages of Wi-Fi 6 compared to Wi-Fi 5, as well as its cost-effectiveness. Authors also recommend of using appropriate network hardware that will be compatible with newer Wi-Fi 6 standard for better performance.

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Usluge e-uprave za studente: primjeri dobre prakse nekoliko zemalja i rezultati anketiranja studenata

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***Sažetak* - Jedno od načela razvitka državne informacijske infrastrukture jest dostupnost podataka iz javnih registara svim tijelima javnog sektora, građanima i drugim korisnicima. Nakon implementacije sustava e-Građani, u Hrvatskoj se ubrzano razvijaju i šire različite vrste e-usluga za građane, uključujući usluge namijenjene učenicima i studentima. Cilj ovog pilot-istraživanja bio je napraviti prikaz dostupnih e-usluga (na engleskom jeziku) za studente u nekoliko zemalja te ispitati koliko studenti u Hrvatskoj smatraju različite vrste e-usluga korisnima i potrebnima. U prvoj fazi istraživanja napravljen je anketni upitnik koji je provjeren u online verziji na prigodnom uzorku od 31 ispitanika. Nakon provjere i manjih korekcija nova verzija upitnika primijenjena je u papir-olovka formi na ukupno 305 ispitanika. Obradom podataka utvrđen je znatan interes za skoro sve oblike e-usluga javne uprave, lokalne samouprave, kao i javnih ustanova koje su potencijalno važne za studente visokih učilišta. Na temelju dobivenih rezultata ankete načinjena je preporuka za uvođenje novih vrsta e-usluga koje mogu implementirati nadležna državna tijela, lokalna samouprava i visoka učilišta.**

Ključne riječi – e-usluge; e-uprava; portal; studentska populacija; elektroničke informacije

I. UVOD

Intenzivniji napori na razvoju e-uprave u Hrvatskoj započeli su 2000. godine (vidjeti npr.: [1]), a posebno donošenjem strategije „Informacijska i komunikacijska tehnologija – Hrvatska u 21. stoljeću“ [2], kao i operativnog plana provedbe programa e-Hrvatska 2007. za 2004. godinu [3]. Inače, zbirka službenih dokumenata vezanih uz razdoblje uvođenja e-uprave u Hrvatskoj objavljena je na mrežnim stranicama Ministarstva uprave [4]. Prvi hrvatski portal javne uprave kreiran je 2007. godine pod nazivom „Moja uprava“, a središnji državni portal, koji djeluje i danas, uspostavljen je 2014. godine. U nastavku rada objašnjene su njegove najvažnije komponente te su opisane e-usluge za posebnu skupinu korisnika: studente.

A. Središnji državni portal javne uprave Republike Hrvatske

Središnji državni portal predstavlja centralno internetsko mjesto za jednostavan pristup svim informacijama iz državne i javne uprave, njihovo pretraživanje i informiranje o političkim aktivnostima koje provodi izvršna vlast. Cilj ovog središnjeg online rješenja za informacije/usluge na jednom mjestu jest nedvosmisleno, jednostavno i moderno prezentirati strukturu, funkciju i ulogu svih tijela državne uprave putem tri potportala (1) Moja uprava, (2) e-Građani i (3) O Vladi i tijelima državne uprave [5].

Središnji državni portal jedna je od triju glavnih sastavnica koje predstavljaju zajedničku infrastrukturu javnog sektora u projektu e-Građani. Projekt e-Građani pokrenut je na temelju odluke o pokretanju projekta e-Građani (NN 052/2013) iz 2013. godine, a glavni cilj projekta bio je omogućiti pristup javnim informacijama i informacijama o javnim uslugama na jednom mjestu, siguran pristup osobnim podacima i elektroničku komunikaciju građana i javnog sektora. Osim središnjeg državnog portala, kao sastavnice projekta e-Građani integrirane su još dvije sastavnice zajedničke infrastrukture javnog sektora, a to su Nacionalni identifikacijski i autentifikacijski sustav (NIAS) i Osobni korisnički pretinac [6].

NIAS upravlja elektroničkim identitetima u nacionalnom sustavu autentifikacije krajnjih korisnika s e-uslugama javnog sektora te svim korisnicima omogućava uspješno, sigurno i vremenski povoljno korištenje javnih e-usluga. S druge strane, pružatelji e-usluga oslobođeni su poslova upravljanja korisničkim računima i procesom autentifikacije [7].

Najvažniji element sustava e-Građani je osobni korisnički pretinac koji omogućava svakom građaninu Republike Hrvatske koji posjeduje osobni identifikacijski broj (OIB) primanje osobnih službenih poruka vezanih za javne usluge, postupke (odnosno njihov tijek) i osobne statuse te njihov pregled, upravljanje i pohranu [8].

Na dijelu središnjeg državnog portala Moja uprava građani mogu pronaći informacije i usluge podijeljene u dvanaest kategorija: (1) zdravlje, (2) rad, (3) državljanstvo i isprave, (4) pravna država i sigurnost, (5) promet i vozila, (6) financije i porezi (7) obitelj i život, (8) hrvatski branitelji, (9) obrazovanje, (10) stanovanje i okoliš, (11) poslovanje i (12) aktivno građanstvo i slobodno vrijeme [9]. Treća komponenta portala, O Vladi i tijelima državne uprave, nudi građanima informacije i poveznice o tijelima državne uprave uključujući urede Vlade, ministarstva, središnje državne urede te državne upravne organizacije.

Osnovni cilj portala je informirati građane o radu Vlade, novostima i sjednicama Vlade.

B. Informacije hrvatske javne uprave za studente

Na središnjem državnom portalu u dijelu Moja uprava nalazi se odjeljak vezan uz predmet istraživanja ovog rada, a to je „obrazovanje/visoko obrazovanje“. Na navedenom dijelu portala građani se mogu informirati o Bolonjskom procesu, Hrvatskom kvalifikacijskom okviru kao programu osigurane relevantnosti i kvalitete, načinima i uvjetima upisa na studije, opcijama prelaska na drugi studij i usporedno studiranje, vojnim studijskim programima i dr.

Nadalje, građani se mogu informirati o pitanjima vezanima uz studentski standard, kao što su studenski smještaj, prijevoz za redovite studente s invaliditetom, subvencije školarina na visokim učilištima vrhunskim sportašima, subvencionirana prehrana te pristup internetu u studentskim domovima. Između ostalog, na portalu postoji odjeljak posvećen studiranju za strane državljane i objašnjenja pojmova sveučilišnih, odnosno stručnih studija, objašnjenja vezana uz nove akademske i stručne nazive te nove studije. Studenti na portalu mogu pronaći informacije vezane uz studentske stipendije i informacije vezane uz priznavanje inozemnih obrazovnih kvalifikacija [10]. Portal omogućuje i jednostavan pristup Informacijskom sustavu visokih učilišta (ISVU), koji služi za vođenje baze podataka o studentima, nastavnicima, kolegijima, nastavnim planovima, upisima i ispitima.

Vezano uz dostupne elektroničke usluge putem središnjeg državnog portala, studentima se omogućuje preko e-Razmjena studentskih ocjena preuzimanje prijepisa ocjena ostvarenih na visokim učilištima u RH i slanje drugom visokom učilištu. E-usluga vezana uz online tečajeve omogućuje svim zainteresiranima besplatan pristup i korištenje tečajeva Sveučilišnog računskog centra (SRCE), kojima je cilj proširenje znanja i stjecanje kompetencija u području korištenja IKT-a.

Sustav AAI@EduHr je autentifikacijska i autorizacijska infrastruktura sustava znanosti i visokog obrazovanja u Republici Hrvatskoj pomoću koje visokoobrazovne ustanove studentima dodjeljuju elektronički identitet za korištenje različitih internetskih aplikacija koje koriste AAI@EduHr infrastrukturu za prijavljivanje i pristupanje (autentifikaciju i autorizaciju) korisnika. Studenti pomoću identiteta AAI@EduHr mogu pristupiti portalu e-Građani, sustavu ISVU i servisima koje nudi pojedini fakultet. Korisnici imaju pravo na elektronički identitet u sustavu AAI@EduHr do isteka njihove povezanosti s ustanovom koja im je dodijelila elektronički identitet, a to je najčešće završetak studija [11].

Kako bi studenti mogli jednostavnije doći do potvrde kojom dokazuju studentski status, kreirana je i e-usluga e-Zapis o statusu studenta. Uz sve navedene e-usluge dostupna je i usluga prijave na diplomske studijske programe koja omogućava da se digitalnim putem preko Nacionalnog informacijskog sustava svaki potencijalni korisnik može prijaviti na do 10 diplomskih studijskih programa visokih učilišta [12].

II. ELEKTRONIČKE USLUGE I INFORMACIJE KOJE SE PRUŽAJU STUDENTIMA NA STRANICAMA MINISTARSTAVA OBRAZOVANJA OSTALIH ZEMALJA

Od europskih zemalja, Ujedinjeno Kraljevstvo studentima pruža široku lepezu informacija i e-usluga na službenim internetskim stranicama. Studenti imaju mogućnost elektroničke prijave za različite vrste stipendija, potpora, studentskih kredita za sve razine visokog obrazovanja, a informacije su namijenjene i specifičnim studentskim skupinama: studentima s invaliditetom i posebnim potporama, inozemnim studentima, studentima koji žele nastaviti studij u drugoj državi [13].

Na stranicama su detaljno objašnjene razine obrazovanja i upute vezane uz proces svake razine studija, kao i detaljne upute o načinima dobivanja stipendije za strane studente. Nadalje, vezano uz visoko obrazovanje na stranicama ministarstva mogu se dobiti i informacije o prepoznatljivosti visokoškolske institucije i mogućnosti prijave na visokoškolske elektroničke tečajeve (npr. *Full-time courses, Part-time courses, Open University courses. Specialist music, Dance and drama courses, Postgraduate courses, Courses at private institutions*) [14].

Internetska stranica njemačkog Ministarstva obrazovanja i istraživanja za studentsku populaciju nudi informacije vezane uz studentsku mobilnost, npr. o Erasmus+ programima. Na stranicama nisu pronađene informacije o elektroničkim uslugama za studente, kao ni značajne informacije vezane uz studiranje u toj državi.

Na stranicama Ministarstva obrazovanja i kulture Finske informacije vezane uz visoko obrazovanje i elektroničke usluge za studente dostupne su u obliku informacija i poveznica na sva sveučilišta, sveučilišta primijenjenih istraživanja te agencija i instituta u Finskoj. Nadalje, internetska stranica sadrži i informacije o strategiji razvoja visokog obrazovanja, financiranju visokoškolskog obrazovanja te poveznice na informacije o studijskim programima i načinima prijave. Sve informacije o visokoškolskom obrazovanju i prijave na studijske programe moguće su elektroničkim putem, kao i praćenje i dobivanje rezultata prijave putem internetske stranice Studyinfo.fi [15].

Internetske stranice kanadskog Ministarstva nude sljedeće informacije i e-usluge: financiranje obrazovanja, plan štednje za edukaciju, profesionalno usavršavanje, informacije o stipendijama, potporama i ostalim mogućnostima za studente, informacije o mogućnostima dobivanja stručne prakse i specijalizacije, o edukaciji i stipendiranju studenata s posebnim potrebama i nižeg socijalno-ekonomskog statusa te informacije za doktorske studente i mogućosti postdoktorskog obrazovanja [16].

Na internetskim stranicama Ministarstva javne uprave Indije dostupan je niz elektroničkih usluga vezanih uz edukaciju i obrazovanje. Od onih namijenjenih studentima tu je mogućnost pretraživanja i prijave na različite programe obrazovanja i različita sveučilišta, poveznice na informacijske sustave fakulteta i instituta koji djeluju u Indiji za sve razine studija, kao i mogućnost plaćanja

školarine elektroničkim putem. Od ostalih e-usluga, omogućena je e-prijava za stipendije za različite studentske skupine, pristup javnim knjižnicama uz pretraživanje literature, informacije o mogućnosti dobivanja naknade za prijevoz za studente s posebnim potrebama te poveznice na smještajne kapacitete za studente (domove, hostele) [17].

III. CILJEVI I ISTRAŽIVAČKA PITANJA VEZANA UZ EMPIRIJSKI DIO ISTRAŽIVANJA

Prvi cilj ovog pilot-istraživanja bio je da se analiziraju i prikažu dostupne e-usluge za studente u Hrvatskoj, kao i u nekoliko drugih zemalja engleskog i njemačkog govornog područja te u Finskoj. To je napravljeno u prethodnom poglavlju ovog članka. U drugom, empirijskom dijelu istraživanja cilj je bio ispitati koliko studenti u Hrvatskoj smatraju korisnima i/ili potrebnima različite vrste elektroničkih usluga, posebice onih koje su namijenjene studentskoj populaciji.

Sukladno izloženim ciljevima, istraživačka pitanja za *empirijski* dio ovoga rada bila su:

1. Koliko studenti koriste ili namjeravaju koristiti standardne usluge e-uprave namijenjene svim građanima Hrvatske?

2. Kako studenti procjenjuju još nedostupne usluge e-uprave koje imaju druge razvijene zemlje u Europi i svijetu, a Hrvatska e-uprava još nema dostupne te koliko ih smatraju potencijalno korisnima i potrebnima?

Na prethodna istraživačka pitanja odgovoreno je putem *inicijalnog online prikupljanja podataka* (internetske ankete), koja je provedena zbog evaluacije anketnih pitanja, kao i potonjom *anketom u papir-olovka formi*. Obje ankete provedene su na prigodnom uzorku, studentima različitih studijskih smjerova i godina studija, što je detaljnije opisano u sljedećem poglavlju o metodologiji istraživanja.

IV. METODOLOGIJA

Prikupljanje podataka u ovom pilot istraživanju provedeno je u dvjema fazama: (a) probnom online anketom s 31 ispitanikom i (b) anketom u papir-olovka formi s 305 ispitanika. Za provođenje ovog istraživanja službeno je zatraženo i dobiveno odobrenje Etičkoga povjerenstva visokoškolske institucije.

A. Probna online anketa o e-uslugama za studente

Empirijski dio istraživanja započeo je online anketom izrađenom u *Google Forms* aplikaciji koja je imala 5 demografskih pitanja (dob, spol, studentski status, vrsta studija, mjesto stanovanja – gradsko, prigradsko, ruralno). Nakon toga slijedilo je 15 pitanja o pružanju osnovnih e-usluga za studente, zatim 6 pitanja o korištenju identiteta AAI@EduHr, pa 17 pitanja vezanih uz procjenu važnosti postojećih e-usluga i u budućnosti mogućih e-usluga te informativnih sadržaja na stranicama e-uprave. Na kraju ankete bilo je 8 pitanja o korištenju postojećih informacija i usluga e-uprave koje su namijenjene svim građanima Hrvatske. Na većinu anketnih pitanja odgovaralo se pomoću skale procjene Likertova tipa (od „5 - potpuno nevažno“, do „1 - izrazito važno“). Ta inicijalna verzija ankete primijenjena je na 31 ispitaniku (radilo se o studentima različitih vrsta studija, studijskih godina i smjerova na jednom fakultetu hrvatskog sveučilišta), od kojih je 58% bilo ženskog, a 42% muškog spola. Dob im je uglavnom bila u rasponu od 21 do 26 godina. Ukratko rečeno, osnovni rezultat primjene inicijalne online ankete bio je da studenti percipiraju važnost većine postojećih i mogućih usluga e-uprave (više od 50% odgovora bilo je u rasponu od „umjereno važno“ do „izrazito važno“). Primjeri anketnih pitanja za obje forme ankete navedeni su u tablicama I.-IV.

B. Papir-olovka anketa o e-uslugama za studente

Papir-olovka anketa bila je gotovo identična onoj koja je nekoliko tjedana ranije primijenjena kao *Google Forms* online upitnik. U ovom drugom anketnom istraživanju, koje je provedeno u veljači 2019. godine, ispitanici su bili sa istog fakulteta, ali drugih studijskih smjerova i godina studija nego u ranijoj online anketi. Ukupno je u papir-olovka anketi sudjelovalo 305 ispitanika, od kojih je 68,5% bilo muškog spola, a 27,5% ženskog spola, dok preostali studenti nisu odgovorili na pitanje o spolu. Čak 98% ispitanika bilo je u dobi od 18 do 26 godina (od toga 51% u dobi 18-20 godina). Skoro svi studenti bili su redoviti (96%) i upisani u sveučilišni preddiplomski studij (99%). Njih 48% imalo je prebivalište u urbanoj gradskoj sredini, 21% u urbanoj prigradskoj sredini, a 28% u ruralnoj seoskoj sredini.

C. Analiza podataka

Za analizu podataka korištena je deskriptivna statistička analiza uz pomoć specijaliziranog statističkog alata IBM SPSS Statistics 23.

V. REZULTATI

Radi veće preglednosti dobivenih rezultata ankete, u tablici I. prikazani su samo postoci za ponuđene odgovore „izrazito važno“ i „uglavnom važno“ na odabrana anketna pitanja (ostali ponuđeni odgovori bili su „i važno i nevažno / ne mogu se odlučiti“; „uglavnom nevažno“ i „potpuno nevažno“.

Kao što je vidljivo iz podataka koji su prikazani u tablici I., većina anketiranih studenata (od ukupno 63,1% do čak 82,6%, ovisno o pitanju u anketi) smatra da je „izrazito važno“ ili barem „uglavnom važno“ imati mogućnost pribavljanja administrativnih dokumenata putem servisa e-uprave, kao što su, primjerice, (a) pravovaljana potvrda o studentskom statusu s podacima o matičnom visokom učilištu i dr., (b) pravovaljani prijepis ocjena tijekom i nakon završetka studija, (c) pravovaljana potvrda o završenom studiju i postignutom stupnju obrazovanja i (d) certifikati o izobrazbi koju su završili izvan fakulteta (npr. iz stranih jezika, računalnih vještina itd.). Inače, u vrijeme pisanja ovog rada, preko sustava e-uprave u Hrvatskoj bila je dostupna samo *usluga vezana uz dobivanje pravovaljane potvrde o studentskom statusu s podacima o matičnom visokom učilištu, razini i vrsti studija (stručni ili sveučilišni) te akademskoj godini u koju je student upisan*. Rezultati provedene ankete pokazuju da su već kod studenata preddiplomskih studija prepoznate koristi ostvarivanja ranije navedenih (b-d) usluga u budućnosti.

TABLICA I. ODGOVORI NA ODABRANA PITANJA O PRUŽANJU OSNOVNIH E-USLUGA ZA STUDENTE (N=305)

ANKETNO PITANJE	% UGLAVNOM VAŽNO	% IZRAZITO VAŽNO
Koliko vam je važno to što *preko portala e-Građani* možete dobiti **pravovaljanu potvrdu o studentskom statusu** s podacima o matičnom visokom učilištu, razini i vrsti studija (stručni ili sveučilišni), te akademskoj godini u koju ste upisani?	33,8	37,7
Koliko bi vam bilo važno da *preko servisa e-uprave* (npr. portala e-Građani) možete tijekom i nakon završetka studija dobiti **pravovaljani prijepis ocjena**?	32,1	41,0
Koliko bi vam bilo važno da, nakon završetka fakulteta, *preko servisa e-uprave* (npr. putem portala e-Građani) možete dobiti **pravovaljanu potvrdu o završenom studiju i postignutom stupnju obrazovanja**?	25,9	56,7
Koliko bi vam bilo važno da *preko servisa e-uprave* možete dobiti **certifikate o izobrazbi koju ste završili izvan fakulteta** (npr. iz stranih jezika, računalnih vještina, računovodstva, menadžmenta itd.)?	29,2	44,3
Koliko bi vam bilo važno da vas *preko servisa e-uprave* **informiraju o natječajima za državne studentske stipendije**?	28,9	39,3
Koliko bi vam bilo važno da se *preko servisa e-uprave* može izvršiti **prijava za dobivanje državne studentske stipendije**?	30,5	42,3
Koliko bi vam bilo važno da *preko servisa e-uprave* možete **dobiti informaciju i prijaviti se za dobivanje studentske stipendije od grada ili županije u kojoj imate prijavljeno prebivalište**?	27,5	45,6
Koliko bi vam bilo važno da *preko servisa e-uprave* možete **dobiti informaciju i prijaviti se za subvencije za troškove za javni prijevoz** od grada ili županije u kojoj imate prijavljeno prebivalište?	31,8	35,7
Koliko bi vam bilo važno da se *preko servisa e-uprave* (ili drugih e-servisa) možete **prijaviti za smještaj u studentskom domu**?	20,7	44,3
Koliko bi vam bilo važno da **sve informacije vezane uz mogućnosti koje se pružaju studentima/studenticama slabijeg imovinskog/socijalnog statusa** (npr. različite subvencije) možete pronaći *na stranicama e-uprave*?	24,9	31,8
Koliko bi vam bilo važno da se *preko servisa e-uprave* možete **pretplatiti na dobivanje obavijesti o mogućnostima međunarodne studentske mobilnosti** (3-6 mjeseci**) i stručne prakse u inozemstvu** (Erasmus+)?	25,6	26,9

Podaci koji su prikazani u tablici I. također upućuju na važnost informiranja i o drugim, za studente važnim mogućnostima poput stipendija, subvencija za prijevoz, smještaja u studentskom domu i pomoći za studente slabijeg statusa. Informiranje o tim stavkama i mogućnost prijave na natječaje iz tih područja ocijenjeni su kao „izrazito važno“ ili „uglavnom važno“ u rasponu od ukupno 56,7% do 72,8% anketiranih studenata, ovisno o sadržaju anketnog pitanja. Čak je i mogućnost pretplate na dobivanje obavijesti o mogućnostima međunarodne studentske mobilnosti (3-6 mjeseci) i stručne prakse u inozemstvu (Erasmus+) procijenjena kao „izrazito važna“ ili „uglavnom važna“ kod čak 52,5% studenata, iako ih se za međunarodnu razmjenu i stručnu praksu u inozemstvu prijavljuje manje od 10% ukupno upisanih na fakultet u kojem je provedena anketa.

U tablici II. prikazani su još neki odgovori studenata koji se odnose na trenutačno nedostupne usluge putem e-uprave kao što su (a) mogućnosti obavljanja stručne prakse u Hrvatskoj, (b) podaci o školarinama poslovnih organizacija, (c) reguliranje zdravstvenog osiguranja, (d) mogućnosti pripravništva nakon diplomiranja, (e) mogućnosti specijalizacije nakon diplomiranja, (f) podaci o tečajevima koje nude razne organizacije, (g) prilike za poslove preko studentskih ugovora i (h) ponuda programa cjeloživotnog obrazovanja. Ovisno o sadržaju pitanja, ukupno je informiranje o stavkama koje su prikazane u tablici II. kao „izrazito važno“ ili „uglavnom važno“ ocijenilo od ukupno 61,6% do 84,9% anketiranih studenata. Naime, za informiranje o mogućnostima koje su navedene u tablici I. i tablici II., kao i za prijavu na različite natječaje i pozive, u trenutku pisanja ovog rada bilo je potrebno posjećivati desetke različitih internetskih stranica upravnih, obrazovnih i poslovnih organizacija. Mogućnost dobivanja takvih informacija na jednom mjestu bila bi vrlo korisna za ispunjavanje različitih potreba studentske populacije i diplomiranih studenata.

U tablici III. prikazano je stvarno i/ili namjeravano korištenje postojećih usluga e-uprave koje su dostupne preko portala e-Građani i na drugim lokacijama na internetu/webu. Iz podataka koji su prikazani u toj tablici vidljivo je da postoji velika zainteresiranost studenata za korištenje postojećih usluga e-uprave premda je na to dijelom utjecala i činjenica da su u papir-olovka anketu bili uključeni studenti informatičkih studijskih smjerova. Te usluge, koje koristi ili ih namjerava, prema potrebi, koristiti od 70,1% do 84,2% anketiranih studenata, jesu: „e-Zahtjev za izdavanje ePutovnice“; „e-Prijava boravišta hrvatskih državljana“; potvrda da se protiv građana ne vodi kazneni postupak; „e-Zahtjev za izdavanje vozačke dozvole“; e-Matica za dobivanje pravovaljane domovnice; e-Matica za dobivanje pravovaljanog rodnog lista; prijava na diplomski studij putem usluge e-uprave pod nazivom „Središnja prijava na diplomske studijske programe“; mogućnost prijave i pristupa na online tečajeve Srca.

TABLICA II. ODGOVORI NA PITANJA O PRUŽANJU E-USLUGA ZA STUDENTE KOJI STUDIRAJU ILI SU DIPLOMIRALI (N=305)

ANKETNO PITANJE (sadržaj)	% UGLAVNOM VAŽNO	% IZRAZITO VAŽNO
Mogućnosti **stručne prakse** u Hrvatskoj.	34,1	48,9
Podaci o **školarinama poslovnih organizacija.**	37,0	33,8
Reguliranje **zdravstvenog osiguranja.**	31,1	53,8
Mogućnosti **pripravništva** nakon diplomiranja.	29,8	46,6
Mogućnosti **specijalizacije** nakon diplomiranja.	29,5	45,9
Podaci o **tečajevima** koje nude razne organizacije.	35,7	37,0
Prilike za **poslove preko studentskih ugovora.**	29,8	54,1
Ponuda **programa cjeloživotnog obrazovanja.**	29,8	31,8

Podaci dobiveni od 305 ispitanika primjenom papir-olovka ankete podudaraju se s podacima koji su na mnogo manjem broju od 31 ispitanika dobiveni prethodnom primjenom online ankete, premda su u tom prvom probnom online anketiranju sudjelovali u prosjeku malo stariji studenti, a ta skupina ispitanika bila je i dosta drukčije strukture s obzirom na spol i studijske smjerove.

TABLICA III. ODGOVORI NA PITANJA O STVARNOM ILI NAMJERAVANOM KORIŠTENJU POSTOJEĆIH USLUGA E-UPRAVE (N=305)

ANKETNO PITANJE	% VJEROJATNO DA	% SIGURNO DA
Kad mi zatreba **putovnica**, spreman/spremna sam koristiti *uslugu e-uprave* **„e-Zahtjev za izdavanje ePutovnice“**.	31,1	52,1
Ako bih trebao/trebala prijaviti ili tražiti **promjenu boravišta,** to bih izvršio/izvršila putem *usluge e-uprave* **"e-Prijava boravišta hrvatskih državljana"**.	29,5	49,5
Kad bih trebao/trebala **uvjerenje da se protiv mene ne vodi kazneni postupak**, spreman/spremna sam koristiti takvu *uslugu e-uprave*.	30,5	51,5
Za izdavanje/zamjenu **vozačke dozvole** spreman/spremna sam koristiti *uslugu e-uprave* **„e-Zahtjev za izdavanje vozačke dozvole“.**	26,6	54,8
Za dobivanje pravovaljane **domovnice** poslužit ću se uslugom ***e-Matice***.	25,9	58,4
Za dobivanje pravovaljanog **rodnog lista** koristit ću uslugu ***e-Matice*** preko sustava e-uprave.	28,2	58,0
Izvršio/izvršila sam ili namjeravam izvršiti **prijavu na diplomski studij** putem *usluge e-uprave* **"Središnja prijava na diplomske studijske programe"**.	33,4	45,2
Spreman/spremna sam koristiti **mogućnost prijave i pristupa na online tečajeve Srca** *preko sustava e-uprave*.	25,2	44,9

Na kraju, u tablici IV. prikazane su procjene koristi od uporabe sustava AAI@Edu.Hr za anketirane studente. Čak 88,8% ispitanika u papir-olovka anketi smatraju da im je korištenje autentifikacije pomoću tog sustava za pristupanje fakultetskim/sveučilišnim resursima, sustavu e-Građani i Studomatu (sustavu ISVU) „izrazito važno“ ili „uglavnom važno“. Zanimljivo je da bi 64,2% anketiranih željelo zadržati taj identitet za autentifikaciju kod pristupa javnim uslugama barem 5 godina nakon završetka studija. Također, 71,8% studenata izjavilo je da bi im odgovaralo kad bi taj sustav mogli koristiti za prijavu za glasovanje u mjestu studija, bez vraćanja kući tijekom izbora.

TABLICA IV. ODGOVORI NA ANKETNA PITANJA VEZANA UZ PROCJENU VAŽNOSTI POSJEDOVANJA ELEKTRONIČKOG IDENTITETA AAI@EDU.HR ZA STUDENTE PRIJE I POSLIJE DIPLOMIRANJA (N=305)

ANKETNO PITANJE	% UGLAVNOM VAŽNO	% IZRAZITO VAŽNO
Koliko vam je važno to što **imate elektronički identitet iz sustava AAI@EduHr**?	23,6	65,2
Koliko bi vam bilo važno da **još barem 5 godina nakon završetka studija** (prestanka studiranja) **zadržite elektronički identitet iz sustava AAI@EduHr**?	29,8	34,4
Koliko bi vam bilo važno da se *preko sustava e-Građani i putem AAI@EduHr korisničkog računa* možete **registrirati za glasovanje u mjestu studiranja, bez vraćanja kući radi izbora**?	22,6	49,2

VI. ZAKLJUČAK

U zaključnim napomenama prvo će biti odgovoreno na istraživačka pitanja.

1. Koliko studenti koriste ili namjeravaju koristiti standardne usluge e-uprave namijenjene svim građanima Hrvatske?

Odgovor: Prema podacima koji su prikazani u tablici III., čak 70,1% do 84,2% anketiranih studenata odgovaraju sa „vjerojatno da“ ili „sigurno da“ s obzirom na *korištenje ili spremnost na korištenje postojećih usluga e-uprave*: onih koje su dostupne preko sustava e-Matica, „e-Zahtjev za izdavanje ePutovnice“, „e-Prijava boravišta hrvatskih državljana“, potvrda da se protiv građana ne vodi kazneni postupak, „e-Zahtjev za izdavanje vozačke dozvole“ i sl.

2. Kako studenti procjenjuju još nedostupne usluge e-uprave koje imaju druge razvijene zemlje u Europi i svijetu, a Hrvatska e-uprava još nema dostupne te koliko ih smatraju potencijalno korisnima i potrebnima?

Odgovor: Većinu e-usluga za studente koje imaju druge zemlje u Europi i svijetu, a koje nisu dostupne u Hrvatskoj, studenti procjenjuju kao „izrazito važne“ ili barem „uglavnom važne“, i to najčešće u rasponu od približno 60% do 80% anketiranih (vidjeti tablicu I. i II.)

U ovom istraživanju analizirane su e-usluge za studente koje imaju razvijenije zemlje poput Ujedinjenog Kraljevstva, Kanade i Finske. Na temelju dostupnih e-

usluga za studente u tim zemljama napravljena je online i papir-olovka verzija ankete koja je primijenjena na studentima fakulteta jednog hrvatskog sveučilišta. Rezultati analize podataka prikupljenih anketom pokazali su da velika većina studenata prepoznaje važnost postojećih, ali i još nedostupnih e-usluga koje bi im mogle biti korisne, posebno ako bi im bile dostupne preko jednog zajedničkog e-servisa javne uprave kao što je to e-Građani, uključujući s njim povezane aplikacije niže razine.

Iz prethodno navedenih razloga, a na temelju empirijskih podataka prikupljenih putem pilot-istraživanja, autori ovoga rada zastupaju mišljenje da je potrebno, kao i da će biti posebno korisno, u Hrvatskoj nastaviti s razvojem i integracijom e-usluga za studente koje se sada nude na platformama različitih subjekata, od sveučilišta i pojedinačnih fakulteta, do javne uprave, otvorenih pučkih učilišta, udruga civilnog društva i poslodavaca iz javnog i privatnog sektora.

Na kraju, potrebno je naglasiti da se ovim pilot-istraživanjem prvi put ispituje koliko studenti u Hrvatskoj smatraju korisnima i potrebnima različite vrste e-usluga. Također, ovo je anketiranje provedeno na prigodnom uzorku studenata jedne visokoškolske institucije, što je jedno od ograničenja ovog istraživanja. Budućim istraživanjima namjerava se provesti anketiranje na reprezentativnijem uzorku ispitanika koji potječu sa više visokoškolskih ustanova u Hrvatskoj.

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Dedicated Wireless Personal Area Network Specification for Retail Shop Management

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***Abstract*—RFID technologies have been used in retail industry over the last couple of decades. There are many examples of using RFID tags in retail stores as part of retail shop floor management. In this paper we will consider some of the most important solutions that are either being experimented with or already implemented to determine their potential in improvement of customer experience. Data collected through a well-organized RFID system in combination with mobile application can provide invaluable set of dynamic data that can further improve both back office operations and front office operations. Goal of this paper is to analyze the impact of employing this new technology and collected data on established customer experience services such as loyalty programs, promotions and overall customer experience. We propose establishing a dedicated specification that will cater for the information requirements of this type of applications in retail store in higher OSI layers.**

Keywords— RFID technology, Retailing, Technical Standards, Wireless Personal Area Networks, Real-time Location System, Retail 4.0

I. INTRODUCTION

Retail shop management is a part of logistics that has introduced various technological solutions in order to improve efficiency of operations [1, 10]. Some of the most important technologies that are currently being implemented are various wireless technologies such as radio frequency identification technologies (RFID) [9]. There are lot of innovative and experimental implementations covered in current literature, and some of these implementations are being used commercially in some of the most innovative companies. As the benefits of wireless technologies as the information infrastructure continue to be recognized, there is a need for standardization in order to provide additional incentive to service providers in creating dedicated information systems that are specifically designed for particular logistic problem such as inventory management, transportation, and retail management.

In this paper we will present an analysis of implementing wireless technologies in a retail shop floor management setting in order to determine what key features are required to be covered in technical standards in order to provide interoperability of solutions offered to retail companies by the service providers. Based on the described wireless network model and prototype of mobile application we can determine and propose changes and additions to existing protocols that would result in a protocol specifically aimed at retail floor management applications. This specification would include RFID technologies and their complementary technologies as well as personal area network protocols dedicated for retail implementations. Based on the requirements specifications of the protocol derived from the described implementation example possible benefits to the customer experience improvements are also discussed.

The organization of the rest of the paper is as follows: In Section 2 background on key components of the presented systems is given, including wireless personal area networks and standards, as well as key technology – RFID technology and its impact on retail shop management. In Section 3 conceptual model of the overall system is described divided into two main modules: RFID based distributed network system and mobile application for end users. Both models are analyzed and discussed in the following Section, where main properties and requirement for dedicated wireless personal area network protocol specifications are identified and described. Finally, conclusions are given in the last Section of the paper.

II. BACKGROUND

Improving customer experience is one of key topics in retail shop management. Customer satisfaction plays a key role in equity returns of a company [7] and there is ample evidence of positive correlation between customer satisfaction and profitability [3]. In retail industry eliminating queuing times is of fundamental importance as waiting times directly influence level of customer satisfaction. Managing queuing times is just one determinant of customer satisfaction. Some of the others include expedient delivery of goods to customers, impact of marketing actions, adaptive pricing strategies, customer loyalty management, customer relationship management, post-purchase services, etc. Studies also show that these factors affect customer experience in long term [8], and as such are a source of competitive advantage for retailers.

Many retailers have embraced new technologies as means of improving their inventory management, supply chain management, and also shop floor management [10, 16, 17, 18].

Currently, there is a group of innovations that intend to convert simple product tagging within a supply chain using barcodes with smart tagging usually performed by implementing RFID technologies. Many authors have observed that customer experience that is created at the point of contact between retailers and end users is the best time to enhance customer satisfaction and feedback [3, 4, 8]. This is the reason we will focus on the application of wireless technologies in the final stage of retail process – retail shop management.

As the potential of using RFID technology becomes more and more recognized and even commercialized it is important to understand the distinction between various stages of supply-chain management. Contactless identification of bulk items such as palettes is mainly used in earlier stages of supply chain process, production, transportation etc. In the final stages of supply chain management item identification is required. Customer interactions enter the focus of activities. This is why implementing RFID or any other wireless technology in final stages in retailing is different from earlier logistic problems and needs to take advantage of these technologies that are not relevant for earlier stages in a supply chain.

In recent years, various companies tested an array of technologies to achieve streamlined customer experience up to the point of eliminating any queues or even checkout itself [15, 13]. Amazon is one of the first examples of exercising this approach to retail shopping through the use of several technologies such as computer vision, deep learning algorithms and sensor fusion [13] but also RFID, mobile technologies and, consequently, wireless networking technologies.

Wireless personal area networks are computer networks used to transmit data over short distances ranging from as little as couple of centimeters and up to few meters [6]. There are several wireless network technologies that are based on standard IEEE 802.15 such as Wireless USB, Bluetooth, and Zigbee. Some of these specifications are being further developed and enhanced to provide better properties for specific types of WPANs created for a particular purpose. In this paper we consider retail shop management network that can support multiple technologies and devices such as radio frequency identification technologies, near-field communication technologies and WiFi technologies in order to improve real time localization accuracy and enrich data management properties of the specification required by retailing industry.

Finally, key component of the proposed implementation is RFID technology. It is a set of wireless automatic identification technologies, which perform simple tasks of remote data storage and remote data retrieval using tags and readers [12]. Readers act as peripheral units of the enterprise information system that provide data interchange between tagged objects and information system software [5]. Tags are specialized components that are capable of storing limited amounts of data that can be transmitted on demand by the reader component of the system. In order to achieve data transfer, different methods of manipulating electromagnetic fields of RFID tags and readers are used. This is why RFID technologies is already widely used in logistics in ship containers and cargo carriages in trains [19] and inventory management systems [9, 10]. Current case studies and implementations in retail mostly implement passive RFID tags due to their low cost, easy handling and low maintenance cost.

III. Conceptual Model And Requirements Specification

In this section we will describe the concept of implementing wireless technologies as part of the retail shop infrastructure, as well as some of the functionalities that need to be enabled for seamless, effortless and efficient operation.

A. Modelling RFID network for retail shop

Typically, the implementation of an RFID network will be based on one of current specification architectures. Various devices that are used can establish communication depending on the type of RFID technology used from a couple of meters to 10 or 100 meters. In retail applications, as any logistics application problem, there are some organizational circumstances that will influence the optimal choice of technologies and configuration of the system itself.

One of the most important factors is the physical distribution of the network that will depend on the ground plan of the shop. The ground floor is fixed and requires good lightning which can be used for physical arrangement and distribution of RFID readers (Fig. 1).

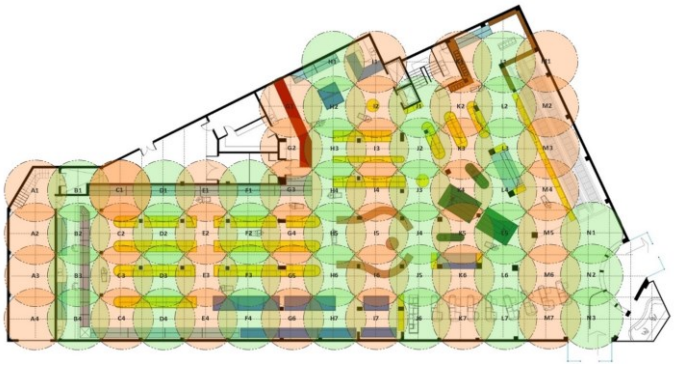


Fig. 1. Ground plan and signal coverage per RFID reader of the proposed implementation network model (*source: authors*)

It is important to note that each reader signal should overlap with adjacent readers' signals to a total of at least 50% in order to enable better performance of micro location of RFID tags in space. There are some restrictive factors such as materials that may decrease the quality of signal, so implementation of several location algorithms is required, such as proximity, ranging, triangulation, or signal strength maps [2, 11]. In addition to these fixed RFID readers, each shopping cart is furnished with a RFID antenna that can keep track of the content of the shopping cart. Fixed RFID readers are used to divide the shopping floor into sectors providing the information about currently available products and their position in space, while the RFID antennas affixed to the shopping cart will provide confirmation of selected and removed products from the shop shelves.

The system will be used to capture data from two types of RFID tag – tags that are used to label products which are

primarily stationary and secondary tags that are used to label shopping carts and are primarily mobile. Tags used to label products will capture data about product handling within the shop while the tags affixed to shopping carts will provide data about the dynamics and movement of customers in the shop space.

As we can see in Fig. 1 lightning fixtures that are already available in the shop space can be used for the distribution of RFID readers in a cost-effective way, by providing optimal position for signal propagation while providing required power to the system. Each reader is connect to the IT infrastructure using integrated wireless modules such as existing WiFi 802.11 connection (if it already exists), or dedicated W-MBus EN13757-4 or ZigBee 802.15.4 a network device with a central processing unit. Depending on the connection type each RFID antenna can transmit its data to server application (using predefined IP address and IEEE 802.11 specification). Some of the raw data include RFID identifier, time, RFID tag identifier (preferably MAC), etc.

In the prototype cloud solution is used for MySQL database that is used to hold the data about each of 75 RFID antennas. This database also receives all the data generated by the system during operation, as well as it stores arriving data about RFID tags and positions (Fig. 2).

```php
<?php

    // Prepare variables for database connection

    $dbusername = "probuyerrfid";  // enter database username
    $dbpassword = "NekiT35tn1!";  // enter database password
    $server = "localhost"; // if acc. local IP "localhost", if online enter address,
    ie."www.probuyer.com", if not on 80 or 8080 exposed ad :PORT

    // Connect to your database

    $dbconnect = mysql_pconnect($server, $dbusername, $dbpassword);
    $dbselect = mysql_select_db("test",$dbconnect);

    // Prepare the SQL statement

    $sql = "INSERT INTO test.RFID (value) VALUES ('".$_GET["value"]."')";
    //...
    //...

    // Execute SQL statement

    mysql_query($sql);

?>
```

Fig. 2. Execution of sample code for accessing MySQL database (*source: authors*)

Described configuration of the system allows for additional redundancy of the system, in order to reduce the number of incorrect localizations of product tags in space, by error detection algorithms or even error correction algorithms that can be implemented using both fixed positions of RFID antennas located in lightning fixtures and mobile antennas contained in the currently mobilized shopping carts. Each algorithm should have at least two layers of redundancy before data can be verified. This is a property of the system that should be used to extend the currently available specification in the application layer of OSI reference model. Processed data about location and content of each tag can then be stored into a data base that can be used for real time analysis to provide interaction with customers or deep analysis that can provide additional insight in the retail operations and improve decision making for the management staff.

In the case of real time analysis data can be returned to tags that have been detected in the shopping cart and flagged as being selected by the customer to enable automated creation of the payment bill, and initiation of payment procedures. Flagged states on product tags, can further be used for dynamic advertising using in-shop display screens that can adjust their sales offers and advertising messages depending on the proximity and line-of-sight of near-by customers in order to maximize the customer response. Finally, combining this information with a mobile application additional services and quality of customer experience services can be offered such as advanced loyalty programs.

B. Prototype of mobile application

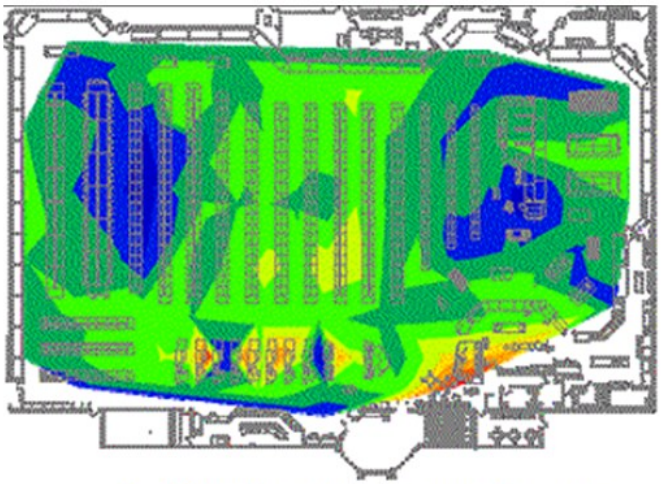
Based on the information that can be provided by the described distributed system a mobile application can use this information to provide customers with additional services and improvements.

Mobile application can make use of common functionalities of a personal mobile device to provide the user with smart services that depend on the current data about the location of product tags in the store. Most mobile devices have near-field communication (NFC) networking capabilities. The application can associate user with shopping cart wirelessly and use the available information infrastructure to offer specific services to the customer, such as plotting route through the store space depending on the items on the shopping list within the application (Fig. 3).

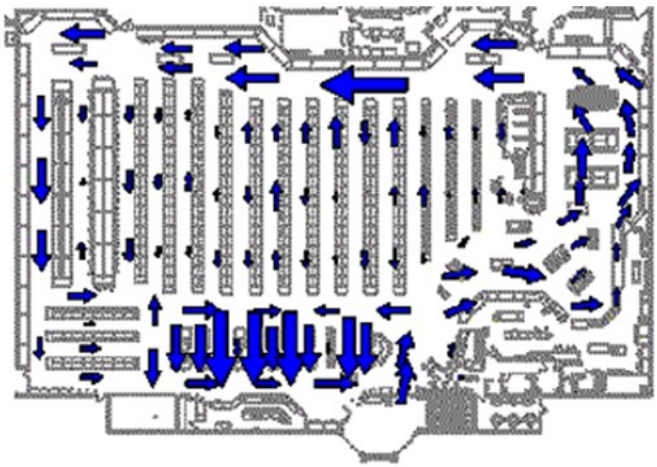


Fig. 3. User interface of mobile app prototype showing location of the user and location of a product from the stored shopping list (*source: authors*)

User can also use the application to create shopping lists, browse products, products on sale and discounts. Application can also generate, and store information required for advanced loyalty program that will track customer visits, preferences and feedback. Using this information special offers can be personalized for each customer according to patterns in shopping habits. Each customized discount that awards customer loyalty can be dynamically flagged using RFID tag associated with the product that the customer removes from the shelf and puts it in the shopping cart. The mobile application will instruct this change in the system and the RFID tag will activate flag in the database denoting special discount for the selected product. In this way the system can be used to implement dynamic pricing strategies that are not time-based as well as implement the best demand driven pricing in physical stores which is currently still rarely available in "offline" stores.



a) Distribution of customers in store space



b) Customer movement and route intensity

Fig. 4. Sample visualization of data retrieved by the RFID based WPAN model using *RSI PathTracker (source: TNS)*

The benefit of using a mobile application for the store management is the possibility to capture depersonalized customer data that can be used to visualize customer habits and movements in store (Fig. 4).

In Fig. 4.a) the locations with highest frequency of customers is shown in yellow and red which means that customers do not stay for long at these places in the store, and lowest values shown in green and blue show places where customer spent more time looking at the products or getting the information about products. This information is generated by tracking the number of product tags that are removed from the shelves. In Fig. 4.b) intensity of movements through the shop space is visualized using shopping cart movement information. This information can be used to optimize the locations of different groups of products in store. If the layout of the store is changed, the information about new locations by product groups can be easily tracked, changed and recorded to product tags using the wireless system. To implement this functionality for all product tags additional specification of the network protocol can allow the application layer to prepare and send the information for each product group using the information infrastructure of the wireless network.

IV. Analysis and Discussion

The described concept can be included as part of the inventory management system, providing this system with additional data. Investment costs with the current state and maturity of RFID technology are no longer proscriptive and in the future will become even less so. The added value from the additional floor management data can improve cash flow and return the investment in acceptably short period, through improvement of sales and efficiency of marketing campaigns. The impact of the system is threefold: (1) Optimization of inventory management, (2) enhancement of customer services and (3) improvement of security policies.

Optimization of inventory management is achieved dynamically in two ways: (a) through monitoring quantities of products on shelves and (b) tracking the demand for each product and product group by monitoring shopping cart content. For each of these approaches data from the product tags and shopping cart tags can be used to activate business rules depending on the current real-time situation in the store. Visualization of the store floor can be used to send information to staff for replenishment of certain products and product groups or indicate products that need to be removed from the shop (e.g. products that are close to their expiry date or other reasons). Finally, compiled historical data about dynamics of the retail shop floor can be used for deep analysis in order to discover new patterns in customer behavior, optimize product placement, etc.

Enhancement of customer services can be achieved by the system in both existing services that are integral part of the customer experience and introduce new innovative services that may further improve customer experience through improved convenience, better product pricing, rewarding customer loyalty and involvement, etc. Existing services can benefit from better availability of product stock in the shop area through better inventory management. Another important way of improving existing services is the removal of waiting times, by automating payment processes through the system of RFID enabled shopping carts. Some of the new innovative services that may positively influence customer experience have already been described earlier, such as dynamic pricing of

products. Also, by implementing an additional mobile application for each interested customer additional cervices based on the RFID sensory network can be offered such as, better navigation through the shop area based on customer query for a particular product or based on the shopping list created by the customer using the mobile app.

Improvements in security can also greatly benefit from a described system. Protection form theft can be improved by tracking tagged products in the coverage area of the RFID network. If a particular product is not readable by any of the RFID readers but have not been placed in shopping cart or paid for, security system or security personnel can be automatically alarmed.

In order to achieve these functionalities, we believe that a dedicated WPAN protocol specification would greatly enhance the implementation of wireless technologies in retail stores. A dedicated protocol and specification that is built on IEEE 800000 and ZigBee can provide additional functionalities that are required to accomplish the described implementation in retail. Here are some of the most important functionalities that these modifications for retail implementations should entail. As noted by [6] specification should incorporate several different technologies such as RFID with passive tags for the core system infrastructure and NFC capabilities to incorporate mobile devices. Higher layers i.e. application layer should specify additional algorithms for data preparation Introduction of additional ways of real time localization algorithms and the requirement of redundant verification of these positions as they are crucial for the operation of the complete system. Another important addition is the handling of RFID tags that contain references to products, as well as operations for modifying tag content, primarily as flagging and de-flagging capabilities. This is the basis for the system of flagging conditions for each RFID tags present in the system. Flagged tag can be used to determine changed conditions such as applied product discounts, out-of-date products, etc. Flagging can support business rules that may trigger the network to access product tags and apply appropriate states. These flagged items can in turn activate applicable rules and dynamically change information for customers displayed in store view screens or mobile application.

V. CONCLUSION

In this paper we have described a model of typical implementation of wireless personal area network in retail shop floor management. The model includes RFID technologies, WiFi technologies and mobile communication technologies.

Even though there is a number of standards dedicated to various types of wireless technologies, we have analyzed the presented network model and described technical and user requirements specific to retailing. According to current level of adoption in retail shop floor management operations and the results of presented analysis a technical specification directed specifically for the purpose of wireless networks in retailing are called for. These standards would provide interoperability of solutions offered to retail companies by the service providers and opened up the market for such products and services.

Some of the key features that should be included in the standard are (1) capabilities of redundant verification algorithms that would assure correct micro locations of products tagged with passive RFID tags, (2) infrastructure based on fixed network of RFID readers and a network of movable RFID readers, (3) standardized flagging of passive RFID tags that can be used to implement various services and improvements that influence customer satisfaction and customer experience, and (4) security requirements that could allow improvements in maintaining protection against product theft, expiration of products and similar applications.

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Electronic Auction in European and Croatian Public Procurement Law

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***Abstract* - Electronic auction is the electronic process of implementation of a part of a public procurement procedure, which enables bid ranking by using automated evaluation methods, and it is recommended when technical specifications of the items of procurement can be accurately determined. We believe that this procurement process, which is envisaged by the EU legislation, as well as Croatian legislation, however, underutilised in the Republic of Croatia. As a consequence, an electronic auction has a very strong market match between the bidders, and thus the lower prices of procurement items. Likewise, this form of public procurement reduces the possibility of misuse. That is why we believe it is necessary to analyze in detail the possibilities of the E-governance, and the practice of its use in order to understand its advantages, which are significant in pursuit of a more transparent and more favorable public procurement.**

Keywords - electronic auction; public procurement; E-governance; automated evaluation methods;

I. INTRODUCTION

Electronic auction (further: E-auction/reverse auction) is an instrument of public procurement in which prices and other elements of tenders are revised downwards. It is an effective technique for negotiating tender prices and achieving cost savings. A substantial part of public investment is spent through public procurement (around €2 trillion per year, representing 14% of EU GDP), and high-quality public services depend on modern, well-managed and efficient procurement. Improving public procurement can yield big savings: even a 1% efficiency gain could save €20 billion per year [1]. In the Republic of Croatia (further: Croatia), the total value of public procurement purchase in 2017 amounted to 40,451,227,766 Croatian kunas without VAT [2]. Also, procurement expenses amount to approximately 13% of GDP on average in OECD countries [3]. Considering the aforementioned amounts, we have decided to explore and evaluate opportunities of using E-auctions in Croatia for savings in public procurement.

Therefore, the aim of this paper is to explore the development and implementation of E-auctions, to determine its benefits and as well as the best practices for its successful application, and to propose *de lege ferenda* solutions to enhance the use of the E-auction technique.

II. E-AUCTIONS IN PUBLIC PROCUREMENT LAW

In the traditional auctions, also referred to as forward auctions, a seller offers a product that is demanded by several buyers who compete and bid up the price. The highest bidder wins and buys the product. On the contrary, in a reverse auction, it is the buyer who is in control of the process. Unlike traditional auctions that occur at physical locations, reverse auctions are accessed online, through web browsers, via private software companies known as "market makers" [4].

According to the Institute for Supply Management, in the procurement context, reverse auctions are: "A type of E-auction that is conducted online, in real-time, between a single buying organization and pre-qualified suppliers. Suppliers compete in presenting bids to the buyer for the supply of goods or services whose specifications for design, quantity, quality, delivery, and related terms and conditions have been clearly defined" [5].

E-auction was introduced into European public procurement legislation in 2004 in the Directive 2004/18/EC [6], while the institute was introduced in Croatia in 2011 [7]. The preamble (14) of the Directive states: "Since use of the technique of electronic auctions is likely to increase, such auctions should be given a Community definition and governed by specific rules in order to ensure that they operate in full accordance with the principles of equal treatment, non-discrimination and transparency. To that end, provision should be made for such electronic auctions to deal only with contracts for works, supplies or services for which the specifications can be determined with precision. Such may in particular be the case for recurring supplies, works and service contracts. With the same objective, it must also to be possible to establish the respective ranking of the tenderers at any stage of the electronic auction. Recourse to electronic auctions enables contracting authorities to ask tenderers to submit new prices, revised downwards, and when the contract is awarded to the most economically advantageous tender, also to improve elements of the tenders other than prices" [6].

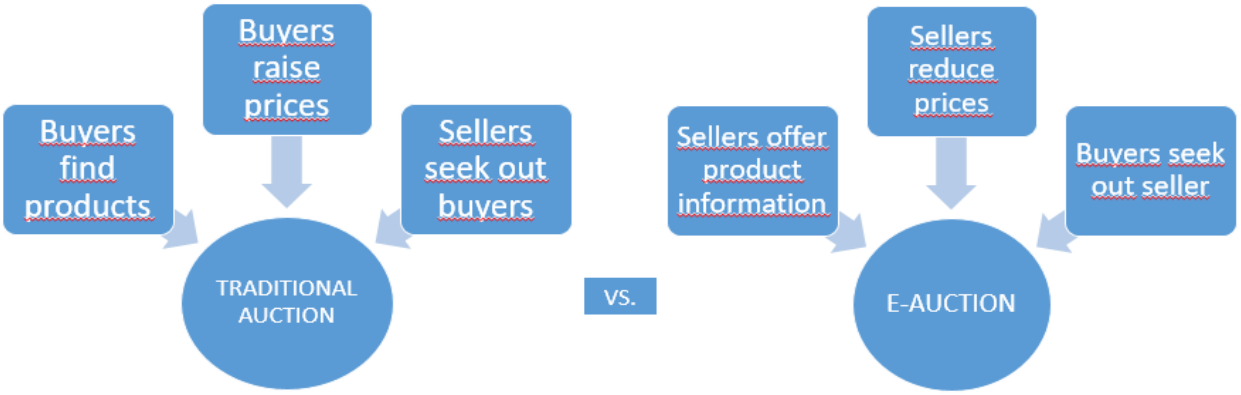

Figure 1. Traditional auction versus E-auction.

The European Union continued to promote E-auctions in other documents: "The Contracting Authorities may decide that the award of a public contract shall be preceded by an electronic auction provided the contract specifications can be established with precision. This allows Contracting Authorities to achieve better offers by suppliers before awarding the contract, while allows suppliers to improve aspects of their tenders. Tenders from all qualified suppliers are already evaluated at this stage, so the purpose of E-auction is to seek for better prices, quality, quantity or other quantifiable aspects of the suppliers' tenders" [8].

The reason why Directive 2004/18/EC introduced E-auction, and why it was actively promoted by the EU in the later period; was due to the early good practice by some of the Member States who launched the E-auction even before 2004, which resulted in visible savings. Table I. shows few positive examples.

What is not mentioned in the table (probably because it would be difficult to compare) which part of the savings is for the electronic application of the electronic public procurement system, which is an E-auction (the right research with the control group would be very difficult to implement). However, one cannot deny that E-auction yields significant savings in the public procurement system.

TABLE I. SAVINGS FROM E-AUCTIONS ON PURCHASING PRICES AND ADMINISTRATIVE COST [9]

DOPI, Denmark (e-auctions)	18% realised savings
National e-Procurement Program, Portugal (e-auction)	25% savings in the purchase of paper supplies for a month
Essex Marketplace (e-auction)	53 % realised savings on goods 26% saving on IT consumables 25% saving on stationery
NHS Purchasing and Supply Agency (e-auction)	31% savings from IT hardware
Wales Health Supplies (e-auction)	10% lower price – projected savings of £600,000 over three years

III. WHY E-AUCTION?

An electronic auction is a repetitive process involving an electronic device for the presentation of new prices, revised downwards, or new values concerning certain elements of tenders, which occurs after an initial full evaluation of the tenders, enabling them to be ranked using automatic evaluation methods. Consequently, certain service contracts and certain works contracts having as their subject-matter intellectual performances, such as the design of works, may not be the object of electronic auctions [10].

E-auction is optimal for the purchase of clearly-defined types of goods, works and services (especially conducted in the construction sector and for procurement of simple goods, such as police cars, firefighting equipment etc.) [11], and where price plays a key role. For example, it may involve the purchase of office or any other consumable material (e.g. hospital supplies, toilet paper), where quality preparation is very important in terms of making the relevant bidding documentation. Tender documentation must be precise, but of course not in a way that promotes a particular producer, or selection criteria or technical specifications include absolutely irrelevant elements.

Specifically, in Croatia, it was noted that in the case of public procurement of toilet paper the technical specifications included the color of the packaging! After this condition was excluded from the tender documentation, the price fell sharply, and in respect to this specific case, the hospital director who discovered this irregularity said: "The most important person for the hospital business is that person or group of people who write technical specifications for public procurement" [12].

E-auction is not optimal for the procurement of very complex goods or services, the type of procurement of a complex machine or very complex works, there are other forms of public procurement [13]. This limitation has long been known: "Electronic auctions can be used under most procedures but because they include automatic evaluation, they cannot be used for certain service contracts and certain works contracts having as their subject-matter intellectual performances (…)" [14]. According to the Art. 35 (1) of the Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC (further: Directive 2014/24EU) certain public service contracts and certain public works contracts having as their

subject-matter intellectual performances, such as the design of works, which cannot be ranked using automatic evaluation methods, shall not be the object of electronic auctions [15]. And the recital 67 states that ''it should be clarified that electronic auctions are typically not suitable for certain public works contracts and certain public service contracts having as their subject-matter intellectual performances, such as the design of works, because only the elements suitable for automatic evaluation by electronic means, without any intervention or appreciation by the contracting authority, namely elements which are quantifiable so that they can be expressed in figures or percentages, may be the object of electronic auctions" [15].

A. Benefits

Why is E-auction a convenient way to purchase typical goods and services for a contracting authority? (Typical services could be easily defined as services with an easily determinable price, e.g. washing per piece or per square meter).

Business entities which have accessed the E-auction and thus become bidders are able to see the prices offered by the other bidders in the application and determine their relative ranking at any stage of the auction, though without a possibility of seeing the identities of the other bidder participating in the search [13, 16]. As a tender gets a bidder who has offered the lowest bid at the given end of the E-auction, in that way other bidders are encouraged to lower their prices, e.g. work with minimal profit margins.

In the countries where the public procurement system is similar to the one in Croatia, the question of the applicability of an E-auction may be raised, and the criterion of the most economically advantageous tender is applied, and it's not any longer only the lowest price. For example, other important criteria which may be negotiated during the E-auction include maintenance, warranties, quality, location, delivery conditions etc. [17]. The theory has long ago solved this question: "The e-auction can be based either solely on prices (whether award criteria is the lowest price or the most advantageous tender) or on prices and/or new values for other features that are indicated in the specification. The features have to be quantifiable and expressed in figures" [14]. The above is provided in the current Croatian Public Procurement Act, in the Art. 174: "(1) The contracting authority is obliged to submit a full initial score of the relevant bid of the individual bidder with the invitation to the E-auction. (2) An E-auction call contains a mathematical formula used in an E-auction to determine automatic change in ranking on the basis of new prices, or new values offered. (3) The mathematical formula contains a weight of all the criteria of the most economically advantageous tender as indicated in the notice used as a means of calling for competition or in other procurement documents, except where the most economically advantageous offer is identified on the basis of price alone'' [18].

Electronic reverse auctions can decrease contracting costs, increase transparency and achieve better economic outcomes as a result of increased competition. It follows that the electronic tendering procedure should be preferred to the traditional tendering procedure due to its clear advantages with respect to transparency. This stems from the fact that under the electronic auction procedure, the danger of having the procuring entity favouring a particular firm by providing it information on other tenders is limited. Under the electronic auction procedure, information on other bids is available to all tenderers in an open and equal manner. Moreover, all bidders are allowed to amend their tender at any time within the limits of the time period. Thus, the electronic auction increases transparency in two levels: (1) information available on other tenders; and (2) the availability of the procedure phases and its outcome to all interested tenderers [19]. Volk also indicates that reverse auctions improve transparency [20].

Like buyers, suppliers can benefit from online auctions in various ways. For example, in traditional auctions, bids are sealed. By contrast, suppliers can alter their bids during an online auction, increasing their chances of winning the contract. They also can bow out of the process at any time. *De facto*, there are many advantages which will enhance the legal principles of fairness, transparency, competitiveness, and cost-effectiveness. The correct use of the aforementioned can lead to substantial savings both in costs and in time. What is also very significant is: E-auction could limit fraud and corruption, only if properly used, it eliminates the possibility for human misuse [21].

B. E-auction challenges

In fact, it is not surprising that suppliers may feel endangered by reverse auctions. Many established suppliers have problems adjusting to on-line arrangements due to the personal nature of the relationship and negotiating tactics they have created with customers over the years. In this way, their relationship is also distanced. Knowledge and fear of technology can also play a role in decision making. By forcing bidders to gradually lower their bids, reverse auctions can reduce profit margins of suppliers and even endanger business sustainability. Some authors claim that E-auctions may harm the buyer-supplier relationship [22] and that it is important to specify qualitative requirements for the E-auction to be successful [23].

Despite the positive reduction of purchasing price for the contracting authority, some unexpected costs may appear: For example, if the selected contractor agreed on performing the public procurement contract after the price was reduced by the E-auction, the contractor may start losing money and have no other choice but to cut quality, as a way to compensate his narrow profit margins. It may be argued that such risks in quality may be secured in the awarded contract (with contractual penalties or judicial remedies). However, such security instruments are not always the optimal approach to enforce quality, especially if the contractor has issues to afford to keep high quality for the agreed price [24].

It might be argued that E-auctions are suitable almost exclusively for the much simpler types of procurement that can be precisely specified. Criteria other than price are not given attention. There is always a potential risk which is present that value for money may be reduced because non-economic factors may also not be taken into account.

IV. BENEFICIAL EFFECTS OF E-AUCTIONS

Despite the fact that the Government of Croatia announced E-auctions will be promoted and adopted in procurement processes [25], E-auctions have not been used and are not used in public procurement purchasing. The use of E-auctions in the European Union is less than 1% in terms of number and volume of contracts awarded [26], and a Portuguese study reveals that E-auctions had a use rate of 0.7% in the period of January 2013 to April 2014 [27]. According to the Croatian statistical report on public procurement, in 2017 E-auctions have not been used at all [2]. Author's research found only two Croatian public procurement procedures that used the E-auction in 2018: one city used the E-auction technique for the procurement of natural gas while another city for electric energy. This statistic is alarming, considering the *supra* mentioned benefits of E-auctions. In order to facilitate the usage of the purchasing technique, this section will analyze positive practices of using E-auction for public (and private) procurement.

E-auction is an objective procedure which should be used in order to attain the best value for money offers cost less, and as such some authors argue that they represent full competition in the market [28].

In particular, during the review of recent publications from different countries, a conclusion has imposed: practical cases have shown possible savings in millions of euros from the state budget/s while using E-auction. On the aforementioned, the work of Singer *et al.* [29] found that estimated benefits (in terms of a reduction in tendered prices) related to the introduction of e-procurement in Chile are slightly below 3%. Similar reduction of prices due to digitalization and electronic auctions are found in the study by Metty *et al*. [30], which has been carried out with data of the Motorola company and reached 3.75%.

Experience in the UK demonstrates that the projected savings can be considerable. A specific case was an online auction for IT hardware (desktop PCs and laptops) for a group of National Health Service Trusts. According to the Office of Government of Commerce, the achieved projected savings were worth around 30% of purchasing costs. On the one hand, electronic auctions are a useful tool for bringing prices down and delivering significant financial benefits, on the other hand, they may only be suitable for the procurement of certain types of products and services [31].

Impact of the electronic auction on the winning price seems to be very indirect. The hypothesis that implies the positive impact of more intense competition; which gives the opportunity to bid during the auction; may be discarded. However, the use of the electronic auctions is connected with an increase of the number of the submitted bids by 0.7, which would mean, if we calculate it roughly, an average decrease of the winning price by approximately 2.4% of the expected price. Therefore, it could be concluded that a proper application of the electronic auction brings an impact on the winning price [19].

Hackney *et al.* also indicate that products in E-auctions tend to be of lower complexity and that E-auctions, when used, drive down the costs of public procurement [32].

One research shows that in Kuwait the reverse auction process, which included five suppliers, generated a 19.9% saving from the lowest initial bid price for 29 power generators prior to the start of the auction [33].

Some authors indicate that potential savings by using the E-auctions for the private sector range from 5% to 30% [34, 35, 36], and that they significantly reduce procurement costs and delivery times [37].

V. PROPOSALS FOR FUTURE REGULATION

This study suggests that usage of E-auctions in the public procurement process should be the next obligatory condition in public purchasing in all Member States. As discussed above, there are many positive benefits provided by the E-auction purchasing technique:

- It enhances financial savings
- It limits corruption and fraud if properly used
- It may encourage competition and tenderer participation in public procurement processes

The paper also discussed several setbacks and risks that are indirectly possible with using the E- auction. However, the evidence above shows that using E-auctions for public purchasing (and private as well) correlates with lower purchasing costs and more transparency of the complete procurement process. E-auctions should, ultimately, encourage more bidders to participate in public procurement processes. Having in mind that the total sum of purchased goods, services and works is 40,451,227,766 kunas without VAT in Croatia and around €2 trillion per year in EU Member States, saving of at least 5% annually is reason enough to further implement the usage of E-auctions.

It should be mandatory in the Public Procurement Act (refers to Croatia and the recommendations should apply to the other Member States too), *semper in omnium casibus*, to apply the E-auction process in open, restricted or negotiated procedures with three (3) or more tenderers who have submitted admissible tenders in cases of:

1. procurement of standardised, simple, and generally available goods (e.g. printing paper, simple medical equipment like syringes or gloves, light bulbs and other high volume standardised mass-produced goods where near-perfect market competition exists) or;
2. procurement of standardised, simple and generally available services (e.g. transport, cleaning or maintenance services).

Reasoning: In the contract notice or in the invitation to confirm interest it should be specified that in all tenders involving three (3) or more tenderers (for procurement of aforementioned "simple" goods and services which could be defined in the Public Procurement Act annex and the Directive via CPV nomenclature), it would be obligatory to use the E-auction purchasing technique and, accordingly, the Directive 2014/24EU should be amended; whereas the Art. 35 (1) and (4) should be modified in according to this principle.

VI. CONCLUSION

This research paper is set out to explore the development and implementation of E-auctions, to determine its benefits and as well as the best practices for their successful application, and to propose *de lege ferenda* solutions to enhance the use of the E-auction technique.

The findings of this study suggest that E-auction is an excellent model of implementation of public procurement procedures. Although it is hard to visualize its usage for procurement of highly complicated technical goods, such as a complex construction machine, the E-auction procedure stands out as an optimal technique for public purchasing of common, "simple" goods and services. In cases of such procurement purchases, the E-auction enables lower prices, competition between tenderers and transparency of the procedure. It is especially suitable for framework agreements when several contracting authorities acquire the same goods or services.

Despite the analysed positives, the E-auction is underused in the Republic of Croatia, as well as in other EU Member States. It is difficult to obtain an accurate and honest conclusion as to why this trend is visible within the EU. It can be assumed that the reason is insufficient knowledge of this purchasing technique (in a typical educational training program in the field of public procurement, electronic auction is being studied for only one school lesson) [38] or some contracting authorities are unwilling to alter their well-known suppliers and relations with them. The statistics indicate that E-auctions are still underused and avoided by contracting authorities. Therefore, we suggest that legislative bodies support the above explained *de lege ferenda* and that the E-auction technique becomes obligatory by the law for public procurement of "simple" goods and services, especially considering the positives of this purchasing technique. E-procurement, to conclude, should be considered as the main tool for reducing corruption and costs while also increasing transparency and thus the efficiency when using public funds.

The legal solution proposed in this paper should not be, however, regarded as final, but as an initial observation and a proposal, which is susceptible to further development.

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Percepcija društveno odgovornog poslovanja kod generacije Z

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***Sažetak* - Kako pripadnici generacije Z, koji su odrasli s IKT tehnologijama od najranije dobi, polako preuzimaju svoj dio u kupovnoj moći, njihovi zahtjevi i navike postaju bitan segment proučavanja u današnjem korisničko-centričnom poslovanju. Kao izrazito „povezanoj" generaciji, društveni mediji čine ključan element oblikovanja njihovog svjetonazora, pružajući transparentnost iskustva i povratnih informacija drugih korisnika, potrebnih u donošenju odluka. Prema istraživanju Sveučilišta Northeastern iz 2014., pripadnici post-milenijalaca, kao još jednog naziva za Z generaciju, vrlo su progresivni po pitanju socijalnih politika, sa sve većim težnjama prema ravnopravnosti svih ljudi, neovisno o seksualnoj orijentaciji te nacionalnoj pripadnosti. To je generacija koju je oblikovala recesija 2008. godine, pojava ISIL-a i porast terorizma. Radom se analizira percepcija društveno odgovornog poslovanja (DOP) kod generacije Z prema prehrambenim trgovinskim lancima u Hrvatskoj, temeljem istraživanja provedenog tijekom lipnja i kolovoza 2018. nad 112 ispitanika godina rođenja između 1995. i 2001. godine.**

Ključne riječi* - *DOP, društveno-odgovorno, poslovanje, trgovački lanci, generacija Z

I. UVOD

U susret novim tehnološkim izazovima, organizacije se sve više okreću naprednim tehnologijama umjetne inteligencije i automatizaciji poslovnih procesa, gubeći pri tome svoju „ljudskost". Ipak, ona postaje sve veći čimbenik konkurentnosti organizacija prema novim generacijama kupaca, zbog čega organizacije se sve više okreću mjerenju novih područja poslovanja, razvijajući nove metrike, poput korporativne empatije, novog pokazatelja uspješnosti poslovanja u odnosu na sve dionike.

Prvi puta postavljena kao indikator za unaprjeđenje korisničkog iskustva 2015. u Harvard Business Reviewu [1], empatija unutar organizacija se počela mjeriti kroz globalni indeks (The Global Empathy Index) u segmentima kupaca ili korisnika, zaposlenika te područja društvenih medija. Daljnja kategorizacija unutar postavljene metodologije uključuje etičnost, vodstvo i kulturu organizacija, percepciju brenda te komunikaciju putem društvenim mreža, a 2016. počinje se bilježiti i ugljični otisak organizacija, kao pokazatelj uspješnosti organizacije na području ekologije.

No, aktivnosti vezane uz tzv. „korporativnu empatiju" i njihovo mjerenje nisu novi koncept na području poslovanja. Pod pojmom društvenog odgovornog poslovanja ova praksa već je dugo dio poslovne etike organizacija. Razmatrana dugo vremena kao svojevoljna politika same organizacije, u posljednje vrijeme ona postaje bitan segment i na višim razinama [2]. DOP tako postaje svojevrsna misija organizacije, vodilja prema potrebama potrošača, nudeći odgovore ne samo na primjenjiva etička pitanja u poslovanju, već i prihvatljive procedure i aktivnosti (ISO 26000 kao prepoznati međunarodni standard).

Današnjim korisnicima sami proizvod više nije dovoljan, već žele i iskustvo kao dodanu vrijednost tijekom kupnje, angažiranost, što DOP može pružiti. Stoga, organizacije trebaju mijenjati svoje prakse i strategije u skladu sa istančanim svjetonazorima novih generacija.

Istraživanje i detaljna analiza podataka objavljeni su kao završni rad suautorice [3] te su isti analizirani radom u odnosu na slično istraživanje provedeno Norveškoj i Francuskoj.

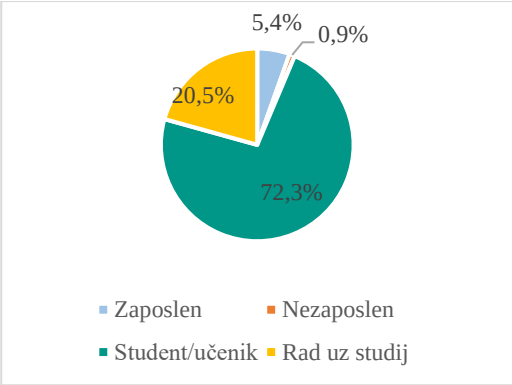
II. METODOLOGIJA I DEMOGRAFIJA ISPITANIKA

Analiza percepcije društveno odgovornog poslovanja kod generacije Z, s naglaskom na prehrambene trgovinske lance, provedena je pomoću online anketnog upitnika nad 112 ispitanika godina rođenja između 1995. i 2001. godine. Prema popisu stanovništva Republike Hrvatske iz 2011. godine [4], u ukupnom stanovništvu generacija Z „zauzima" gotovo 3%; odnosno 2011. zabilježeno je 235 402 stanovnika između 10 i 14 godina starosti, rođenih između 1997. i 2001. godine. Nadalje, broj stanovnika starosti od 15 do 19 godina u 2011. bio je 244 177, od kojeg dio predstavlja Z generaciju provedenog istraživanja (odnosno ispitanike rođene u 1995. i 1996. godini).

Upitnik je sastavljen od 22 pitanja kojima se ispituje dostupnost informacija o društveno odgovornom poslovanju te mišljenja ispitanika o glavnim stavkama kojima bi svaka poslovna organizacija trebala voditi računa vezana uz DOP praksu, kao i osobni stav pojedinih ispitanika prema društveno odgovornom poslovanju, uz glavne utjecaje i razmišljanja koji ih vode prilikom donošenja odluka za kupovinu.

Istraživanje je provedeno u dva vala, od 19.06.2018. do 22.06.2018, te od 14.08.2018. do 16.08.2018., objavom upitnika putem Facebook stranica studentskih domova u Zagrebu, Facebook stranice Tehničkog veleučilišta u Zagrebu te Facebook stranice studenata 3. godine studija informatike Tehničkog veleučilišta u Zagrebu, odnosno generacije 2015/2016.

Uzorak ispitanika sastoji se prvenstveno od studenata (88,4%) ženskog spola (64,3%).



Grafikon 1 Uzorak ispitanika prema radnom statusu

III. REZULTATI ISTRAŽIVANJA I ANALIZA PODATAKA

Daljnja analiza podataka provedena je prema pitanjima koje su podijeljena u tri dijela:

- Pitanja o osobnim podacima ispitanika te informacije o prehrambenim trgovinskim lancima dostupnim u medijima i na društvenim mrežama
- Pitanja o kupovnim navikama ispitanika i o njihovim društvenim navikama općenito
- Pitanja o ispitanikovim stavovima o čemu bi jedan prehrambeni trgovinski lanac trebao voditi brigu u kontekstu društveno odgovornog ponašanja

A. Učestalost, kanali i sadržaji komunikacije

Na početku istraživanja postavljena su pitanja za određivanje učestalosti komunikacije trgovačkih lanaca putem elektroničkih kanala (newslettera, SMS-a, društvenih mreža) prema kojima se 41,1% ispitanika izjasnilo da redovito prima obavijesti istih, od čega je njih 91,3% označilo akcijske cijene i prilike kao primarnu poruku komunikacije. Slijedeći najčešći odgovor vezan uz sadržaj komunikacije je primitak obavijesti o zaštiti i sigurnosti podataka korisnika (45,7%), što je i očekivani rezultat s obzirom da je nedugo prije provođenja ispitivanja na snagu stupila Opća uredba o zaštiti osobnih podataka, a prilikom usklađivanja s istom organizacije su svojim korisnicima slale brojne obavijesti o promjeni politika te postavki privatnosti. Nastavno, obavijesti o podršci organizacije sportu, umjetnosti i/ili obrazovanju označilo je da prima samo 13% ispitanika, dok je obavijesti vezane uz humanitarne donacije te radnje usmjerene k očuvanju okoliša označilo da prima 10,9% za svaku od navedenih opcija. Da prima redovite obavijesti trgovačkih lanaca o ravnopravnosti prema spolovima, rasi, religiji ili invaliditetu prilikom zapošljavanja i plaćama visoko pozicioniranih zaposlenika izjasnilo se samo 2,2% ispitanika. Obavijesti ni o čemu od navedenog prima njih 4,3%.

Nadalje, preko polovice ispitanika, točnije 51,8% njih, ponekad prati objave prehrambenih trgovinskih lanaca i na društvenim mrežama, dok to uvijek čini 10,7%.

Također, 45,5% ispitanika izrazilo je želju za primanjem obavijesti o radnjama prehrambenih trgovačkih lanaca usmjerenim očuvanju okoliša, dok njih 27,7% želi primati obavijesti o humanitarnim donacijama, 25,9% njih o pružanju jednakih prilika prema dobavljačima i prilikom zapošljavanja neovisno o spolu, rasi, religiji ili invaliditetu. 23,2% njih želi primati informacije o zaštiti i sigurnosti podataka, dok je za financijske izvještaje i druge pokazatelje poslovanja te plaće visoko pozicioniranih zaposlenika zainteresirano njih 9,8%.

Ipak, 48,6% ispitanika ocjenjuje da trgovački lanci najviše objavljuju sadržaje za poticanje kupnje, dok rijetko komuniciraju kupcima svoje doprinose na području ekologije. Nešto više ocjenjuju sadržaje vezane uz društveno korisne aktivnosti.

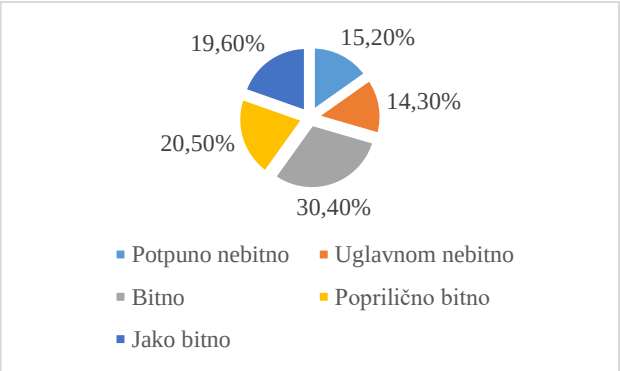
Nadalje, po pitanju zadovoljstva dostupnošću informacija vezanih uz etičnost poslovanja, 95,5% ispitanika slaže se da informacija o etičnosti poslovanja u medijima ili nema dovoljno ili bi ih trebalo biti još i više. Također, njih 83% smatra kako nije niti transparentno, niti u dovoljnoj mjeri prikazan napor trgovinskih lanaca na području DOP-a.

Ovakve informacije ukazuju da su mladi generacije Z zainteresirani za dodatne informacije, ali, također, da tih informacija nema niti približno dovoljno, niti da ono malo što ih ima nisu dovoljno transparentne, tj. ne uspijevaju prenijeti poruku za koju su namijenjene.

B. DOP i izbor trgovaca

U nastavku istraživanja ispitano je u kojoj mjeri neke DOP aktivnosti usmjerene prema potrošaču generacija Z smatra bitnim prilikom izbora trgovine za kupovinu.

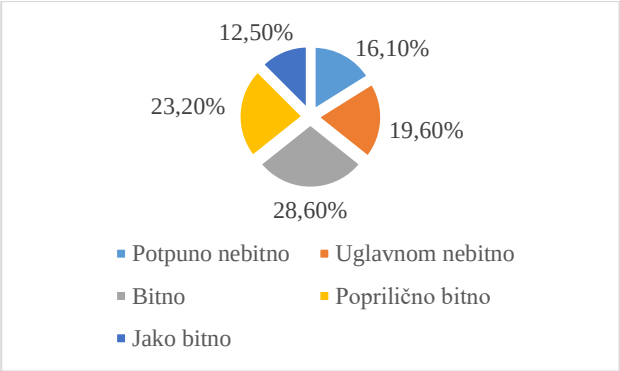
Rezultati su pokazali da u velikoj mjeri bitnim smatraju odnos prema ekološkim praksama trgovaca, prikazano grafikonima 1 i 2.



Grafikon 2 Važnost upotrebe ekološki razgradivih vrećica u trgovačkim lancima

No, prilikom izbora trgovine, ispitanici razmatraju i druge čimbenike.

Najviše ispitanika, njih 65,2%, smatra najbitnijim faktorom da trgovina „nudi dobru vrijednost za novac, što navodi na zaključak kako bi ispitanici bili spremni izdvojiti i više novaca za kvalitetan proizvod. Ipak, gotovo polovica ispitanika, njih 49,1%, vrlo bitnim atributom trgovine je naznačilo niske cijene, dok njih 7,1% taj čimbenik smatra uglavnom nebitnim.



Grafikon 3 Važnost transparentno označene i jednostavne mogućnosti reciklaže otpada u trgovačkim lancima

Nadalje, prilikom izbora trgovine, ispitanici smatraju jako bitnim i veliki izbor proizvoda (53,6%), lokaciju trgovine (50,9%), dobru uslugu (42,9%), čistoću prostora i ljubaznost osoblja (37,5%) te lijep interijer i raspored unutar trgovina (26,8%).

No, koliko zapravo onda pojedini segmenti društvene odgovornosti trgovačkih lanaca zaista utječu na odluke kupovine ispitanika?

63,4% ispitanika izjasnilo se kako bi kupili proizvod s većom društveno odgovornom reputacijom u odnosu na proizvod s istom cijenom i kvalitetom[1]. Polovica ispitanika (50%) slaže se s tvrdnjom da prilikom kupovine u obzir uzima reputaciju trgovine te bi platila više proizvod u trgovinama koje vode brigu o dobrobiti društva. Nadalje, njih 42,9% tvrdi da izbjegavaju kupovinu u trgovinama koje su bile uključene u nemoralne radnje.

U nastavku se ispitivalo koliko su ispitanici socijalno i ekološki osviješteni po pitanjima ponude domaćih, hrvatskih proizvoda, testiranja na životinjama te naplate plastičnih vrećica.

Upravo s naplatom plastičnih vrećica, kao načinom za podizanje svjesnosti o potrebi zaštite okoliša, se slaže 67,9% ispitanih. Ipak, samo polovica njih (50,9%) kod odlaska u kupovinu uvijek nosi vlastitu vrećicu sa sobom.

Što se tiče poticanja kupovine lokalnih ili domaćih proizvoda, njihova ponuda u trgovinama presudna je za 48,2% ispitanika, dok je na to pitanje ravnodušna četvrtina (25%) ispitanika. Za 14,3% ispitanika ponuda hrvatskih proizvoda nije bitan faktor prilikom odabira trgovine.

Testiranje na životinjama u proizvodnom procesu kod većine ispitanika (35,7%) ne utječe na kupovinu.

C. Angažiranost ispitanika

Definicija društveno odgovornog potrošača postavljena je još 1975. godine kao „potrošača koji uzima u obzir društvene posljedice vlastite privatne potrošnje ili koji pokušava iskoristiti svoju kupovnu moć kako bi doprinio pozitivnom učinku društvenoj promjeni“[5]. Nadalje, ponašanje društveno odgovornog potrošača definira se njegovim stjecanjem, korištenjem i raspolaganjem proizvoda na način da se minimiziraju ili eliminiraju štetni utjecaji ili maksimiziraju dugotrajni povoljni utjecaji na društvo [6].

Vezano uz odgovornost, odnosno društvenu angažiranost ispitanika, rezultati pokazuju kako bi 46,4% ispitanika radije platilo više za proizvod koji je proizveden odgovorno, što nije slučaj za četvrtinu (25%) ispitanika, dok je ravnodušno njih 28,6%. Također, 24,1% ispitanika smatra da njihova društveno odgovorna kupovina ne može napraviti nikakvu razliku, dok se njih 31,1% niti slaže, niti ne slaže s tom tvrdnjom. Unatoč tomu, većina, odnosno 44,7% ispitanika, vjeruje da njihove akcije mogu napraviti razliku.

Ipak, rezultati su drugačiji kada se radi o aktivnostima trgovačkih lanaca prema zaposlenicima. Na pitanje o voljnosti promjene prehrambenog trgovinskog lanca u slučaju spoznaje da se isti prema zaposlenicima odnosi nepošteno i/ili nehumano najveći broj ispitanika (67,9%) u tom slučaju postupilo bi ovisno o situaciji, tj. ovisno o tome koliko su im drugi čimbenici važni kad razmišljaju o samom prehrambenom lancu. Samo 17,9% njih bi odmah promijenilo prehrambeni lanac, dok kod 7,1% ispitanika ne bi utjecalo na njihovu buduću kupovinu. No, isti broj ispitanika tvrdi i da bi poduzelo nešto unutar vlastitih mogućnosti u vezi toga, no ne bi mijenjao prehrambeni lanac.

Ispitujući navike ispitanika u nastavku, rezultati pokazuju kako od 112 ispitanih, njih 56,3% odvaja i reciklira otpad kod kuće, 48,2% limitira svoju potrošnju električne energije i plina za smanjenje svog negativnog utjecaja na okoliš, 47,3% izbjegava korištenje automobila ukoliko je moguća upotreba javnog prijevoznog sredstva ili bicikla.

Nadalje, njih 35,7%, izbjegava proizvode proizvedene uporabom ekološki opasnih supstanci, dok se 14,3% ispitanika nastoji snabdijevati u trgovinama koje brinu o ekološkim pitanjima, a trgovine koje sponzoriraju lokalni sport, škole ili kulturne događaje svojom kupnjom „podržava“ 12,5% ispitanika. Samo 8,9% ispitanika tvrdi kako nastoji kupovati proizvode koji ostavljaju povoljan ugljični otisak.

U posljednjih 12 mjeseci 44,6% ispitanika izjasnilo se da je kupilo proizvod s društvenom ili ekološkom koristi, njih 26,8% doniralo je novac, a 20,5% njih je volontiralo. Također, njih 15,2% istražilo je način poslovanja neke kompanije, dok je njih 11,6% bojkotiralo trgovinu ili proizvod saznavši da je proizveden na društveno neprihvatljiv način ili je trgovina sudjelovala u neodgovornim radnjama.

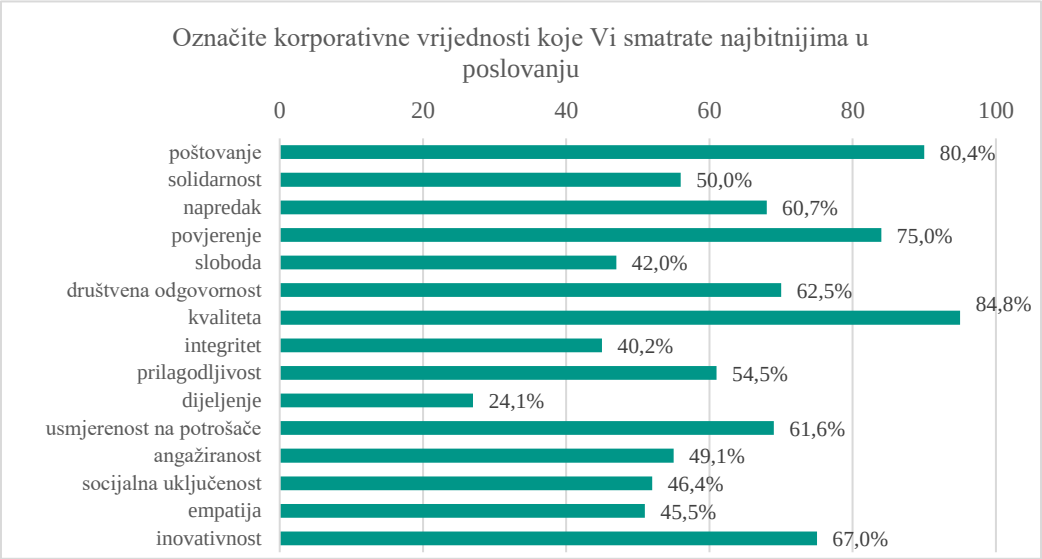
D. DOP stavovi ispitanika i trgovački lanci

Visoka svjesnost prema socijalnim pitanjima generacije Z iskazana je pružanjem jednake prilike kod zapošljavanja, što bitnim smatra 91,9% ispitanika. U usporedbi s rezultatima već spomenutog istraživanja „2017 Cone Gen Z Study: How to speak Z“ su dobiveni su podaci da generacija Z među Amerikancima, starosti od 13 do 19 godina, daje potporu kompanijama koje podržavaju raspon problema od rasne jednakosti (88% ispitanih), prava žena

1 Ove rezultate se može staviti u odnos s onima dobivenim istraživanjem „2017 Cone Gen Z Study: How to speak Z“ koje je ispitivalo Amerikance u dobi od 13 do 19 godina, a koji navode da bi čak 92% ispitanih kupilo drugi brand/proizvod ukoliko taj ima društveni odgovornu reputaciju te je cijena i kvaliteta slična [7].

(86% ispitanih), imigraciju (81% ispitanih), LGBT(Q) prava (65% ispitanih) [7], iz čega proizlazi da se i generacija Z u Republici Hrvatskoj ne razlikuje u tom aspektu.

U nastavku, prilikom ispitivanja bitnih korporativnih vrijednosti za pripadnike Z generacije, dobiveni su rezultati prikazani grafikonom 4.



Grafikon 4 Važnost korporativnih vrijednosti za pripadnike Z generacije

Naredno su se istraživali stavovi ispitanika o radnjama koje kompanije trebaju činiti prema zaposlenicima i društvu. Tako mogućnost usavršavanja zaposlenika i nadogradnje znanja, kao osnovu za daljnji profesionalni razvoj smatra vrlo bitnim 88,4% ispitanih, dok se 77,7% ispitanika slaže kako je bitno da kompanija svoje strateške ciljeve pokušava ostvariti poboljšavajući društvo i zaštićujući okoliš. Stoga, ne iznenađuje da se veliki broj ispitanika (66%) izjasnio da kompanija ima društvenu odgovornost iznad stvaranja profita te da kompanije trebaju „vraćati natrag zajednici“ koja im je omogućila uspjeh ulažući u istu (64,3%). Naposljetku, s tvrdnjom da se „cjelokupan uspjeh kompanije može odrediti po tome što ona radi za društvo“ slaže se većina ili 61% ispitanika. Kako je 56,3% ispitanih izjavilo da odvaja i reciklira otpad kod kuće, ne iznenađuje da je 46,4% ispitanika jako bitnim označilo upravo reciklažu kao segmentu poslovanja kojem se trgovački lanci trebaju posvetiti.

Ipak, iako se 66% ispitanih složilo da kompanija ima društvenu odgovornost iznad stvaranja profita, njih 90,2% smatra profit bitnim aspektom kojem bi kompanija trebala pridavati važnost

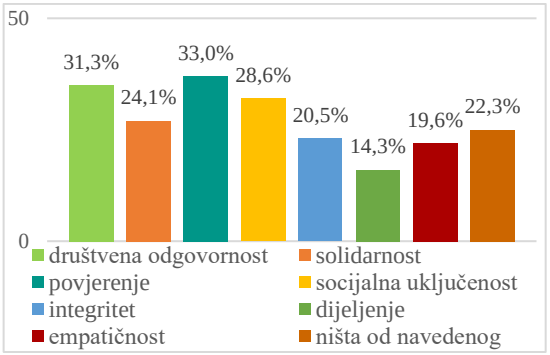
Rezultati za ostale ispitane stavke prikazani su u tablici 1.

E. Asocijacija korporacijskih vrijednosti i poznatih prehrambenih trgovinskih lanaca u Republici Hrvatskoj

Prema istraživanju tržišta trgovine na malo u 2017. godini Agencije za zaštitu tržišnog natjecanja [8], u Republici Hrvatskoj najveći tržišni udio zauzima trgovački lanac Konzum grupe Agrokor (20-30%), a slijede ga Lidl i Kaufland Schwartz grupe te Plodine sa udjelom od 10-20%. Od ukupno 38 trgovina, na 5. mjestu je Spar te ga slijedi Tommy sa 5-10% udjela te su među prvih 10 prema udjelu svrstani i Studenac, K.T.C., NTL i Lonia sa tržišnim udjelom manjim od 5%.

Tijekom istraživanja ispitanicima u odgovorima ponuđene opcije odabira poznatih prehrambenih trgovinskih lanaca u Republici Hrvatskoj (Konzum, Plodine, Lidl, Kaufland, Tommy, (Inter)Spar, NTL) u odnosu na već ispitivane korporacijske vrijednosti (društvenu odgovornost, solidarnost, povjerenje, socijalnu uključenost, integritet, dijeljenje, empatičnost) kako bi se ispitale asocijacije koje ispitanici imaju na pojedine trgovačke lance.

Budući da je tvrtka Lidl Hrvatska u 2017. godini sedmi put za redom dobitnica priznanja Certifikat Poslodavac Partner [9] kojim se potvrđuje pozitivna praksa na području zapošljavanja i upravljanja ljudskim resursima grafikonom 5 izdvojene su korporacijske vrijednosti i njihovi omjeri u percepciji Z generacije.



Grafikon 5 Lidl i korporacijske vrijednosti

Za ostale trgovačke lance prikaz pojedinih DOP aspekata prikazan je u tablici 2.

TABLICA 1 PRIKAZ VAŽNOSTI POJEDINIH DOP ASPEKATA ZA POSLOVANJE

	Potpuno nebitno	Uglavnom nebitno	Bitno	Poprilično bitno	Jako bitno
Zaštita okoliša	2,7%	6,3%	29,5%	25%	36,6%
Redukcija zagađenja	2,7%	6,3%	25,9%	24,1%	41,1%
Zaštita životinja	5,4%	7,1%	27,7%	23,2%	36,6%
Ulaganje u očuvanje resursa	3,6%	2,7%	28,6%	28,6%	36,6%
Fair-trade trgovina	3,6%	3,6%	33,9%	25,9%	33%
Jednakost prilika	1,8%	2,7%	25%	25%	45,5%
Donacije lokalnim zajednicama	7,1%	20,5%	31,3%	22,3%	18,8%
Ušteda troškova	6,3%	8,9%	27,7%	32,1%	25%
Nove tehnologije	1,8%	7,1%	25%	31,3%	34,8%

F. Autentičnost DOP aktivnosti u percepciji ispitanika

Na kraju istraživanja nastojalo se ispitati koliko ispitanici, odnosno generacija Z, vjeruju u tvrdnje o DOP radnjama s kojima se susreću.

U velikom broju ispitanici, njih 85,7%, su se složili da smatraju da prehrambeni lanci sve inicijative provode s ciljem stjecanja korporativne dobiti te uspješnog marketinga, dok samo 14,3% ispitanika vjeruje da prehrambeni trgovinski lanci uistinu žele doprinijeti dobrobiti društva.

TABLICA 2 VAŽNOST POJEDINIH KORPORACIJSKIH VRIJEDNOSTI

	Konzum	Plodine	Kaufland	Tommy	(Inter)Spar	NTL
društvena odgovornost	2,7%	6,3%	16,1 %	4,5%	13,4 %	4,5%
solidarnost	8%	17%	15,2 %	6,3%	17,9 %	8%
povjerenje	2,7%	16,1 %	29,5 %	9,8%	25%	10,7 %
socijalna uključenost	17,9 %	9,8%	10,7 %	5,4%	2,7%	0%
integritet	8%	20,5 %	8,9%	8%	16,1 %	5,4%
dijeljenje	3,6%	9,8%	13,4 %	3,6%	9,8%	6,3%
empatičnost	4,5%	2,7%	8%	3,6%	8,9%	10,7 %
ništa od navedenog	54,5 %	48,2 %	42,9 %	64,3 %	36,6 %	64,3 %

IV. USPOREDBA SA ISTRAŽIVANJEM U FRANCUSKOJ I NORVEŠKOJ

Loussaïef et al. [10] su proveli slično istraživanje u Norveškoj i Francuskoj, nastojeći utvrditi koliki je utjecaj društveno odgovornog poslovanja na mlade od 18 do 25 godina, tj. kakva je njihova percepcija istog pretežno u prodajnom sektoru, prehrambenim lancima. Kao definiciju socijalne odgovornosti kod kompanija uzeta je potreba inkorporiranja potreba i vrijednosti ciljnih grupa, investitora, zaposlenika, kupaca, dobavljača, javnih organizacija u strateške i operacijske procese donošenja odluka, a istraživanje je provedeno putem intervjua na uzorku od 8 studenata prvo u Francuskoj te zatim na 8 studenata u Norveškoj.

Francuska mladež upoznatija je s pojmom održivog razvoja (Sustainable development - SD), nego s društveno odgovornim poslovanjem (DOP) te se taj pojam uglavnom koristio prilikom provođenja istraživanja u Francuskoj. Održivi razvoj se može definirati kao pristup kojim se zagovara važnost poštovanja prema okolišu, socijalna jednakost te ekonomska profitabilnost kao ujedinjeni cilj za dugotrajni razvoj i sinergiju društva. S druge strane, norveškoj mladeži pojam DOP je bio poznatiji te se uglavnom on koristio tijekom razgovora. Intervjuima su se ispitivali asocijacijski pojmove za DOP ili SD, što je kod Francuza automatski rezultiralo asocijacijama na ekološki aspekt društvene odgovornosti, ali su potpitanjima dobivene i asocijacije vezane uz socijalne i ekonomske aspekte, dok je norveška mladež automatski izrazila asocijacije za sva tri aspekta.

Promatranjem ekološkog aspekta DOP-a istraživanjem se dobio najveći broj asocijacija u obje zemlje za redukciju zagađenja i zaštitu okolišu (91,1% ispitanika) te reciklažu (93,7% ispitanika). Od ostalih stavki društveno odgovornog poslovanja mladi u Francuskoj i Norveškoj su još spomenuli i organske proizvode te energetsku ekonomiju. Francuzi su još istaknuli i nove materijale, zaštitu voda, energetske kompanije, planet bez granica, zelene političke stranke kao bitne pojmove i aspekte očuvanja okoliša, dok su Norvežani istaknuli poštovanje prema prirodi, zaštitu životinja (koje u RH 87,5% ispitanika generacije Z smatra bitnim), ulaganje u očuvanje resursa (koje u RH 93,8% ispitanika generacije Z smatra bitnim), etička pravila ulaganja povezana s okolišem.

Slijedeće su ispitivali asocijacije na socijalni aspekt djelovanja trgovačkih lanaca. I u Francuskoj i u Norveškoj ispitanici su u najvećem broju spomenuli bolje uvjete rada u zemljama trećeg svijeta, *fair-trade* trgovinu, koju bitnom smatra 92,8% ispitanih u RH, te dijeljenje među generacijama i poštovanje ljudi. U Francuskoj ispitanici su još spomenuli i skladnost, jednakost prilika (koju 95,5% pripadnika Z generacije u RH smatra bitnom), orijentiranost na ljudski faktor, različitost radne snage, pravdu, jednakost među zemljama, dok su u Norveškoj izrazili protivljenje radu djece te spomenuli etičke poslovne principe te donacije lokalnoj zajednici i školama (koje u RH većina od 27,6% ispitanih označila nebitnim) te etička pravila za ulaganje u socijalne probleme (mirovine) i razvoj lokalne zajednice.

Ekonomski koncept nije rezultirao nikakvim zajedničkim asocijacijama kod Francuza i Norvežana., već su im stavovi različiti. U odnosu na istraživanje provedeno u RH, Francuzi isto smatraju nove tehnologije bitnima, dok Norvežani, isto kao i Hrvati, smatraju profit bitnim aspektom kojem bi kompanija trebala pridavati pažnju.

Baš kao i hrvatski, ispitanici u obje zemlje složili su se da je zamjena plastičnih vrećica s ekološki prihvatljivijim vrećicama važan korak društveno odgovornog poslovanja, a jednako se slažu i oko motiva trgovačkih lanaca za provođenje DOP aktivnosti. Ispitanici iz Norveške i Francuske, zajedno sa 85,7% ispitanika iz Hrvatske, slažu se da prehrambeni trgovinski lanci nemaju totalnu posvećenost DOP akcijama, već da ulažu u iste zbog povećanja profita te uspješnog marketinga. Vezano uz komunikaciju i transparentnost DOP aktivnosti trgovačkih lanaca, u Francuskoj se mladi žale na nedostatak vidljivosti DOP akcija, dok Norvežani smatraju da trgovci ne ulažu veliki trud u podučavanje kupaca o svojim DOP radnjama, što su potvrdili i pripadnici Z generacije u Hrvatskoj.

V. ZAKLJUČAK

Analiza dobivenih podataka percepcije društveno odgovornog poslovanja kod generacije Z u Hrvatskoj pokazala je kako informacija o društveno odgovornom poslovanju trgovačkih lanaca nema u dovoljnoj mjeri u medijima te da se vezane aktivnosti ne prikazuju dovoljno transparentno. Kao jedan od pokazatelja odgovornosti i korporativne empatije, i vodeći magazin maloprodajne prakse u SAD-u *Chain Store Age* je označio DOP kao „vodeće pitanje našeg vremena“ [11], nastojeći navesti upravo prehrambene trgovinske lance da postanu aktivniji, transparentniji u svojim društveno korisnim radnjama. Upravo radi novih potrošača – generacije Z koja, kako je i potvrdilo istraživanje, želi biti informirana te osviještena o pitanjima društvene odgovornosti.

U više navrata ispitanici su potvrdili podržavanje naplate plastičnih vrećica te, općenito, svoju osviještenost ekološkim pitanjima, dok se od socijalnih pitanja najviše zalažu za jednakost prilika, *fair-trade* trgovinu, kao i za ulaganja: u zajednicu koja im je omogućila razvoj te u svoje zaposlenike. Nadalje, iskazali su da su društveno odgovorni potrošači jer većina reciklira kod kuće te se trude kupovati društveno odgovorne proizvode, no još uvijek ima onih koji ne vjeruju da njihova kupovina i akcije mogu napraviti značajnu razliku.

Ipak, najveći razlog za brigu od strane prehrambenih trgovinskih lanaca je podatak da generacija Z ne vjeruje da oni provode DOP radnje za dobrobit društva, već isključivo za svoju korporativnu dobit.

Provedeno istraživanje može biti ishodište za dodatno, podrobnije ispitivanje stavova o DOP aktivnostima ne samo prehrambenih trgovačkih lanaca, već i organizacija u drugim industrijama, dok su i daljnja istraživanja o stavovima mladih o socijalnim i ekološkim pitanjima dobrodošla.

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An Overview Of Security Challenges Of Seaport IoT Systems

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***Abstract* - Introduction of Internet of Things (IoT) and accelerated digitalization have globally improved productivity of seaports. The underlying problem of IoT is data vulnerability, and the effects are very pronounced within the complex business processes that take place in seaports. The main consequences of the unprotected connected devices are unauthorized access, theft of important information, and loss of information control. In the future, new vectors of intrusions will be developed, and it is important to anticipate possible weaknesses. Furthermore, IoT data must be continuously backed up in remote locations, which would facilitate the prevention of irrecoverable loss of data. Some seaports, where large volume of traffic is present, demonstrate that it is possible to utilize IoT advantages after the correct implementation and monitoring of the entire system, while minimizing errors or consequences of security attacks.**

Keywords - Internet of Things, Seaports, Security systems

I. INTRODUCTION

With the development of international trade and globalization, it is possible to notice the tendency of the traffic and cargo increase, so numerous seaports were compelled to accept changes in the transport sector and turn to more effective practices by introducing the Internet of Things (IoT) in their own seaports. The IoT can be considered as "the novel generation of Wireless Sensor Networks (WSN) and it represents a network composed of heterogeneous sensing devices, connected together over the Internet, to acquire information and forward it to a center of collect (base station)" [1]. The main goal of digitalization is to speed up business processes but also to reduce environmental pollution which is increasingly being regulated by the "green laws". "The most obvious benefit of IoT connectivity lies in how it can transform day-to-day operations at sea, at port and as part of a wider logistics network: issues can be pinpointed, downtime can be reduced, and processes can be streamlined, changing the face of the maritime industry as we know it" [2].

Adequate security levels are required in ports, with respect to the facilities and assets they utilize. Therefore, the infrastructure and access to the restricted areas should be monitored [3]. The main concern is directed towards consequences, security of the system and possible solutions after attacks which occur more often as density of devices increases. If the focus is only on benefits of IoT, assuming that security is maximized, huge advantages can be noticed: effective monitoring of operations concerning the vessels, timely reactions and speeding up of overall business processes.

II. SECURITY AS A BASIS FOR SUCCESSFUL DIGITALIZATION OF PROCESSES AT THE SEAPORTS

The Internet of Things represents the digital, or "smart" connection of objects using RFID sensors, Wi-Fi, Bluetooth and other "smart" protocols in order to accelerate business processes. By 2020, there will be about 26 billion devices connected to the Internet [4]. The maritime industry, due to the digitalization process, comes out of its traditional frameworks by creating solutions to improve the productivity and the sustainability of logistics [5].

The goal of IoT is facilitating planning and management of business processes by introducing modern information technologies. Preventive security mechanisms are needed to ensure the entire network implemented by protocol such as: "managing identity devices, entering and controlling a device access and monitoring" [6].

Figure 1 [7] shows the global number of connected Internet of Things devices (in billions) from 2016 to 2024 (projected).

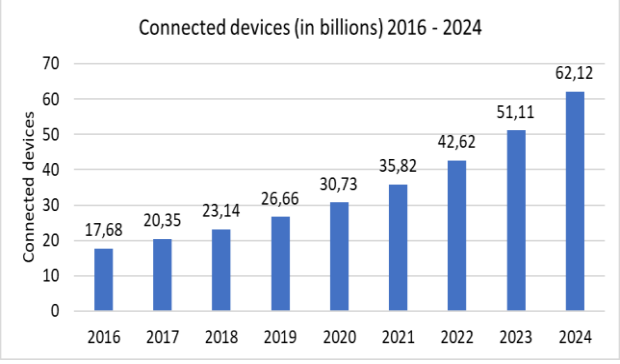

Figure 1: Connected devices in billions 2016 – 2024 [7]

Security and privacy are main issues because connecting various devices to the Internet opens the possibility of unauthorized access and control as well as theft of valuable information.

From the figure, it is possible to see the growth of the connected devices. In 2016 there were 17.68 billion networked devices, while by 2018 the number grew by 2.6 billion [7]. An additional growth of connected devices is forecasted, and by 2024, connection of about 62 billion additional devices is expected, 39 billion more than in 2018.

According to the Internet Society, overall system security is as good as its weakest connection because various components can be controlled by different actors in different jurisdictions (e.g. a server may be located in one country, while the device may be manufactured in another, and in use in yet another), making it more difficult to cooperate while solving security issues [8]. According to Statista, an investment in the endpoint security amounted to US $ 302 million in 2017 [7]. It is also predicted that $ 631 million will be invested in end-point security for affiliated devices in 2021, while $ 415 million will be invested in the access points, which is 216 million less than the 'end-point investment. From 2016 to 2021, the trend of the security investment will be on the rise, given that security is the basis for the undisturbed functioning of the system of interconnected devices.

The classification of IoT architecture related to security consists of 4 layers, as shown in Figure 2, and each of them has its own security issues [9].

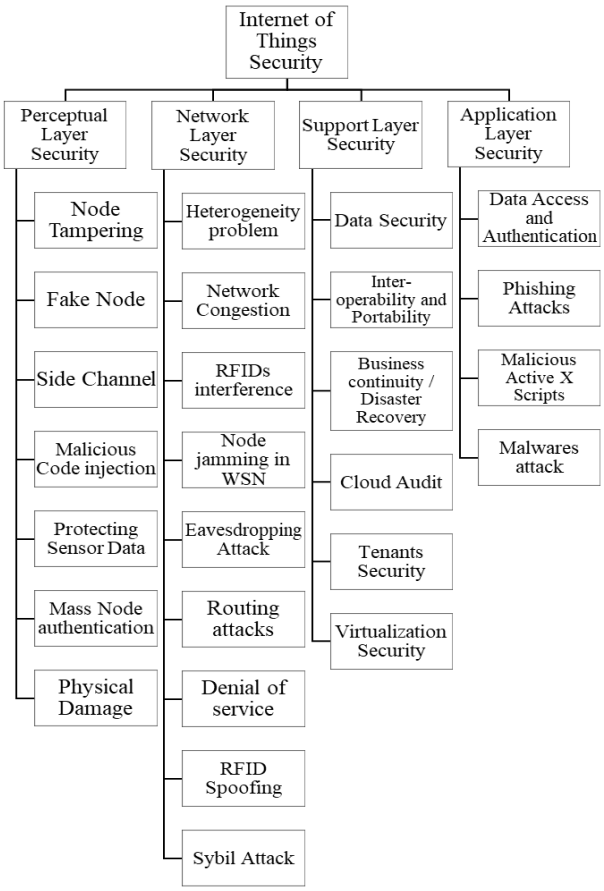

Figure 2: IoT security and attacks [9]

Basic IoT security problem is caused by the fact that the connection runs in two directions: the device can send data to the cloud and take the information from the cloud. If this basic connection is compromised, there will be immense security issues.

There are several basic characteristics of the attacks related to IoT architectures [9].

- Perceptual layer consists of resource constrained IoT devices i.e. Sensors, RFID tags, Bluetooth and Zigbee devices.
- Many types of network attacks like eavesdropping attack, DoS attack, Man in the Middle attack, and virus invasion are still affecting network layer.
- Support Layer Security hosts IoT user's data and applications so both should be protected from security breaches.
- Data sharing is one of the characteristics of IoT application layer.

In a study commissioned by Inmarsat (the world leader in global mobile satellite communications) and presented at the Press Briefing during the international shipping exhibition "Posidonia" in 2018, the following question was asked: "How mature is the maritime sector's approach to the IoT security?" The answers were [10]:

- The cyber security fears focus on inward-facing matters such as data storage (55%)
- 53% believe that more security skills would help deliver IoT based solutions.
- 87% believe that data mishandling processes could be improved

III. MEASURES FOR PREVENTION OF THE IOT SECURITY THREATS

Michael Sentonas (VP and Global Chief Technology Officer at Security Connected for McAfee) has outlined the biggest threats to information and digital security that threaten business security in seaports [11]:

- The attacks on devices (IoT): confidentiality of information would be com
- promised in ports, i.e. business processes or designs that are key for the competitiveness of the port itself. The problem arises when governments and companies cannot agree upon a definition what is an authorized data access.
- Ransomware and Mobile Malware - this kind of attack is on the rise, and in today's business, seaports are trying to utilize faster ways of exchanging information by introducing tablets or mobile devices that speed up business processes among stakeholders. Over time, threats to mobile devices will quickly increase, as new mobile technology spreads the attack surface.

In order to transfer data between nodes safely, it is necessary to create "lightweight cryptographic algorithms". This will ensure the confidentiality of data

between the nodes [9]. When the device/network is compromised, cybersecurity teams must instantly take the following measures [12]:

- Cybersecurity teams must be ready to react at any time to minimize the damage and ultimately stop spreading ransomware within the IoT network.
- It is necessary to install current and secure software that will monitor the security of the IoT network.
- In order to prevent file recovery costs, data should be stored in the secure data storage.

Fortinet's 2014 survey of Australian CIOs showed that 88% of CIOs and IT decision-makers (ITDMs) noticed the increasing frequency and complexity of threats, as well as the new demands of emerging technology like the Internet of Things (IoT) [11]. According to the survey, 53% of all ITDMs surveyed have slowed down or cancelled a new application, service, or other initiative because of cyber-security fears.

In a recent Check Point Study (2018), involving 850 organizations, it has been found that each of these organizations have faced an attack (mobile malware); 94% of security experts expect the number of mobile malwares to continue to increase; most of these malwares comes from third parties but are found and embedded in applications that have been sold through the application store [13].

Complex supply chains make security assessments more challenging, requiring holistic approach, while providing coordination among different sides and system components. IoT systems are controlled and interactively managed by "cloud" services rather than being controlled locally.

California is an example of the US state introducing a law for regulating IoT, as a first concrete step in the fight against security threats caused by increased connectivity of the devices. Earlier, the use of IoT was largely self-regulated, or regulated by the best practices of the industry. Law on safety-related devices aims to equip the devices with a security feature or features that are appropriate for the nature and function of the device, appropriate to the information that they may collect, contain, or transmit [14]. It is also designed to protect the device and all information contained therein from unauthorized access, destruction, use, and modification.

IV. CONSEQUENCES OF CONNECTING THE DEVICES (IOT) AT THE SEAPORTS WITH EMPHASIS ON THE SECURITY

According to TechRepublic, an online trade publication and social community for IT professionals, the Internet of Things (IoT) continues to grow as a prime target for cybercriminals to exploit, and according to a new threat report from Symantec security company, the number of IoT attacks has increased from about 6,000 in 2016 to 50,000 in 2017—a 600% rise in just one year [15]. According to SIA partners and their case study "The Internet of Things in Transportation" (2016), connecting things to the Internet presents a potential security and privacy problem because of the unauthorized access, the theft of information and the control over them [16].

Gamundani [17] has classified the threats and consequences of IoT into four categories:

- Application based: Each seaport should have surveillance cameras as one of the security measures which should be placed in the position with maximum coverage. But in the case of burglary, the camera cannot provide the detailed information about the method or mechanism of information theft or misuse. Therefore, in order to facilitate data protection, additional studies and methods are required. More advanced IoT cameras that would prevent adverse consequences are required and they ought to be equipped with intelligent cloud-based sensors, such as heat sensitive sensors.
- Connection based: Connecting things to the Internet is based on IP network and if its security is not closely monitored, the entire IoT network can be compromised.
- Platform based: "Wireless sensor network has pending issues to be addressed which comprise of applications like communication platforms, security and management". As with the connectivity problems, there is a problem with the communication platform as well - the more connected devices, the more possible attacks.
- Other forms of attack: "Combining application and platform-based threats, gives an intertwined force of challenges that leaves the whole security ground weakened, hence proper thriving of IoT applications is endangered".

The consequences of unprotected IoT are shown by using examples at several seaports. One of the leading seaports in IoT adoption and implementation of security measures is the port of Rotterdam. The port is increasingly turning towards smart digitalization and cloud-based IBM technology. Special efforts are invested in IoT development. "Sensors are being installed across 42-kilometers of land and sea - spanning from the City of Rotterdam into the North Sea" [18]. Since Rotterdam is the largest port in Europe, it has 140,000 vessel calls each year. Each ship call is a complex task, and with the help of IoT it is possible to safely manage processes involving the arrival and departure of the ship [19]. Namely, it is possible to create digital twinning that covers all resources in Rotterdam, allowing "tracking of ships' movements, infrastructure, weather data, water depth, and geographic data with 100% accuracy" [20]. The port of Rotterdam will be able to predict the best time based on water level, to have a ship arrive and depart Rotterdam, ensuring that the maximum amount of cargo is loaded on board. With all the benefits provided by IoT to the port of Rotterdam, some concerns about the potential risk of the connected system exist.

In 2017 a cyber-attack occurred, with large impact on port operations, especially at the container terminal. "A few weeks of "repairing and improvement" were

necessary to get the ATM (Asynchronous Transfer Mode) systems in the function-unemployed cranes and trucks couldn't do anything, and ships could not be unloaded and loaded" [21]. According to Yaqoob et al. [12], "key management is one of the crucial issues in cybersecurity and is more complex in the IoT, wherein many devices are resource constrained". The main problem of IoT is the data vulnerability within the cloud and the measures like the encryption algorithms and strong key management procedures are necessary. "Protection of the web facing cloud instances must be ensured with IDS/IPS, host-based firewalls" [12].

The partnership FERM has had a big role in stopping or recognizing new attacks in order to minimize its impact at port of Rotterdam. FERM is a part of the Port Cyber Resilience Program. The aim of the program is to enhance collaboration between companies in the port of Rotterdam and raise awareness among companies about cyber risks in order to become the best digitally protected port in the world [22]. FERM still helps the port of Rotterdam with security actions by monitoring the threats. as the big risk exists in the smart digitalization processes.

According to Paul Smits, chief financial officer of the Port of Rotterdam Authority, the entire digital ship industry will encourage hackers to find new, more complex attack methods, specially designed in this area. The Harbor Master of Rotterdam established the Port Cyber Notification Desk on 11 June 2018 [23]. "Companies in the Port of Rotterdam area are asked to report large-scale IT disruptions within their company and a reporting obligation applies to companies that fall under the Port Security Act Regulation (EC) no. 725/2004 and companies that are required to comply with ISPS" [23].

Port of San Diego uses IoT-shore-power system that allows cargo ships to plug in at port rather than having to run their diesel engines at the dock [24]. This port is the example of the port where a "Ransomware" attack has occurred, and the cyber-security has been disrupted. The port first received reports of the disruption on Tuesday, September 25, 2018 [25]. In order to overcome the consequences of the attack and return to the functionality and security of the system, the partners from all levels had to be involved: local, regional, state and federal. The Harbor Police Department has alternative systems and procedures in place to minimize impact to public safety [25]. In the previous example, the importance of new alternative ways of the work is emphasized if the incidents occur, in order to prevent completely stopping the business processes (in the most cases, limited functionality is available). Therefore, it is important to pay attention to all the possible situations that might occur and data from IoT networks must be continuously backed up using the back-end servers. Yakoob et al. [12] have proposed a novel framework that helps to detect sinkholes and selective-forwarding attacks in IoT in order to minimize such attacks. The framework is comprised of two modules:

- Anomaly-based module: the anomaly-based agent works in a distributed manner because it is based on a MapReduce framework. The proposed solution employs a voting method to analyze the suspicious behavior. Results of the proposed solution show that it outperforms the existing solutions. In the future, incorporation of the data mining techniques and intelligence-based methods may improve the performance of the proposed framework.
- Specification-based intrusion detection module: helps to analyze behavior of the host nodes and send their data to the root nodes, whereas an anomaly-based agent employs the unsupervised optimum-path forest algorithm for projecting clustering models.

Port of Antwerp has also recognized the importance of IoT security by creating a platform for digital data exchange called Nxtport. SIA partners stated that "the platform was launched by Flemish sector organization Alfaport VOKA, whose goal is to create a financially self-sustaining data-commercialization company that will collect, centralize, store, analyze and exchange data from a wide range of logistics actors in the port (carriers, freight agents, etc.), and generate profits by inspecting the information pertaining to each stakeholder" [16]. The project is currently running with four applications designed to test and prove the importance of Nxtport. According to Opstaele, "all these applications are tested or need to be experimented in Antwerp port and are aimed at improving efficiency and security" [26]. Like every port, Antwerp is the site of illegal smuggling and accidents, and security is a key priority [26]. Therefore, although the possibility of unauthorized device management and theft of information exists, intensive work on safety improvement will ultimately enable the ports to experience additional growth.

V. CONCLUSION

In parallel with the increasing number of connected devices, there is a proportional rise of the number of attacks which target IoT devices. The problem of connecting the device to the cloud comes from a two-way connection: the device can send data to the cloud, but it can also retrieve it from the cloud. If the basic connection is compromised, major security issues will arise. Therefore, a need for wider regulation arises, which should involve all levels of government: from local to transnational.

When governments and companies cannot agree upon a definition of "what is an authorized data access", then a problem arises. Initial steps in understanding of the seriousness of the problem were taken by California, USA, which has undertaken concrete measures in the fight against security threats, representing the first example of introducing the law on IoT regulation. Therefore, if other countries follow the example of USA, it could present a significant boost in IoT security, driving forward the digitalization of business processes. In addition, technological innovations will be boosted, and new opportunities will be created, resulting in increased productivity, competitiveness and sustainability of seaports.

The security needs to be controlled from the very start, in the stage of making a "device connection", but it is also

essential to include the "monitoring" phase coming after the implementation because of new and emerging forms of threats. If one device is compromised, it can lead to security threats imposed on the entire system. Threats and consequences of IoT security attacks can be classified into four categories. The first are application-based consequences when the issue represents, for example, the inability to find a culprit for the information theft by a security camera which are needed in seaports, because the cameras are not sufficiently developed to prevent a theft within the network; the next are the connection-based consequences which refer to the connecting things by IP network. If its security is not closely monitored, the entire IoT network can be compromised; furthermore, platform-based issues are related to wireless sensor network that has a pending issue which comprises the applications of communication platforms, security and management. The last category are other forms of attack linked with the combining application and platform-based threats that give an intertwined force of challenges that leave the whole security ground weakened.

The security assessments of complex supply chains are more challenging, therefore holistic approach and coordination among different sides and system components are needed. Control and interactive management of IoT systems are performed in the "cloud" rather than locally. In order to minimize the damage and stop spreading ransomware within the IoT network, cybersecurity teams have to be ready to react at any time. A current and secure software that will monitor the security of the IoT network should be installed and the prevention of file recovery costs is possible by storing data in the secure data storage.

The benefits of IoT in seaports are evident in advanced "digital" seaports, such as the ports of Rotterdam and Antwerp. They are the proof of the profitability of IoT applications and the successful monitoring of digitalized business processes.

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Financijska pismenost studenata Više stručne škole ŠC Kranj

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***Sažetak* – U svakodnevnom životu suočeni smo s odlukama koje imaju financijske implikacije na svakom koraku. Ne samo kada odlučujemo gdje pohraniti štednju, na naše financije utječu odluke o dnevnim i budućim kupnjama, o odabiru škole, usluge itd. Studenti trebaju neke vještine, znanje i strategije kako bi olakšali svakodnevno donošenje odluka. Zbog situacije koja se brzo mijenja, financijsko obrazovanje postat će doživotno iskustvo za studente tehničkih programa.**

Za potrebe istraživanja napravljena je anketa koja je analizirana u radu. U ovom smo radu proučavali financijsku pismenost među studentima tehničkih programa i saznali koji će se sadržaj morati usredotočiti na financijsko obrazovanje.

Ključne riječi – financijska pismenost; obrazovanje; studija; procesi

I. Uvod

Za uspješno djelovanje u društvu koje se suočava s globalnim, ekonomskim, tehnološkim, društvenim i kulturnim promjenama, nužan je razvoj različitih oblika pismenosti, kao što su informacijska, digitalna, medijska i, u konačnici, financijska pismenost.

Upravljanje financijama vrlo je važno u životu svakog pojedinca, jer samo prave odluke o ulaganjima znače povećanje imovine, a loše donošenje odluka je smanjenje čak i gubitak ukupne imovine. Postoje mnoge mogućnosti ulaganja, kako financijske tako i ekonomske nefinancijski. Nažalost, ljudi su vrlo malo svjesni mogućnosti ulaganja.

Financijska pismenost shvaća se kao kombinacija svijesti, znanja, vještina, stavova i ponašanja koja su potrebna za odgovarajuće financijske odluke i postizanje financijske dobrobiti.

I. FINANCIJSKA PISMENOST STUDENATA TEHNIČKIH PROGRAMA ŠC KRANJ

Financijska pismenost je u osnovi vrsta pismenosti koja predstavlja sposobnost uspješnog rukovanja novcem. Uključujemo značenje i funkcioniranje novca, mogućnost odabira racionalnih investicija i pronalaženje izvora prihoda. Financijska pismenost uključuje i čitanje i matematičku pismenost uz osnovnu pismenost, a istodobno je i njihova nadogradnja, jer zahtijeva više znanja i vještina u određenom, financijskom području. Primjenjuju se sva načela opće pismenosti, a uz to i iznad svega, razumijevanje i sposobnost korištenja financijskih informacija u odlučivanju. Financijska pismenost kao financijska sposobnost ogleda se u razumijevanju i poznavanju financijskih proizvoda i usluga, koncepata i rizika. Financijskom pismenošću nastojimo steći znanja, vještine i informacije kako bismo postigli vlastiti financijski prosperitet.

Prema riječima Trunk Šircove, Barle Lakotove, Mohorkove, Kolenčeve i Dermole (2013), obrazovanje je bilo važan čimbenik od početka moderne države i uspostavljanja masovnog obrazovanja, što pridonosi jačanju veza između političkih institucija i pojedinaca. Ulaganje u obrazovanje i usposobljavanje pojedinaca u svim fazama života pogoduje svim dobnim skupinama i prihodnim skupinama. Koristi donose pojedincu, gospodarstvu i cijelom društvu. Financijsko obrazovanje mora nadopuniti osnovno financijsko znanje pojedinaca. Pružatelji financijskog obrazovanja trebali bi pružati pružatelji financijskih usluga, koji bi trebali biti odgovarajuće osposobljeni. Financijski obrazovani korisnici biraju proizvode i usluge koji najbolje odgovaraju njihovim potrebama bez obzira na mjesto pružatelja financijskih usluga. Iskorištavaju mogućnosti koje nudi jedinstveno tržište. Povećana financijska pismenost i svijest pojedinaca potiču životnu konkurentnost.

Financijsko obrazovanje adolescenata u školama ili drugdje nije novo. Mlađe generacije ne samo da će se morati nositi sa sve složenijim financijskim proizvodima, uslugama i tržištima, nego će vjerojatno morati preuzeti više financijskih rizika nego njihovi roditelji tijekom odrasle dobi. Konkretno, morat će odgovornije planirati uštede za mirovinu, ulaganja i troškove zdravstvene zaštite; međutim, morat će se nositi s složenijim i raznovrsnijim financijskim proizvodima. Stoga studenti VSŠ ŠC Kranj u svojim programima imaju obvezni predmet, gdje uče o poduzetničkom sadržaju, a najčešće se susreću sa Ekonomikom i poslovnim upravljanjem.

Osim korporativnog sadržaja, veliki je naglasak na Ekonomiji, koja se u osnovi bavi upravljanjem, imovinom tvrtke, kalkulacijama, dobiti ili gubitkom, itd. Osim navedenih tema, zanimali su nas poznavanje i razumijevanje financijskih uvjeta (inflacija kamatne stope, povoljna kupnja) i vještine (upravljanje i planiranje financijskih pitanja). Obrazovanje mora biti prilagođeno potrebama ciljane populacije i mora biti u skladu s procesom stalnog poboljšanja. Obuka i obrazovanje za financijsku pismenost je cjeloživotni proces.

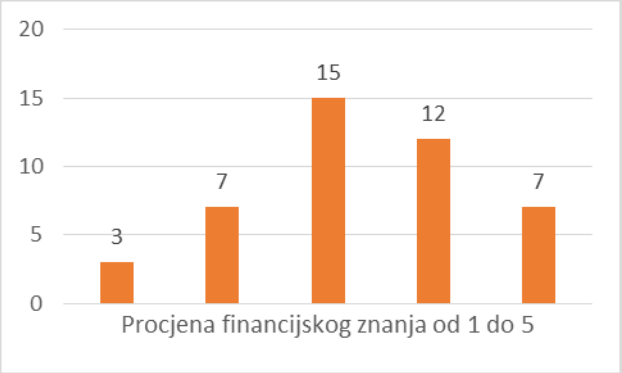
II. ANALIZA FINANCIJSKE PISMENOSTI STUDENATA

Kao predavač na području računalnih i informacijskih znanosti, ekonomije i menadžmenta, poslovne ekonomije i ekonomije, stalno nastojim koristiti suvremene tehnologije u financijskom području. Područje financijske pismenosti je vrlo široko, pa smo se fokusirali na novac i transakcije, te upravljanje financijama.

1. Na području novca i transakcija najviše nas je zanimalo područje osobnih financija (dnevna plaćanja, potrošnja, povoljne kupnje, različite mogućnosti plaćanja ...)
    a. Novac kao agent za razmjenu,
    b. Različiti načini plaćanja
    c. Načini plaćanja
    d. Platne transakcije
    e. Kredit / Debitna kartica
2. Unutar područja planiranja i upravljanja financiranjem, međutim, usredotočite se na kratkoročno i dugoročno financijsko upravljanje i planiranje.
    a. Što su porezi i olakšice i njihov utjecaj
    b. Potrošnja i ušteda
    c. Troškovi
    d. Planiranje kupnje
    e. Štednja, iznajmljivanje, ulaganje

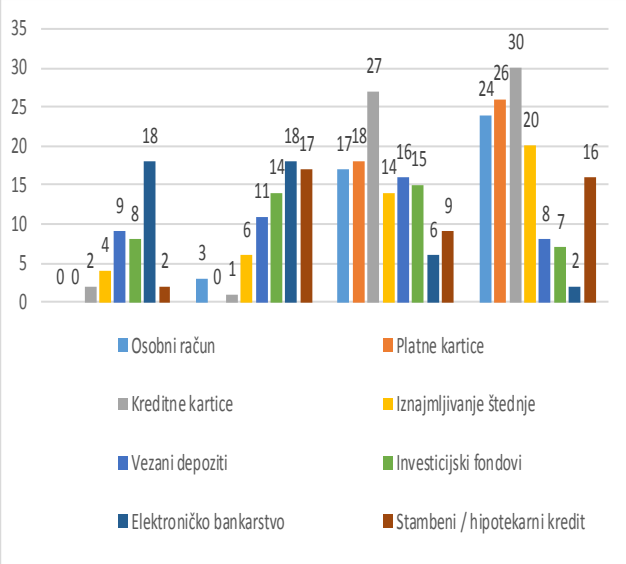
Koristili smo kvantitativnu metodu, metodu ankete koja je bila anonimna za studente. U istraživanju je sudjelovalo 20 studenata redovitog programa Elektroenergetika, 24 redovitog programa Mehatronika.
Svi studenti odgovarali su na isti. Učenici oba tehnička smijera odgovorili su na isti upitnik, a nas su uglavnom zanimali opći financijski aspekti i mogućnost korištenja proizvoda i proizvoda koje mali ljudi danas imaju i mogu koristiti. Poznaju li ih i stvarno ih koriste, te postoje razlike između programa?

Kako ocjenjujete svoje znanje o financijskim pitanjima općenito? Ocjene su od 1 do 5, gdje je 1 "Vrlo loše poznato" i 5 "Vrlo dobro znam"



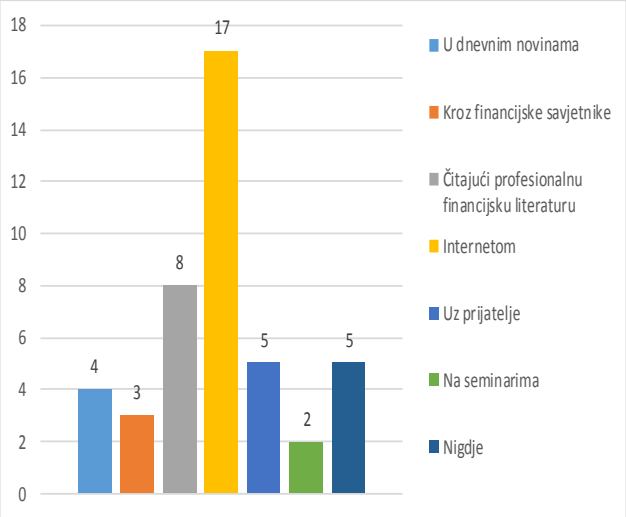
Iz grafikona je jasno da se većina definira kao srednje dobar stručnjak financijske pismenosti. Iz odgovora možemo reći da studenti dobro poznaju financijsku pismenost.

U sljedećem pitanju, pitali smo studente, u kojoj mjeri koristite niže navedene financijske proizvode? 1 "Čak ni ne znam“ do 4" Znam, imam iskustva s ovim proizvodom“



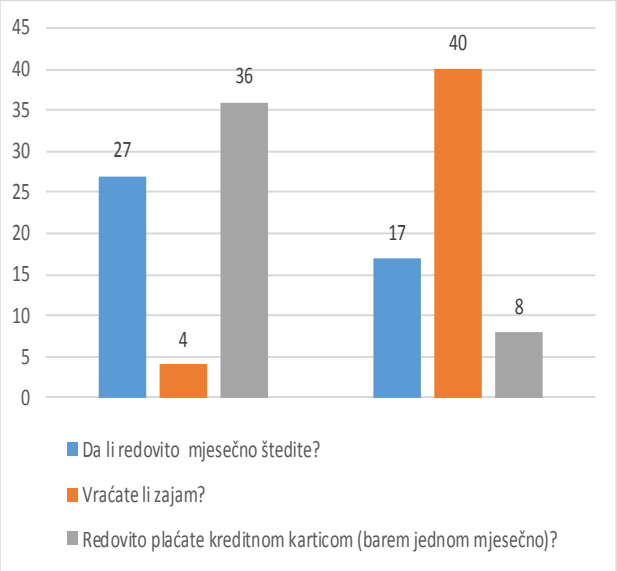
Većina studenata ima svoj osobni račun, gotovo svatko koristi platne kartice, a već su se susreli s kreditnim karticama. Također jim nije strana štednja u različitim oblicima, manje su informirani investicijskim fondovima.

Sljedeće pitanje koje nas je zanimalo, gdje danas studirate području financija?



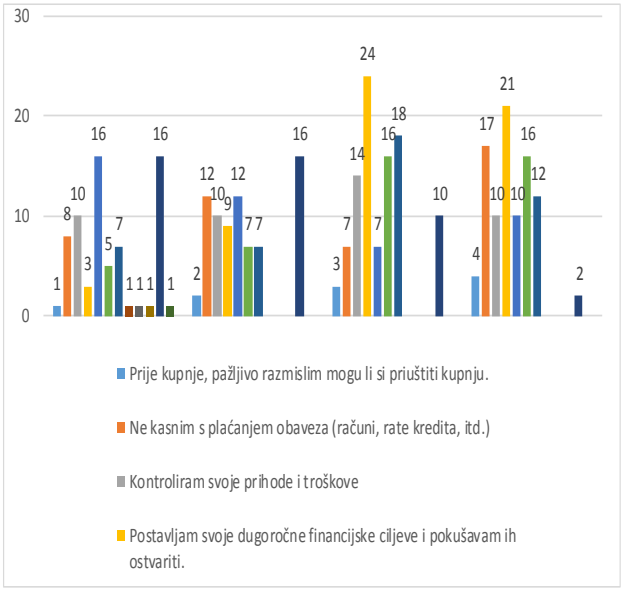
Grafikon pokazuje da se većina mladih danas obrazuje internetom, nakon čega slijedi čitanje profesionalne financijske literature i razgovora s prijateljima te čita dnevne novine. Iz rezultata možemo vidjeti da je dobivanje financijskih informacija prilično fragmentirano na različite izvore.

Redovito li plaćati kreditnom karticom (barem jednom mjesečno)?



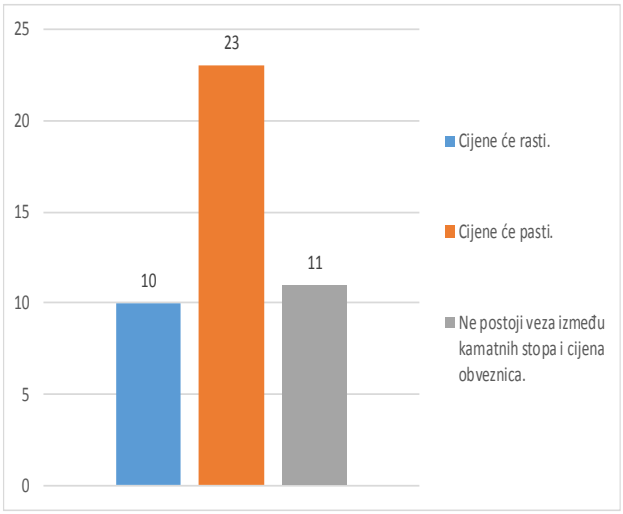
Grafikon pokazuje, da veći postotak studenata štedi na mjesečnoj osnovi, gotovo da ne poznaju zajmove i dosta redovito koriste jedan od oblika kartica (za plaćanje ili kreditiranje).

Sljedeća analiza provjerava navike studenata u kupovini: kako kupuju, koje su njihove navike plaćanja i kako su odgovorni za svoj novac. Sve smo provjerili sa ljestvicom ocjenom od 1 - "Uopće ne stane" do 4 "Potpuno stane"



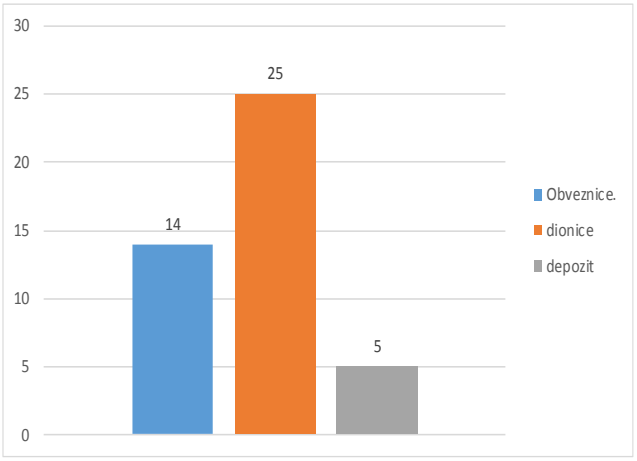
Rezultati pokazuju da većina ispitanika razmišlja o smislenosti kupnje, kontrolira njihove troškove i prati svoje financijske ciljeve prije kupnje.

Jedan od zadataka studentima bilo je sljedeće pitanje: Ako se kamatna stopa poveća, što će se dogoditi s cijenama obveznica?



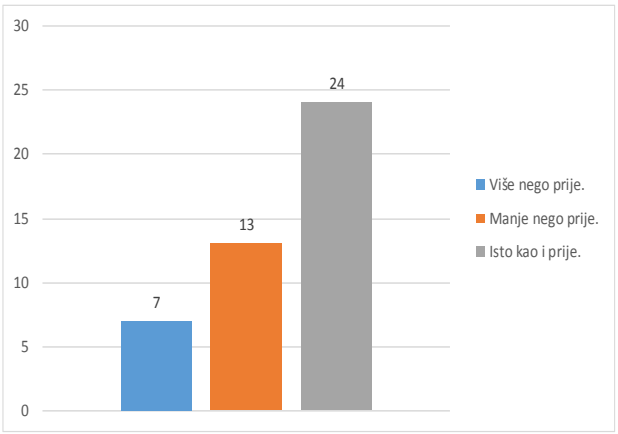
Iz odgovora možemo vidjeti da je samo 22% studenata s pravom utvrdilo, da će cijene porasti, što je 52% mišljenja da će cijene pasti, a druge smatraju da nema izravnog utjecaja.

Zamislite duže razdoblje, recimo 10 ili 20 godina. Koja je investicija potencijalno najprofitabilnija?



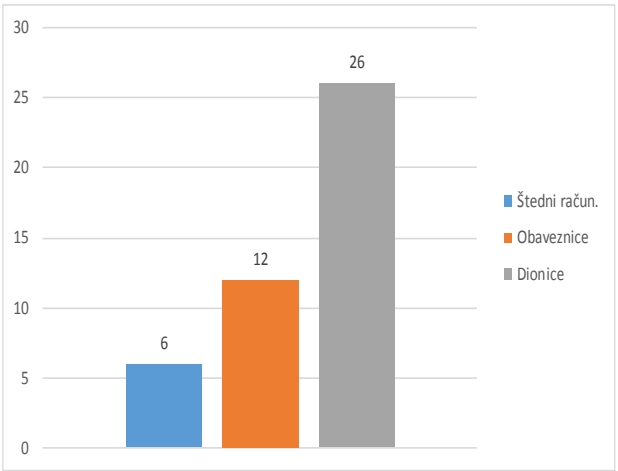
Većina studenata ispravno je predvidjela da je dionica najisplativiji za duže razdoblje.

Zamislite da bi se u 2018. godini vaši prihodi udvostručili, a cijene svih dobara bi se udvostručile. Koliko mislite, da ćete biti u mogućnosti kupiti svoj prihod u 2018. godini?



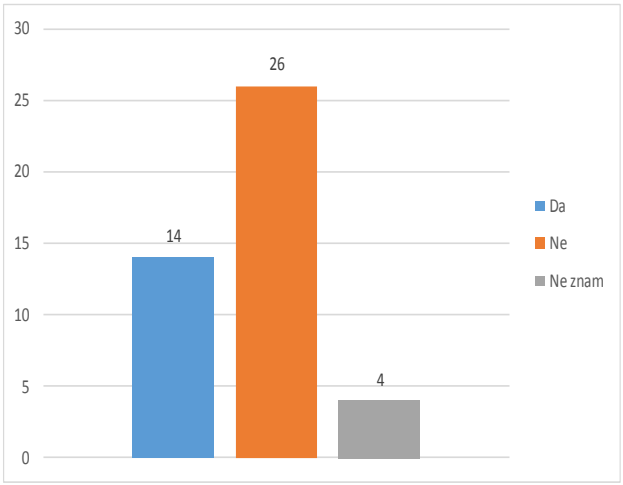
Također, u ovom slučaju, učenici su točno predvidjeli da su u mogućnosti kupiti naše prihode isti kao i prije.

Koja je vrijednost ulaganja tijekom vremena najviše fluktuirajuća?



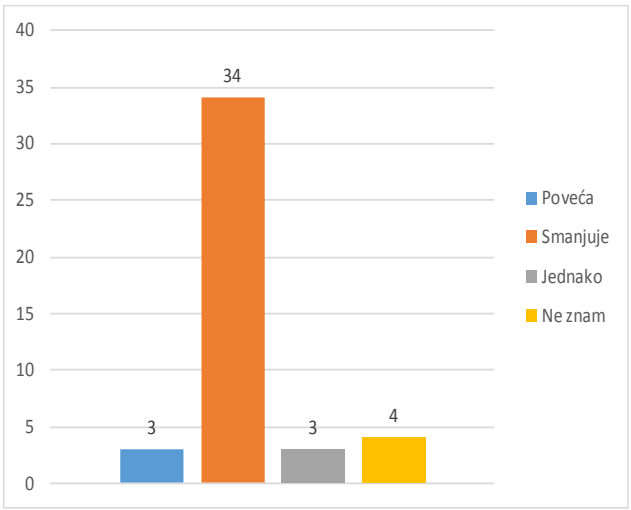
I u ovom slučaju studenti su točno predvidjeli koja su ulaganja tijekom vremena najviše fluktuirajuća, a to su dionice.

Ako investiram u uzajamni fond, ne mogu od njega prikupiti novac u prvoj godini?



Većina studenata ispravno je predvidjela točan odgovor - ako investiramo u uzajamni fond u prvoj godini, ne možemo prikupiti novac.

Ako investitor diversificira svoj novac između različitih vrsta ulaganja, rizik od gubitka:



Oni također odgovaraju na pitanje: Ako investitor dijeli svoj novac između različitih vrsta ulaganja, je li rizik gubitka (povećanja, smanjenja ili zadržavanja istog) prava odluka ... smanjuje se.

III. ZAKLJUČAK

U ovom radu proučavali smo jedan dio financijske pismenosti studenata VSŠ ŠC Kranj. Treba naglasiti da se studenti sa ekonomskim sadržajem susreću prvi put u okviru studija. Analizirajući podatke, utvrdili smo da je financijska pismenost u našem uzorku relativno visoka,

što se može objasniti činjenicom, da su studenti uključeni u uzorak, te da je financijska pismenost statistički značajno povezana s razinom obrazovanja. Većina studenata je u upitniku upoznala vrste financijskih ulaganja i pojedine vrijednosne papire.

Danas je financijsko upravljanje vrlo važno u životu svakog pojedinca, budući da ispravne investicijske odluke znače povećanje imovine, a loše donošenje odluka je smanjenje ili čak gubitak ukupne imovine. Postoje mnoge mogućnosti ulaganja, kako financijske tako i nefinancijske. Nažalost, ljudi su vrlo malo svjesni mogućnosti ulaganja.

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ICTs for Education: An Inclusive Approach to Addressing Challenges Faced by Roma Communities in Europe

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***Abstract* - Despite the fact that education is a basic human right, children and youth from marginalized communities often, lack access to quality education programs. Applying ICTs as a tool to education, rather than the solution, has great potential to narrow existing education gaps, while conveying skills and competences necessary for economic and social survival in today's connected and digitalized societies. Roma are Europe's largest ethnic minority group, and despite multiple efforts to improve the living conditions of Roma people, the majority of Roma households continues to live in deep poverty, is subject to social exclusion and discrimination. Moreover, four out of five students from Roma communities, lack basic cognitive skills and competences. This paper introduces the *Head in the Clouds Project* (HIC), an innovative learning program based on self-organized learning environments, the use of state of the art IT devices and the innovative learning approach *MINIMAX* while shedding light on the use of ICTs in marginalized communities. Particularly it discusses potential long-term impacts of ICT enabled self-organized learning environments on creating more inclusive educational programs and societies, and the potential contribution of inclusive and IT supported learning environments towards the achievement of the United Nations Sustainable Development Goals (SDGs).**

Keywords* - *Technology Enhanced Learning; Computer-Supported Collaborative Learning; Digital Learning; Self-Organized Learning Environments; Inclusive Societies; Roma Minority Group; Sustainable Development Goals; ICTs;

I. INTRODUCTION

Education is a basic human right, which propels long-term social and economic development. In 2015, the 2030 Agenda recognized the right to education in Sustainable Development Goal 4 (SDG4), promoting education and learning opportunities for all. In spite of global efforts to lift barriers to education, in 2016 one-fifth of the global population of children, adolescents and youth were out of school [1]. Marginalized communities especially struggle to secure the right to a basic education.

In Europe, the Roma population faces formidable challenges to access education. Discrimination, intolerance and social exclusion affect various aspects of Roma communities, the largest ethnic minority in Europe with a population of 10 to 12 million [2]. The majority of Roma households face deep poverty and suffer from hunger [3]. Roma attendance in primary and secondary education is mandatory in all EU countries, however, only 86 percent of Roma children are enrolled in primary and early secondary education [4]. Studies show that four out of five students from Roma communities, lack basic cognitive skills and competences [5]. Barriers to education such as poverty, racism, unemployment and poor housing and health circumstances prevent Roma children from enrolling or continuing their schooling. Geographical distance to schools, missing public transportation means, inappropriate teaching methods, lacking infrastructure, cultural differences, unfamiliarity with text, limited language skills as well as mistrust in schools and the education system are further reasons impeding the access to education for Roma children [6]. The children that do have access to education are often enrolled in all-Roma educational facilities with inadequate resources and infrastructures or placed in 'special' classes for children with intellectual disabilities [7]. According to a report on the status of Roma population in Romania, the absence or low quality of education among Roma children results in lower skills development, hindering them from achieving employment, higher education and other social skills [8].

The need for inclusive and quality education programs for Roma children prompted an ERASMUS+ funded project, Head in the Clouds: Digital Learning to Overcome School Failure (HIC) that aims to enhance educational development among Roma students by integrating ICTs in the curriculum. Education systems must prepare children and youth with skills that help them overcome challenges in connected and digitalized societies [9]. For that reason, HIC places great emphasis on a holistic approach to use ICTs as a tool (not the solution) to strengthen the students' learning experience, stimulate their creativity, allow students to acquire basic ICT skills and to become confident in using digital devices and to promote sustainability of education for marginalized communities.

Given the fact that today already 70% (5.18 billion people) of the world's population aged 15-24 years uses the internet on a daily basis and the number of people using smartphone devices already exceeds 2 billion [10], the importance of teaching children and youth from

socially disadvantages groups basic ICT skills becomes even more obvious. Despite the fact that marginalized communities, e.g. Roma people, have generally no or only very limited access to digital devices and technologies, their everyday lives will increasingly depend on it. Having in mind the UN Sustainable Development Goals, digital technologies, infrastructure and services can act as an enabler for marginalized societies to not only overcome existing challenges with regard to education but as well with regard to poverty, hunger as well as wellbeing [11-14].

II. INNOVATIVE LEARNING APPROACH

HIC introduces a holistic and innovative digital learning program that revolves around (i) an alternative educational approach build on the idea of self-organized learning environments, (ii) utilizing technology (including state of the art IT-devices) as a learning tool and (iii) putting the emphasis on learner autonomy and the individual needs and capabilities of the students while educators assume the role of mentors rather than teachers (MINIMAX).

A. Self-Organized Learning Environments

The developed educational modules build on Self-Organized Learning Environments (SOLE), a pedagogical approach based on the idea of "learning by discovering" and the research of Sugata Mitra, an Indian Educational Technology Scientist, proponent of minimally invasive education [15]. In 2013, Sugata Mitra received the TED award for SOLE and the social innovation of this alternative educational concept [16]. Similar to other successful learning theories e.g. constructionism (proponents: Piaget, Resnick, Papert), the educational modules focus on a student-centred, self-driven, experiential and highly engaging learning process in which students learn, explore and develop new skills, knowledge and competences in a variety of subjects by concerning themselves creatively with their own environment. [17, 18].

B. State of the art IT-devices

Using ICT not only as an infrastructure, but as a learning tool to acquire besides digital skills and digital literacy as well knowledge, competences and skills in a variety of subjects and topics is a key aspect of the HIC project. The educational modules use state of the art IT devices, software and programming languages including award winning tech-devices such as Makey Makey boards, Scratch, Ozobot robots, LEGO WeDo, Minecraft and Python, which were also recommended e.g. by the Schwyz University of Teacher Education in Switzerland. The educational materials were created in the form of task sheets (and teacher handouts with explanations), that can be printed or used on a computer/smartphone/tablet and are linked to a digital cloud version. In addition, a digital hand-in application allows students and educators to track the learning progress of participants with regards to topics, competencies and skills addressed and to evaluate how learners perceived individual tasks.

C. MINIMAX

The HIC consortium developed the learning approach away from pure SOLE to an educational approach entitled *MINIMAX*, short for minimal teacher intervention, maximal learner autonomy. As a method, it allows a person to explore, try, experiment, seek with its personal timeframe and capabilities, to learn without being necessarily aware of it. Furthermore, it is highly engaging and is aimed at creating an atmosphere in which learning is perceived to be easy. The emphasis is put on children's creativity, autonomy, and experiential learning, involving all senses. Having said this, tasks consist of text, images, sounds, videos, games and more, and can be very precise or open investigative. They are all designed to be interactive: not traditional teaching content but instead letting the children and youth reach their own learning. Together with the fact that the children and youth are freely able to choose their tasks and follow their own interests. The interactive and digital character of the tasks empower learners and gives them the chance to drive learning according to their own abilities and needs. In fact, it can be described as "buffet-style education" as children can follow their own interest, picking up the tasks they really desire to do.

III. HIC-PROJECT DESCRIPTION

Head in the Clouds: Digital Learning to Overcome School Failure (HIC) is an Erasmus+ Strategic Partnership intended to prevent early school leaving, enhance the quality of learning and digital education, facilitate the development of basic and transversal skills and enable the pursuit of long-term careers for marginalized minorities in Europe, mainly Roma. [19].

The HIC project team consisted of an international consortium of seven institutions from five European countries (universities, NGOs, a foundation, school, SME) coordinated by the Vienna University of Technology. The partners developing the educational modules include the Vienna University of Technology (Austria, project coordinator), Verein Offenes Lernen (Austria) and the Technical University of Kosice (Slovak Republic). SCIO (Czech Republic) took over the task of evaluating the developed educational modules [19]. The HIC program is implemented by Fundatia Crestina Diakonia Filiala Sfantu Gheorghe (Romania) in a Roma settlement near the city of Sfantu Gheorghe,. In Romania, Roma constituted 8.6 percent of the population in 2011 according to the Council of Europe statistics [20]. The implementing partner in the Slovak Republic is Súkromná Základná Škola, a school with a Roma language curriculum and in Kosovo, the HIC project is implemented by GAIA in the city of Gračanica.

A. Overview of the educational project

The three your project started in September 2015 with a needs assessment [21] to tailor the educational modules to the local contexts and needs. To do so the implementing partners collected first-hand quantitative and qualitative data about the knowledge and use of

digital technologies in the participating children's households, living conditions, language skills, and demographic data with the help of interviews and questionnaires with educators, parents, children and youth.

Thereafter the HIC consortium defined and developed six educational modules including activities to acquire basic IT skills, computer programming skills, digital literacy, English language skills, environmental education, culture, history, costumes, medicine and health as well as handicraft skills for everyday use.

Mentors and youth workers from all implementing partners were given the opportunity to experience the educational modules, involved tools and materials in the framework of special trainings and were provided with detailed teacher manuals. In the following the developed learning modules, specifically designed to engage students and youth in their own learning process were implemented by the partners (Súkromná Základná Škola, Fundatia Crestina Diakonia Filiala Sfantu and GAIA) in their afterschool and youth programs. In the three implementing locations in the Slovak Republic, Romania and Kosovo more than 100 children and adolescents from Roma communities (40% girls, 60% boys) aged 6-17 years participated. Throughout the implementation, the developers of the educational models were in contact with the implementing teachers and social workers via regular conference calls to provide assistance, resolve open issues and discuss possible implementation scenarios and improvement suggestions for the developed educational materials.

Based on constant feedback and evaluation, after the trial period the learning modules were further improved and trained to teachers, youth workers and stakeholders both participating in the trial run and beyond as part of the dissemination strategy of the consortium. All developed educational modules, as well as the teacher handouts were published as Open Educational Resources (OER), available in four languages (English, Hungarian, Slovak and Serbian) under a CC-BY-SA license on the project website https://brainsintheclouds.eu/. Moreover, a detailed manual focusing on the projects' aims, teacher roles, training and evaluation approach and outcomes was developed by SCIO supported by the Vienna University of Technology and Verein Offenes Lernen. In addition, GAIA produced a 22 minutes documentary about the Head in the Clouds Project, offering further insights and impressions of the practical work done with children – both the manual as well as documentary are available on the project website.

B. Structure and Content of Educational Modules

The educational modules consist of simple and modular structured task sheets, linked to an online hand-in application via a QR-code. The educational modules were designed to be used independent of locations and in self-organized learning environments and do not require frequent intervention or inputs by mentors (MINIMAX). The role of the mentors is to support children by encouraging them to find their own way (e.g. with words of encouragement: "I believe that you can do it", "just try again you can do it", etc.) rather than providing them directly with solutions.

Based on the structure and the playful and exploratory approach, there are hardly any limits to the applicability of the developed educational materials, as they can be applied in various areas as well as on a larger scale. These settings may include afterschool programs, youth centers, summer programs, day care centers, community centers, social welfare centers, schools, learning-clubs etc. for children aged 7-16 years and independent of their level of knowledge, skills, competences and origin.

With regards to necessary infrastructure, the implementation of the educational materials relies on some basic infrastructure, including internet connection and a handful of ICT devices, as outlined in detail in the teacher manual of each module. To cope with a possible shortage of computers or tablets, the educational modules have been also designed in paper-based format to facilitate large-scale implementation. As unfamiliarity with text and reading and writing problems are widespread barriers for children and youth from Roma families, the developed materials use as little text as possible and work with many pictures and information-icons to facilitate the use of the task sheets. In addition, varying degrees of difficulty of some tasks, shall address different age groups.

The *Video Module* encourages students to learn how to work with devices (smartphones, tablets, digital cameras…), search for information on the World Wide Web and how to film, cut and edit videos and short films. The *IT 101 Module* conveys basics about the usage of different (Open) Office Programs, online services and encourages students to learn elementary level computer programming skills by using *Scratch* [22] and *Raspberry Pi* [23] computers. The various activities and materials of the *English Module* encourage students to develop and enhance their English language skills. The *Programming Module* mainly consists of hands-on programming and engineering tasks and activities using IT-gadgets and software such as *Makey Makey* [24] *Ozobot*s [25], *Minecraft* [26], *Scratch* and *Lego WeDo* [27]. In addition, through the popular online game *Minecraft* students are encouraged to learn some basics in the programming language *Python* [28] for the purpose of automating game-activities. The *Ekopolis Module* aims at addressing environmental issues in a playful and simplified way with the objective to raise awareness for the impact of human actions on our environment and to find ways to improve the living conditions of many people around the globe. The module centers on an educational board game, named *Ekopolis* [29], introducing the students to the concept and necessity of balancing environmental, economic and residential or social interests. The *Real Life Module* conveys knowledge in topics as diverse as Roma culture, hygiene, first aid, relationships, repairing stuff,

travelling and sex-education. The overall goals of the module are to provide participants with useful knowledge necessary to make a difference in the participants' everyday life, help students become more self-confidence and improve participants' general knowledge in order to foster inclusion in society and in economy. To cope with poor self-esteem of the participating children and youth one major focus of the six educational modules (*Video, IT 101, English, Programming, Ekopolis* and *Real Life*) evolves around personal development and development of transversal skills. Transversal skills include negotiation skills, problem solving, collaboration, presentations skills and intercultural skills, to build a safe-learning environment to empower participating kids and children to believe in themselves and to give them perspectives for their future life.

C. Evaluation of Educational Modules

The implemented approach was evaluated, using three types of questionnaires, live observations, interviews with children and educators, written reports and data from the online hand-in application. Quantitative data was collected from the online hand-in application regarding what activities the children performed and how these were related to competencies. Notably, data was collected anonymously by using personalized stickers to identify individual learners.

In total three questionnaires were administrated by the educators after each of the learning modules. (i) Questionnaire on learner autonomy to track students' progress in their level of learner autonomy in seven predefined domains including e.g. the ability to set meaningful and achievable goals, identify a source of failure and work independently towards reaching a goal. (ii) Personality questionnaire to determine whether the level of learner autonomy is related to a child's personality and to reflect the behavior of the participants when working with the educational modules. This was done by assessing pairs of personality traits (e.g. systematic vs. spontaneous, prefers working alone vs. prefers working in a group, likes to think vs. likes to act) on a 5-point scale.
(iii) Accomplishment questionnaire to track students' opinion on the modules and their content, regarding how difficult it was for them, how much they learned and how much the liked the module.

Qualitative data was collected through live observations, interviews with children and educators on a regular basis, and written reports from educators to learn about what kids were particularly interested in, what did not work so well, how they interacted with each other, what new knowledge they acquired and also how parents reacted to the project etc. The evaluation of the collected data provided insights into the status quo, the accomplishment and effectiveness of individual tasks and modules as well as data on the individual performance of the participating kids and youth. The feedback loop especially allowed continuous improvements and further development of the educational modules.

IV. Results & Discussion

Learning with innovative educational materials, based on an approach of minimal teacher intervention and maximal learner autonomy (*MINIMAX*) supported by digital materials and tools, proved to fit the needs of the participants better and led to a higher motivation for learning [30]. In the Slovak Republic children that hardly participated in school classes stayed in school to participate in the program and showed excitement and pride when finishing a task, indicating the great popularity and suitability of the project for its participants. Out of the almost 100 Roma students who participated in the HIC project, only one student withdrew from the program during the trial implementation period. Regular attendance at the HIC program indicates the efficacy of the dynamic and holistic approach towards education and the relevant content of the modules. Research further shows that programs such as HIC, which aim to develop inclusive learning environments, can facilitate sustainable development more effectively if they become part of the wider systemic change [31].

Providing a safe learning environment for children and youth to develop their competences on their own pace, without judgement that they usually face from majority groups and without gender inequalities, raised their performance in the formal school system in subjects as diverse as English, Mathematics, Geography and Biology. All educational modules address and seek engagement in reading, writing and understanding text, which was demanding but influential in practice and development of these skills. Behaviour and social skills of the participating children greatly improved, e.g. one educator from Romania reported that kids went from group work to individual work, which is something very unusual for Roma children, meaning that they became confident enough to tackle issues and solve tasks by themselves without relying on help. [30]

Girls would often come and ask for more tasks. Independence in engagement rose drastically. Fear of failure was also observed to demolish for some of the kids. Gender inequality was addressed at a large scale, representing a serious and overall present problem in Roma communities. Via implementing the project, safe learning environments, atmospheres, and conditions were created, where girls and groups who have difficulties to succeed in established systems of formal-education had better chances to try and engage in a learning process. Students learned to cooperate, communicate and showed increased ambition, as children even wanted to stay longer to solve tasks. Moreover, the evaluation showed that thanks to the learning experience and provided environment, the children increased their overall ability to coordinate, facilitate and analyze their own learning process according to SCIO, while educators developed a new understanding of basic obstacles such as security and safety as a prerequisite for learning. Similarly, one mentor from Fundatia Crestina Diakonia Filiala Sfantu Gheorghe reported: *"Our children's learning autonomy*

improved through gaining the capability of using digital devices. Children learned to fight for themselves to reach their goals." [30]

One very important achievement of the project that has been reported by all implementing partners is the fact that children became interested in learning again, as the *"children experienced the joy of success while working on tasks which seemed difficult, e.g. building models from LEGO or Makey Makey programming. And they did it, often without help"* as one teacher from Súkromná Základná Škola reported. The colleagues from GAIA (Kosovo) reported that the *Real Life* and *Ekopolis* modules gave some amazing and practical solutions that kids applied automatically in the center, at home or in the neighborhood. Observing the positive influences of the approach on the motivation and success of learners, other educators, parents and local partners became interested in the approach and materials. In general, a mind shift could be observed in the work of the educators as they move further towards the inclusion of non-formal education techniques. In addition, also the digital competences of educators were raised. In many cases, the participating organizations have as well witnessed changings in children's attitude towards initiative. Many individuals, who assumed the role of an observer or silent participant before, were starting to take initiative. Individuals who had leadership spirit from the beginning were given the opportunity to grow and engage even more.

As most of the participants did not have the opportunity to engage in anything similar before, the HIC project made a step forward in enabling the children to develop a greater understanding of their possibilities, increase chances of further education and thus create better chances for future employment and mobility.

V. LONG-TERM IMPACT & SDGS

The multi-dimensional goals of the HIC project overlap with a number of the 17 Global SDGs. In the SDGs framing, education is an enabler for economic growth, gender equality, poverty reduction and health [32], [11]. The SDGs are committed to leaving no one behind in efforts to achieve social, economic and environmental sustainability for everyone [33].

Customizing educational modules to local circumstances and requirements, while fulfilling global expectations is key to the sustainability of education for everyone [34]. Although the SDGs per se were not part of the educational module, HIC placed a number of sustainability objectives at the core of its program as shown in Fig. 1.

SDG4 - Quality Education: According to a study from 2011, 0.2 percent of Roma children in Kosovo and 17 percent in Romania attend preschool, while Roma children in the Slovak Republic are 30 times more likely to drop out of school than the rest of the country's population [35]. In southeast Europe alone, only 18 percent of Roma attend secondary school and lower than one percent move on to tertiary education [35]. Quality and inclusive education is key to the sustainable development of every community [36]. To increase accessibility to education through the development of digital competencies and raising awareness about social, economic and environmental rights and challenges, HIC provides marginalized Roma children the opportunity to participate in an educational program that propels long-term economic and social impacts such as higher employment rates, poverty alleviation, economic growth and social inclusion.

SDG 10 - Reduced Inequalities: A disproportionate number of those who do have access to education are placed in Roma-only schools, segregating them from the rest of society. Approximately 46 percent of Roma children between the ages 6-15 attend schools with majority or all Roma classmates [4]. Educational segregation and social discrimination in the EU against Roma children hamper access to quality education, which in turn impacts access to other basic socio-economic rights and opportunities. EU Member States are seeking new avenues for overcoming barriers to employment, housing, health services and other basic social services [37]. Thus, HIC seeks to reduce inequalities by enabling the attainment of education, raising awareness about civic rights, increasing opportunities for employment and pursuing higher education. The long-term impacts of education and employment can reduce inequalities, namely income inequality and push marginalized communities out of poverty [38] and foster economic growth for future generations [39].

SDG 1 - No Poverty and SDG 8: Decent Work and Economic Growth: Approximately 80 percent of the Roma population in Europe are under the poverty line or at risk of poverty [4]. While discriminatory policies exacerbate the social and economic circumstance of Roma communities, public and private efforts to give Roma children the opportunity to receive an education and increasing their chances of employment can contribute to breaking the cycle of poverty for future generations [39], [40], [41]. Poverty reduction is at the center of HIC objectives. The high rate of dropouts among Roma communities results in high rates of unemployment and social segregation. As a result, HIC is working towards a curriculum that motivates Roma children to complete primary and secondary school and facilitate the development of skills that will enhance their socio-economic circumstances.

SDG 3 - Good Health and Well-Being: The correlation between education and employment status and level of good health among the Roma population [42], [43] highlights the need for integrating health and well-being into educational curriculum and the effect of education on meeting health needs. One the one hand education, in the long-term, can increase access to healthcare services by alleviating the financial challenges of Roma families. On the other hand, integrating health education in Roma school curriculum can significantly enhance their wellbeing. Therefore, HIC dedicates a series of tasks to teach Roma children how to access

information about hygiene, well-being and healthcare services and strives to increase knowledge about diseases and healthy lifestyle.

SDG 13 - Climate Action: Roma communities experience higher exposure to environmental hazards due to their socio-economic status and housing location and circumstances [44]. Lower levels of educational attainment are a contributing factor to being at risk of environmental impacts [44]. Climate change is an environmental challenge that effects communities worldwide and has received considerable attention in the SDG framework. Mainstreaming climate literacy can reduce the impacts of humans on the environment and vice versa. Climate change awareness heavily relies on educational attainment and improving climate literacy in educational programs [45]. Consequently, HIC incorporates information about environmental challenges in the *Ekopolis* module to raise awareness about an environmentally conscious lifestyle to introduce sustainable ways of addressing everyday issues. HIC aims to reduce environmental impacts on Roma communities and enhance climate literacy to minimize human-induced environmental impacts.

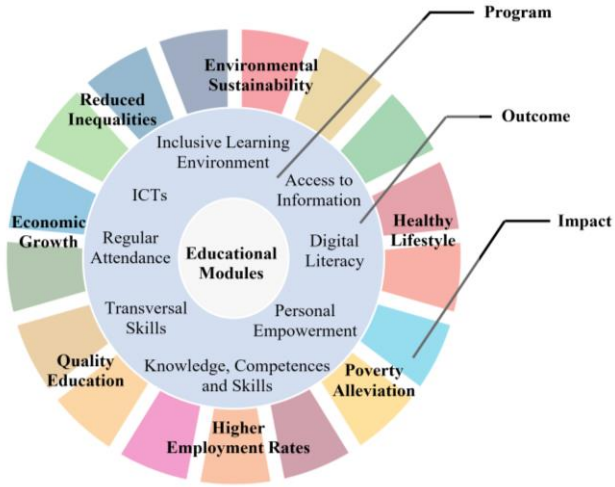

Figure 1. Long-term impact of HIC Educational Moduls

VI. CONLUSION

The HIC program combines self-organized learning environments, state of the art IT-devices and an innovative learning approach based on *MINIMAX*, creating a holistic, inclusive and innovative educational program. Through the implementation of six educational modules (*Video*, *IT 101*, *English*, *Programming*, *Ekopolis* and *Real Life*) in three partner locations in Romania, the Slovak Republic and Kosovo, participants acquire knowledge, competences and skills in various domains and subjects. HIC uses ICT (software and hardware components e.g. tablets, Raspberry Pis, Makey Makey, Ozobots, Minecraft, Scratch and Lego WeDo, Python) as a tool for education and focuses especially on digital literacy, realizing the need of socially disadvantaged groups to gain access to digital technologies for long-term social and economic prosperity in today's connected and digitalized societies. At the same time, it understands the opportunities for access to quality education ICTs entail for marginalized communities. Besides the development of transversal skills, including e.g. negotiation skills, problem solving skills, collaboration, presentations skill and intercultural skills, advances in the personal development (self-confidence, independence and initiative taking) of the participants were observed by the consortium members. Moreover, the HIC project, initiated a mind shift of educators and youth workers, ultimately fostering the use of ICTs in education in the implementing locations.

The modular structure of the educational modules greatly facilitates reuse and customization of contents to local needs and requirements, contributing to the fact that the developed educational modules can be widely adopted. As part of HIC's long-term action plan, the consortium intends to expand this program to other Roma communities in Europe and to marginalized communities facing educational barriers in different regions.

The integration of social, economic and environmental elements into the educational modules and realizing the significance of integrating discussions and lessons pertinent to the daily challenges of marginalized communities has prompted HIC to incorporate sustainability principles at the core of its curriculum. Strengthening inclusive learning environments, digital literacy and engaging learning activities have a multi-dimensional effect on skill development, enhance socio-economic conditions at an individual level and can provide a long-lasting contribution with regard to sustainability of communities and societies across different domains and scales. In this regard, HIC particularly recognizes that a sustainable future for everyone everywhere requires the global community to support projects that fulfil the basic right to education.

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INFORMATION SYSTEMS IN SPORTS ORGANIZATIONS: CASE STUDY OF THE SPORTS ASSOCIATION OF THE CITY OF ZADAR

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Abstract - **The sport system is not a closed system. It is instead conceived as a segment of an integral information system of sports that connects all other information subsystems. Information systems are now used in all activities and greatly facilitate the operation and operation of sports organizations. This paper analyses the information system within the sports organization in the City of Zadar. The introductory part of the paper focuses on the theoretical overview of information systems with a particular emphasis on their presence within sports organizations. The aim of the paper is to present a systematic approach to the use and construction of an information system of sports organizations, together with examples of the information system of the Sports Association of Zadar and the Sports Association of the City of Zagreb, more precisely the particular structure of their information systems together with the subsystems that are particularly related to the valuation of sports and indicators of the information system. This paper provides an overview of the application of the information system as an evaluation support for sports and indicators of the information system of the Sports Association of the City of Zadar. The analysis is based on the survey results conducted with the members of the Sports Association of the City of Zadar.**
Keywords: information systems, information technology, sport, information, data.

I. INTRODUCTION

In the Republic of Croatia, within sports activities as well as in sports organizations the application of information systems (hereinafter referred to as "IS") has not yet been adequately implemented. The creation of an Information System in Sport (hereinafter referred to as "ISS") represents a complex business, given the complexity of sports and the organization and form of sports organizations. The development of the organization of sport activities can be traced and studied through the prehistoric remnants of human existence, but it is only in the 19th century, that an idea was developed according to which the organization should be developed on the principles and laws that are revealed and studied by scientific methods. The organizational structures differ from organization to organization according to form, complexity, and dynamics, and it is derived from the methods of overcoming the uncertainties they face within the environment. As such, organizations represent a social order created to meet collective goals. Each social organization, and accordingly the one in sports, is the result of an organizing process, indicating the situation at a particular moment, while representing the institution of the appropriate legal form, which is in turn in constant interaction with the environment. The systematic approach requires that all phenomena in the real and imaginary world are understood and viewed as entities that work within their own environment. This, of course, refers to sports organizations as well, whose environment in Croatia is an extremely dynamic one and therefore demands adjustments. The successful management in all segments of sports organizations, and in particular the increase of efficiency in order to achieve particular goals of sports organizations, is only possible under the assumption of an excellent knowledge of the internal organization of a system and the sports activities, sport organizations and the application of the IS, the subsystem and its systematic functioning within these organizations. The aim of this paper is to present a systematic approach to the building of an IS within sports organizations by using the case of the Sports Association of the City of Zadar where the IS is being used for the application of evaluation criteria for the sports members of the Sports Association of the City of Zadar and the indicators of the information system.

II. INFORMATION SYSTEMS IN SPORT

The sport system is not a closed system, but instead it is conceived as a segment of an integral information system of sports that connects all other information subsystems. The aforementioned subsystems provide support for top sports, school sports, sports recreation,

sports for people with disabilities, sports communities, scientific activities, media, public sports programs, etc. The ISS collects, stores, retains, processes and delivers information important to the organization and the successful performance of all sports related segments, so that they are accessible for communication and useful to all of the entities in sports. The IS in sports was conceived in such a way that under conditions and with the constraints stemming from the achieved degree of IT development, the degree of information literacy, and the available equipment and material possibilities, it ensures the collection, processing and distribution of data essential for the further development of all entities in sport that create or use IS in Croatian sports.

The basis of the development of a system theory is premised on the ancient Aristotle's conclusion that the whole is more than the sum of all its parts, which made the ancient Greeks understands the existence of an understandable order within a practical world, which can be managed with the help of logical activities. The idea of the system is accepted as a fact, both for living organisms and social groups, and has recently been developed for the various complex systems in which an interaction occurs between different types of living and non-living elements. In order for a concept to be scientifically and professionally considered, it is necessary to look at the theories on which it was founded, that is, their initial forms and developmental stages. The general system theory (hereinafter referred to as GST) seeks to formalize systematic thinking and to direct it towards the pragmatic problems of growth and development of the observed system. GST is a science that deals with systems and the regulations present within them, the theories being characterized by the approach in which each entity is viewed as part of a whole. From the aforementioned, it is obvious that the GST is not a special theoretical novelty, but represents the continuity of the initiated analysis promoted through the biologist-organicist direction of the late 19th century, whose most significant representative is Spencer (1). Research indicates that it is a concept characterized by a broad connotation that leads to the conclusion that the requirement for a more precise definition of the concept of a system in history, as well as today, is a *conditio sine qua non* of future thinking related to system theory and its relationship to other relevant theoretical concepts organizations within social sciences.

In relation to the aforementioned each system with its environment exchanges matter, energy and information, causing therefore the input information within a system to be transformed into output information (2). Therefore, when referring to a concept such as an information system (hereinafter referred to as IS), we acknowledge that part of the real system that serves to transform input information into output information. The IS through history has undergone various development phases where previous development phases are continuing on the next: data processing, the development of the IS, the development of decision support systems, the development of expert systems (3), as well as the development of executive ISs that support the execution of business decisions.

Each IS collects, stores, keeps, processes and delivers information important for organizations, including sports organizations, for their successful performance, making the information accessible and useful to everyone. It should be emphasized that the IS can, but not necessarily, use information technology, and as such is an integral part of the target-oriented system, whose basic function is a permanent supply of necessary information at all management and decision-making levels at any given organizational or technological level. An IS consists of the following elements: hardware, software, lifever, orgver, and netver (4). The IS is one of the layers of the organizational system, whose purpose is also the collection, processing, storage and distribution of information necessary for the managing of this system, therefore their goals must be mutually harmonized. Given that the organizational system exists and operates within a changing environment, there is a need for the construction of an IS that would meet the new requirements in a fast and efficient manner. The construction of appropriate ISs for complex organizational systems, such as, for example, sports, is therefore not an easy task, and requires the understanding of goals and ways of functioning of a sports organizational system in order to develop a systematic approach to the construction of the IS. A planned systematic approach includes a predetermined and purposeful drafting of the system design, the determination of time frames for the performance of a particular construction task, the resources to be used, and, ultimately, the ways of building the IS itself. A quality planning and management is a significant prerequisite for the successful operation of an organizational system and all its subsystems.

The priority of a particular IS construction plan within the hierarchy of plans is defined by the plan of the hierarchy of goals, the plan-management level and the planning period for which the plan is being drafted. The hierarchy of goals, as a hierarchy of states that are to be achieved through the purposeful functioning of the IS, can be divided into strategic, immediate and indirect goals. The strategic goals ensure the survival of the system, the immediate goals quantitatively and qualitatively present the intermediate goals, while the indirect ones refer to the adaptability and growth of the system. Similarly the division according to the organization theory can be structured according to three levels of management: strategic, tactical and operative

Thus, the overall construction of the IS occurs over several steps, and their goal depends on the used method of construction. However, regardless of the method used, the product is expected to be an efficient and reliable IS. The development of an IS takes place according to the applied methodology in a number of planned steps, and through clearly defined phases: the logical design, i.e. planning, analysis and formatting of the IS, the physical

design/construction of the system and the introduction, application and maintenance of the IS.

During the seminar *Establishing a Regional Network of Information Systems in Sport in the Countries of South East Europe* a Slovenian model of sports IS was presented, which, according to the presented data, represents a successful model of informatization of sports that relies on Internet technology, information procedures and partnerships between sports entities and the information center that unifies and channels all of the information (5). Accordingly, it is necessary to understand the goals and the ways of functioning of all levels of the sports organizational system as well as its planning and the systematic approach to the construction of the IS (6). Furthermore, in order for the future better functioning of the IS in Croatian sports, it is necessary to access the construction of databases with information about the characteristics and the selection of athletes, sports schools, the educational levels of trainers and other professional staff, the categorization, methodology and programming of sports preparation and the training process, etc. (7).

The future of informatization in various fields of sports/kinesiology is the development and use of expert systems (8), with the sports field often considered to be a "gold mine". This exploitation will depend on establishing stronger relations between information technology, kinesiology and information science, as well as on the financial investments in the mentioned field. The expertise of the training process, the administrative and organizational processes and the expert simulations of certain sports are close to the future of sport informatization, but they need to be preceded by the process of collecting and analyzing objective statistical indicators for specific areas or segments of sport (9). Consequently, after the construction of a unique national IS, there will be a need for its implementation at the level of local sports communities, while observing the local specificities. Therefore, in order to have a better understanding of an IS's application, it is important to pay attention to the concept of a sports organization, which will be discussed in the following segments.

III. SPORTS ORGANIZATIONS

An organization defines its organizational structure in such a way as to overcome the degree of uncertainty it encounters in its environment, and its structure differs from organization to organization in form, complexity and dynamism. The IS are today ubiquitous and they define every aspect of contemporary human life, while the users (organizations) of such systems are becoming more and more demanding and have different kinds of information requirements (10). By being used in almost all segments of society as well as by diverse organizations, and with the emergence of increasingly modern and more accessible platforms, the IS are becoming increasingly complex. Therefore, the IS in sport organizations represents a systematized set of activities, procedures, methods and technologies for collecting, processing, storing and distributing data and information. For its successful functioning as a system it is necessary to build an IS whose quality is influenced by the construction approach, concept of construction, technical foundation, concept of building management and system functioning (11). The elments of behavior of the individual decision maker existed already in classical theories and that they were presented by Smith and Ricard. The IS organization can be defined as a structural communication within an organization, i.e. within the functional segments and the environment. By taking into account the development of modern theories, and accordingly the ICT technologies, and the application of these theories, the IS within an organization is rapidly evolving and changing. The IS in organizations (such as sports ones), depend on the characteristics of the business system of the organization itself. That means that the ways and procedures for collecting, creating, exchanging, storing, distributing and using data and information in an organization's business system depend on the organization of the entire business system organization, the technological basis of the IS, the nature of the process within an organization, the methods and the levels of management and use of data and information about an organization and the IS, and the type of data and information that is generated in a business system and which the IS is exchanging with the environment (12).

The IS in sport organizations is a representation of the organization's business system, and is divided into formal (which includes information policies, procedures, principles and practices) and informal systems (includes the information related to the organization processes and other events from its environment). Likewise, the IS of sports organizations, according to their performance, can be divided into classical (usually without the ICT technology support) and contemporary sports IS (with the support of modern ICT technology). The next chapter will describe the systematic approach of building an IS in sports organizations.

A systematic approach is presented through modeling, classification and control of the IS in the context of governance, formulation and decision making, and he emphasizes the principles of a systematic approach in building organizational systems: complexity, integrity, dynamism, interdisciplinarity, decision-making orientation, self-organization and openness (13). The analogy with IS in sports organizations can be easily established, since this type of organization is a complex system with heterogeneous elements and processes that are in constant interaction and connection (14). This interaction needs to be described at all levels, from the implementation of the IS within the organization, through the description of processes on which the interaction of IS elements is based on at different organizational levels, to the interaction of the IS itself with its environment. In accordance with the previously mentioned, the systematic approach requires that all occurrences in the real world as well as the imagined ones are viewed as complete entities that exist and work within their surroundings. This approach was acknowledged in the 1930s, and today it is the basis of the research methodology both in

fundamental and applied sciences. The systematic approach, therefore, represents the most comprehensive approach that allows us to observe everything that surrounds us as a system. Based on this, there are several types of systems that are differently defined. A systematic approach to organization in theory and in practice represents a tendency for organizations to be viewed as systems - cohesive sets of subsystems (elements) which are mutually interacting, as well as interacting with their environment. A systematic approach to the organization was developed due to the increased complexity of organizations and the increasing uncertainty of their environment. Consequently, the theoreticians and practitioners have recognized the hierarchical multilayered structure of the organization (each organization consists of a series of subsystems, but it is also part of a higher order system). Furthermore, emphasis is being placed on the importance of developing a broader perspective of viewing which, besides the transformation of the inputs into outputs (closed system), also recognizes the interaction between the system and its environment, that is, the organization's dependence on the environment (open system) (15). Modern sports and sports organizations, both as social and economic systems, are developing intensively in all segments of their activities, especially in relation to business under the influence of globalization segments and their contribution to the development of professional sports, causing sports organizations to develop into a big "business". In order to show the diversity of the IS, and the possibility of its application within sports, the following analysis will focus on two sports organizations that are apparently similar, although structurally different. The Sports Association of the City of Zagreb was used for its comparative value, while the research was conducted on the example of the Sports Association of the City of Zadar.

Zadar has a large number of legal entities within the field of sports with about 10,700 active athletes and approximately 12,600 recreational participants in 57 sports and sporting branches. There are 171 members of the Sports Association of Zadar, representing forty-four sports and institutions important for the development and promotion of sports in the City of Zadar. The activities of the Sports Association of the City of Zadar are focused on the public sports programs, the joint programs of the HOO and the Sports Association, sports promotion programs in the City of Zadar, programs for children and youth, the training of professional staff and publishing activities, the planning, use and construction of sports facilities, international co-operations, health care, IT and professional services. These activities also generate the information for each appropriate ISS subsystem of the Sports Association of Zadar. Additionally, it is important to point out that the subsystem for the sports evaluation criteria and the IS indicators for the evaluation process support were particularly relevant for this research.

The following can be stated concerning the importance of the Sports Association of the City of Zagreb (SACZ): There are about ¼ inhabitants of the Republic of Croatia living in Zagreb, the distribution of financial resources in the Republic of Croatia is the largest in Zagreb, the material base of sporting activities is most developed in Zagreb, the sports in Zagreb are characterized by high quality staff, organizational solutions, and sports-related habits. The management of the sports system at the level of the City of Zagreb, which includes 71 sports associations that are joined in the SACZ, and about 800 sports clubs, where, according to the study *Pedagogical Standards and Norms of Sports Work*, there are 55,000 athletes registered in sports system, over 50,000 citizens involved in sports recreation, 17,000 students involved in the system of school competitions and 4,000 university students, is a very demanding work in terms of satisfying and financing the objective needs of each sport with regard to their specificities. It is therefore imperative to be familiar with the evaluation methods used for the evaluation of sports. The similarities between the Sports Association of the City of Zagreb and the Association of the City of Zadar are centered around the use of the IS for conducting business activities and the evaluation of sport and sports associations. The basic motive behind the design and use of the IS was derived from the analysis of several important facts - legal frameworks, lack of linking between interconnected programming units, the rapid development of ICT technologies, the "capabilities" for connecting to a global IS, etc. By grouping the process and classes according to the needs of the SACZ's organizational system, the following IS subsystems emerged: developmental, professional programming and planning activities, sport resources and conditions, sports offer, personnel, legal affairs, business and general affairs, finances, accounting and IT jobs. Accordingly, it is visible that under the influence of systematic planning different methods were developed for the building, using, modelling and improving of the IS of different sports associations.

The most commonly used are structural diagrammatic methods, which give a clear view of these systems. The integration of the diagrammatical methods also implies the standard notations for the expression of the necessary constructs used to automate systematic analysis. However, when it comes to the systems of the aforementioned sports organizations, in an area of social interest such as sports, the ISs are always complex, and therefore require constant improving.

IV. RESEARCH RESULTS

The research covered 97 subjects that applied for the Public Sport Program in the City of Zadar during 2014 and 2015. The public needs of Zadar City sports during 2014 and 2015 were based on the level of sports achievements during the previous year, the opportunities and the development of sport, as well as activities of sports associations, economic achievements and the possibility of providing funds via the budget of the City of Zadar. The City of Zadar Public Sports Program for the aforementioned period is based on budget funds as the dominant part of Zadar's total sport funding.

For the purpose of testing the correlation of indicators, the defined evaluating criteria and the effectiveness of the information system for the support of the valuation of sports and sports associations, a method of content analysis was used. The content analysis method is considered to be a primary data collection method, using information material as such, as well as texts in general, and it is particularly well developed in sociological research of textual or visual empirical materials.

Table 1 shows the mapping of the observed information system indicators used for the valuation of sports associations of SACZ together with the criteria for the evaluation of sports in the SACZ. Based on the completeness of the mapping process (the default evaluation criterion corresponds to one or more of the relevant indicators), it can be concluded that the relevant indicators of the information system supporting the evaluation of sports associations of SACZ are based on the same valuation criteria used in the valuation of sports in the SACZ.

Table 1 - Mapping of the criteria for evaluation of sports in the SACZ and the indicators of the information system for evaluation support of the sports associations in SACZ

Criteria	Indicators
a) Level of development of sports	• Number of registered clubs in an association • Age category participation in a competition • Number of members / popularity in sports schools • Professional staff
b) Public system	• Number of registered clubs in an association • Number of members / popularity in sports schools • Tradition of a sport • Type of sport (Olympic, Non-Olympic)
c) Quality of sport	• Ranking of an association's competition • Professional staff • Number of team members competing

The only IS indicator from the Regulation of the quality of Zadar sports which could not be mapped with a specific criterion for the evaluation of sports as listed in the document *The Criteria for the Evaluation and Selection of the Sports Public Needs Program in the City of Zadar* refers to the indicator of the number of members of a competing team.

The content analysis units for the purpose of this research are the *Association's Program Reports*, which are collected for the purpose of evaluating the Sports Public Needs in Zadar. In this respect, the sample used for the research was relating to the 2013 and 2014 Program Reports of the associations, used in the evaluation process of sports associations in 2014 and 2015. Using a content based analysis, the correlation between the information system indicators, the criteria for evaluating sports and sports associations and the efficiency of the SACZ information system was examined.

In this regard, the information system is effective if there is at least one indicator that stems from the predetermined valuation criteria. Hence, it becomes easy to conclude that the information system becomes more effective if more indicators arise from the predetermined evaluation criteria. Therefore, the objective of the content analysis method is to find new and refine the existing indicators of the information system for the evaluation of sport and sports associations of the SACZ. New indicators, in most cases, have been suggested in cases where the Association's Program Reports did not come across an indicator resulting from a specific evaluation criterion defined in the Handbook.

On the other hand, the process of refining the existing indicator (i.e. the introduction of a sub-indicator) was done with reference to the encountered problem situation within the program reports that were analyzed. Of course, a reversed situation can occur as well where the information on the identified problem situation generates an indicator that would correspond to a particular evaluation criterion in the Manual, but also that, during the search for an adequate indicator derived from the individual evaluation criteria in the Manual, only the existing indicator specifies or introduces the sub-indicator.

A problem situation involves an insight into the presence of information in the program reports of sports associations that are not covered by existing indicators, and that may have made the evaluation process more just. Accordingly, the information system is more effective if all the problem situations are changed into indicators.

The above-mentioned program reports were submitted by the associations on the basis of a Public Call for the Sports Public Needs Program in the City of Zadar for 2014 and 2015. The analysis covered the reports of all associations that applied for the Public Sports Program in the mentioned period, and were evaluated on the basis of the criteria in accordance with the Regulation of the Quality of Sports in Zadar.[1]

It should be recalled that the SACZ information system in this case refers to a set of documents that sports associations used when submitting their applications to the SACZ according to a Public Call for the Sports Public Needs Program in the City of Zadar published by the City of Zadar and the Sports Community of the City of Zadar in the newspapers of the City of Zadar in December 2013 and 2014. The documentation and data that are being analyzed are determined by the legal provisions of the Sports Act[2] and the criteria for the evaluation of sports and sports associations in the City of Zadar. The program reports were submitted on a specified form distributed to the associations in order to make the analysis and data clarity more accessible and universal to all interested parties.

By analyzing the content of the program reports of the association for the considered period, the need for new indicators as well as the need to improve the existing ones using an IS has been identified, which will affect a more just/effective evaluation of the associations. Given that the

[1] Regulation of the Quality of Sports in Zadar - *http://www.szgz.hr/wp-content/uploads/2014/11/Pravilnik-o-nositelju-kvalitete-zadarskog-%C5%A1porta.pdf (2017-01-29)*

[2] Republic of Croatia (2006) *Sports Act - Offical Gazette, 71/06, 150/08, 124/10, 124/11, 86/12, 94/13, 85/15,96/16.*

above-mentioned criteria in the Manual are generalized and therefore not sufficiently specific for the sports associations themselves, they are, as the title of the Manual suggests, applicable to all associations implementing projects and programs for the general good in the Republic of Croatia. It was therefore expected that some evaluation criteria from the Manual will not be found in the existing SACZ information system. For this purpose, the Manual has been used as a guideline for the upgrading of the existing information system in order to find out more precise indicators that will contribute to a more just/effective evaluation of associations and sports, which in fact reflects the efficiency of the SACZ information system relating in turn to a specific area of sport. Table 2 indicates the mapping of evaluated sports according to the criteria and indicators.

Table 2 Excerpt from the table presentation of the ranking and categorization of sports in the City of Zadar for 2014

Number	1.	2.	3.	4.	5.	6.
Sports	Basket ball	Soccer	Volley ball	Saili ng	Hand ball	At hle tic
Development and tradition of the sport (num. of points)	19	20	20	14	18	18
Quality of the sport (num. of points)	18	17	11	11	9	8
Public status of a sport (num.of points)	20	20	12	15	11	10
Total	57	57	43	40	38	37
Category of a sport	I	I	I	I	I	I

V. CONCLUSION

In the Republic of Croatia, the application of IS in sports activities has not yet come to fruition, given the complexity and comprehensiveness of the problems that sport faces, such as legislation, sport valuation, transparency, lack of modern information communication technology, insufficient funds, etc. As stated, in the field of sports the organizations emerge as "interest associations" with the aim of facilitating sports activities of interested parties through various legal procedures in the form of legal regulations pertaining to organizations within a particular society. The legal regulation of sport is based on the Croatian sport tradition, the tradition of legal regulation of sports, as well as Article 69, paragraph 5 of the Constitution of the Republic of Croatia, according to which "the State encourages and assists in the care of physical culture and sport". Every organization, including sport organizations, owns an IS which is dependent on its environment and is constantly being upgraded. In accordance with all the above, the construction, maintenance, use and even modeling of an IS is not a one-time and conclusive job of a sports organization. As such an IS should not be a book forgotten in some drawer, but instead an encyclopedia of knowledge about the sports organization system, which is constantly being aligned with the actual changes and needs of a sports organization.

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Informacijske tehnologije i intelektualno vlasništvo s osvrtom na regulaciju kaznenih djela protiv intelektualnog vlasništva u Bosni i Hercegovini

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***Sažetak* - Razvojem informacijske infrastrukture porasla je i važnost intelektualnog vlasništva. Internet i intelektualno vlasništvo su dva fenomena koji posjeduju dva suprotna svojstva. Internet kao globalna računalna mreža koja omogućava pristup informacijama te olakšava komunikaciju, predstavlja komunikacijski medij koji po prvi puta omogućava komunikaciju mnogih s mnogima i to na globalnoj razini. Činjenica da internet ne poznaje granice, postavlja pitanje o odgovornosti pružatelja internetskih usluga koji poslužuju internetske stranice kojima se ne poštuju prava intelektualnog vlasništva. Zaštita intelektualnog vlasništva zasnovana je na teritorijalnom principu, za razliku od Interneta koji je neteritorijalan. U radu se ispituje odnos prava korisnika usluga pristupa Internetu i nositelja prava intelektualnog vlasništva, u kontekstu zaštite intelektualnog vlasništva, koje se ne poštuje na Internetu. Ono što je neophodno u suzbijanju kršenja prava intelektualnog vlasništva jest stabilan pravni sustav s jakom zakonskom regulacijom.**

Ključne riječi - Internet, intelektualno vlasništvo

I. UVOD

Intelektualno vlasništvo odnosi se na kreacije uma: izume, književna i umjetnička djela, simbole, imena, fotografije i dizajn, topologiju elektroničkih elemenata, zaštitu verbalnog i grafičkog žiga te licence za korištenje, a koja se koriste na tržištu. Skup prava koje nazivamo intelektualno vlasništvo omogućuje autorima određene povlastice, dok istovremeno onemogućuje drugima da se bez dozvole koriste tim kreacijama. Pravo intelektualnog vlasništva obuhvaća pravne instrumente kojima se uređuje način stjecanja intelektualnog vlasništva i način zaštite od njegovog neovlaštenog korištenja. Ova prava imaju autori i ostali nosioci prava intelektualnog vlasništva. Razvoj informacijske infrastrukture posljednjih desetljeća koja uključuje širenje upotrebe osobnih računala, mreža koje ih povezuju doveo je do promjena u načinu na koji su informacije kreirane, kopirane i distribuirane. Računalna mreža je sustav koji povezuje različite ili slične uređaje u jednu cjelinu. Današnje se računalne mreže sve više temelje na TCP/IP skupu protokola zbog jednostavnog definiranja adresa uređaja na mreži te zbog mogućnosti povezivanja na Internet i korištenje njegovih mrežnih usluga. [4]

Integracija informacijske infrastrukture u svakodnevni život omogućila je ljudima pristup Internetu čime zahvaljujući lakoj dostupnosti sadržaja često dolazi do povrede intelektualnog vlasništva. Intelektualno vlasništvo zaštićeno je odredbama zakona te podzakonskim aktima, a predstavlja i predmet zaštite međunarodnih ugovora. Širenjem intelektualnog vlasništva došlo je do potrebe da se usaglase nacionalna zakonodavstva. Dosad je to učinjeno na nivou Svjetske trgovinske organizacije – WTO. Sporazum WTO-a o trgovinskim aspektima prava intelektualnog vlasništva natjerao je države na brojne regulacijske reforme. Rastuća važnost kreativnih industrija i informacija, vidljiva je u kontinuiranom pomaku prava intelektualnog vlasništva prema globalnom tržišnom modelu.

Svjetska organizacija za intelektualno vlasništvo (WIPO) osnovana je 1967. godine u Stockholmu s ciljem da se ohrabre kreativne aktivnosti, i promovira zaštita intelektualnog vlasništva u cijelom svijetu. WIPO sa sjedištem u švicarskom gradu Ženevi ima 191 državu članicu, a od 1974. godine je jedna od 17 specijaliziranih agencija Ujedinjenih naroda. [1]

Aktivnosti WIPO mogu se grupirati u tri vrste:

- registarske aktivnosti;
- promocija suradnje između država članica i
- programske aktivnosti.

Sve ove aktivnosti predstavljaju samo sredstvo k ostvarenju osnovnih ciljeva WIPO-a, da štiti intelektualno vlasništvo na svjetskom nivou, u cilju stimuliranja gospodarskog i kulturnog razvoja država, i da potiče kreativni rad i olakšava transfer tehnologije i širenje umjetničkih djela. TRIPS sporazum je najsveobuhvatniji multilateralni sporazum o intelektualnom vlasništvu. Osnovna namjera ovog Sporazuma je olakšati međunarodnu trgovinu, uzimajući u obzir zaštitu prava intelektualnog vlasništva. Ovim Sporazumom inzistira se na suradnji između između Svetske trgovinske organizacije i WIPO-a. Na drugom sastanku ekspertne skupine WIPO-a i UNESCO-a u Parizu 1982. godine, glavni zaključci sastojali su se u priznavanju autorskopravne zaštite svim djelima nastalim korištenjem računala, i širenjem odredaba o mogućnosti isključenja trećih iz korištenja tih djela pomoću informacijskih tehnologija. Bez obzira koliko je sofisticirano računalo

koje je korišteno za nastanak djela, ono je ipak samo oruđe, a autor djela nastalog putem računala je osoba koja je zamislila djelo i dala instrukcije računalu prilikom kreacije djela.

Globalna regulacija pomaknuta je od dosadašnje regulacije preko patenta, autorskih prava – WIPO-a i zasebnih nacionalnih prava prema tržišnim režimima, što je 1994. godine rezultiralo potpisivanjem ugovora, koji obavezuje države članice na pojačavanje mehanizama zaštite intelektualnog vlasništva. Nedopuštena razmjena datoteka sa zaštićenim djelima, uz pomoć novih tehnologija, povreda je prava intelektualnog vlasništva na Internetu. Mjere koje se mogu izreći protiv davatelja usluge pristupa Internetu, navedene su u Direktivi 2001/29/EZ o usklađivanju određenih aspekata autorskog prava i srodnih prava i Direktivi 2004/48/EZ o provedbi prava zaštite intelektualnog vlasništva. [2] U području autorskih i srodnih prava, ciljevi Direktive o usklađivanju određenih aspekata autorskih i srodnih prava u informacijskom društvu (2001/29/EZ) su usklađivanje propisa u oblasti autorskih i srodnih prava kako bi ono odražavalo tehnološki razvoj, te prenošenje u pravo EU osnovnih međunarodnih obaveza koje proizilaze iz dva ugovora o autorskim i srodnim pravima, usvojena u okviru WIPO-a.

Cilj ovog rada je naglasiti potrebu pronalaženja i uspostavljanja ravnoteže između otvorenog pristupa intelektualnom vlasništvu i pravnoj zaštiti, odnosno naglasiti važnost stabilnog pravnog sistema zaštite intelektualnog vlasništva, kao i osigurati, koliko god je to moguće, slobodan pristup, kako bi se proizvodnja znanja neometano razvijala.

Rad je struktuiran u šest poglavlja: Prvo poglavlje je uvod u rad. U drugom poglavlju opisane su promjene u društvu znanja koje predstavljaju odraz važnosti znanja i informacija. Zbog rastuće vrijednosti, intelektualno vlasništvo pomiče se prema tržišnom modelu, što je izraženo u kreativnim industrijama. Kao društveni odgovor na restriktivnu politiku intelektualnog vlasništva formiraju se novi društveni pokreti, koji zahtijevaju veći i slobodniji pristup online sadržajima. U trećem se poglavlju daje prikaz računalne mreže Svjetske organizacije za intelektualnu vlasništvo i ostalih mreža intelektualnog vlasništva. Četvrto poglavlje se odnosi na regulaciju kaznenih djela protiv intelektualnog vlasništva u Bosni i Hercegovini kod kojih se kao sredstvo izvršenja javljaju računala. Peto poglavlje je zaključak.

II. INTELEKTUALNO VLASNIŠTVA U INFORMACIJSKOM DRUŠTVU

Intelektualno vlasništvo predstavlja specifičan oblik privatnog vlasništva koji se razlikuje od ostalih oblika vlasništva po upotrebi, objektima posjedovanja i trajanju prava. Objekti posjedovanja intelektualnog vlasništva su nematerijalni, što ga čini atipičnim oblikom vlasništva. Intelektualno vlasništvo opravdano je jer je društveno korisno, a ako ne bi postojalo autori i izumitelji možda bi proizvodili manje ili ne bi uopće proizvodili. Intelektualno vlasništvo omogućuje autorima povlastice poput distribucije i prodaje kopija, prava na nastupe i prikaz djela u javnosti, a onemogućuje drugima korištenje bez dozvole. Ipak, uzimajući u obzir kulturnu i društvenu vrijednost intelektualnih kreacija dopuštene su određene upotrebe i prije isteka vlasništva. Za razliku od ostalih oblika vlasništva intelektualno vlasništvo vremenski je ograničeno. Autori određen period uživaju monopol, međutim nakon isteka trajanja vlasničkog odnosa, djela postaju dostupna svima.

Značaj intelektualnog vlasništva za informacijsko društvo proizlazi iz Interneta i informacijskih tehnologija. Nove tehnologije omogućile su brzo i jeftino objavljivanje na Internetu, što ima značajne implikacije za kreativne industrije. Mnogi autori naglašavali su značaj Interneta kao novog, oslobađajućeg medija i predvodnika novog informacijskog društva u kojem će se pojedinci osloboditi tradicionalne društvene, državne i kulturne kontrole. Sustav intelektualnog vlasništva uključuje sukobe interesa između država i interesnih grupa koja se zalažu za veću ili manju zaštitu. Regulacija intelektualnog vlasništva u informacijskom društvu ima važne implikacije koje uključuje pitanje pristupa tehnologijama i online sadržaju. [3] Pitanja kontrole pristupa i vlasništva nad kreativnim sadržajima, postaju dominantna u informacijskim društvima, budući da su proizvodi reproducirani i distribuirani pomoću novih informacijskih tehnologija. [4] Regulacija digitalnih sadržaja je značajna za autore. Velika pokretljivost digitalnih sadržaja otežava kontrolu zaštićenih radova pri čemu osnovni problem predstavlja neovlašteno preuzimanje i dijeljenje podataka.

Zaštita sadržaja i veća kontrola na Internetu, tema su mnogih debata oko regulacije intelektualnog vlasništva. Posljedica integracije informacijske infrastrukture u društvo jest i postojanje velikog neslaganja u društvu oko prirode i legitimacije institucija intelektualnog vlasništva. Društvo znanja zahtijeva slobodan protok znanja, ideja i kreativnosti kako bi napredovalo. Mnogi ljudi prakticiraju online piratstvo jer smatraju da je sustav intelektualnog vlasništva preskup. Korisnici smatraju kako je „skidanje“ materijala zaštićenog autorskim pravom društveno prihvatljivo, žele veći i lakši, a ponekad i besplatan pristup, te ne vide online piratstvo kao nešto loše.

U posljednjem se desetljeću, od strane civilnog društva često naglašavaju negativni učinci preopširne zaštite intelektualnog vlasništva. Njihov je stav kako je sadašnji sustav intelektualnog vlasništva previše ograničavajući te kako ometa inovaciju i kreativnost, te da je potrebno modificirati sustav intelektualnog vlasništva kako bi više odgovarao potrebama društva znanja. [5]

Jačanje intelektualnog vlasništva, naglašava informacijsku razliku između bogatih i siromašnih država. Većina intelektualnog vlasništva pripada SAD-u, Europi, Japanu i Kini.

III. RAČUNALNE MREŽE SVJETSKE ORGANIZACIJE ZA INTELEKTUALNO VLASNIŠTVO

Informacijsko komunikacijske tehnologije su stvorile preduvjete za objedinjavanje informacijskih

instituta intelektualnog vlasništva u jedan jedinstven resurs dostupan svima na bilo kojem kraju svijeta. Značaj intelektualnog vlasništva u svijetu postaje direktno proporcionalan kvaliteti informacijsko komunikacijskih tehnologija. Svjetska organizacija za intelektualno vlasništvo kao i države članice, raspolažu ogromnim količinama informacija koje se mjere milionima zapisa kompjuterskih baza podataka. Da bi dohvat informacija bio efikasan neophodna je računalna infrastruktura kao podrška. WIPO je računalnom mrežom WIPOnet unificirao informacijski razvoj Svjetske organizacije za intelektualnu vlasništvo. WIPOnet-om se ostvaruje elektronička veza s institutima za intelektualno vlasništvo svijeta i razmjena informacija s njima.

WIPOnet osigurava:

• Komunikacijsku infrastrukturu i Internet pristup za članice;

• Server infrastrukturnog računalnog razvoja, zaštitu i platformu za servise i programe;

• Posjedovanje infrastrukture za korištenje WIPOnet-a: PC, lokalne mreže i softver.

Pristupi mreži WIPOneta se dobivaju:

• Informacije samo za članice WIPO i

• Informacije svima dostupne preko Interneta.

WIPOnet-ovi servisi specifični za područje intelektualnog vlasništva su:

1. Elektroničko podnošenje međunarodnih prijava.
2. Razmjena informacija o registraciji žigova.
3. ON-Line arbitraža koja omogućava međunarodni prijem na elektroničku datoteku koja evidentira rasprave na nivou WIPO-a.
4. WIPOnet elektronička biblioteka za intelektualno vlasništvo, predstavlja elektronički ekvivalent papirnatim zbirkama dokumenata.
5. WIPO Svjetska akademija putem WIPOnet-a priprema video konferencije, učenje na daljinu, čija primjena pomaže prenošenju informacija državama u razvoju. [6]

Realizacijom WIPOnet-a raspoloživi su bazni servisi WIPOnet-a: E-mail, mailing liste, razmjena podataka, web hosting, user directory, helpdesk, digitalna biblioteka, komunikacija vezana za WIPO abitražu, komunikacija vezana za Madridski aranžman, Učenje na daljinu–WIPO Akademija. Pored WIPO-a i nacionalnih organizacija za intelektualno vlasništvo postoje i regionalne organizacije kao što su, Euroazijska organizacija za patente (EAPO) i Europska patentna organizacija (EPO), ili Trilaterala koju čine EPO, USPTO (Patentna organizacija Sjedinjenih Američkih Država) i JPO (Japanska patentna organizacija). Članstvo u ovim organizacijama se ostvaruje dobrovoljnim uključivanjem uz ispunjenje određenih uvjeta i prihvaćanjem sporazuma. [7]

Patent je mreža koja omogućuje sigurnu međupovezanost između europskih nacionalnih instituta za intelektualno vlasništvo. Tendencija je da se mreže intelektualnog vlasništva povezuju pa se može očekivati integracija svih relevantnih izvora intelektualnog vlasništva u svijetu u jednu jedinstvenu globalnu mrežu.

Iz navedenih aktivnosti jasno se nazire daljnji trend integracije parcijalnih računalnih mreža intelektualnog vlasništva u svijetu u jedinstvenu svjetsku mrežu intelektualnog vlasništva.

Prednost koju korisnicima pruža povezivanje u računalnu mrežu jest otvorenost prema drugim računalima i drugim mrežama te mogućnost pristupa informacijama bez obzira na razdvojenost. Računalnoj opremi moguće je pristupiti s brojnih i udaljenih lokacija koje najčešće uopće nisu pod nadzorom vlasnika ili administratora računala. Računalne mreže proizvele su nove produkte koji se štite pravima intelektualnog vlasništa, a zbog kojih je trebalo dopuniti postojeće ili donijeti potpuno nove zakone i međunarodne konvencije. Primjera radi, zbog pojave računalnog programa, mijenjali su se svi nacionalni zakoni o autorskom pravu. Isto tako potreba za zaštitom baza podatka rezultirala je sui generis zaštitom u nacionalnim zakonima o autorskim i njima srodnim pravima. O značaju informacijsko komunikacijskih tehnologija u intelektualnom vlasništvu govori činjenica da u okviru WIPO-a djeluje stalno tijelo za informacijsko komunikacijske tehnologije – SCIT. Pod kontrolom ovog tijela je izvršen razvoj WIPOnet mreže. Značaj koji se intelektualnom vlasništvu daje u 21. stoljeću, ukazuje na opasnosti kojima će biti izložena WIPOnet mreža. Zaštita sustava intelektualnog vlasništva može se promatrati kroz tri nivoa:

1. Ugroženost globalne mreže intelektualnog vlasništva.
2. Ugroženost prava intelektualnog vlasništva, jer se prijave za zaštitu intelektualnih prava podnose elektroničkim putem, što težište sigurnosti svjetskog sustava zaštite intelektualnog vlasništva prebacuje na informacijsko komunikacijske tehnologije.
3. Ugroženost intelektualnog prava podrazumijeva zaštitu pronalazaka iz domene informacijskih tehnologija.

U okviru Europske unije donesene su posebne direktive/smjernica za zaštitu računalnih programa, baza podataka i topografije poluvodičkih proizvoda. Europska konvencija o cyber kriminalu donesena u Budimpešti pod okriljem Vijeća Europe (u daljem tekstu Konvencija), prvi je prihvaćeni multilaterarni sporazum kojim se sankcioniraju kriviča djela izvršena preko Interneta i drugih računalnih mreža i veoma je značajna za zaštitu intelektualnog vlasništva. Sadržajem članka 10. Konvencije, države potpisnice su se obavezale da usvoje legislativne mjere, da u nacionalna prava kao krivično djelo okvalificiraju kršenje autorskih prava definiranih u zakonima, te članice koji se odnose na obaveze koje je ona preuzela po Praškom aktu iz 1971. godine, Konvenciji iz Berna o zaštiti književnih i umjetničkih djela, Konvenciji iz Rima o zaštiti izvođača i proizvođača fonograma, Sporazumu o aspektima prava na intelektualno vlasništvo i WIPO ugovoru o autorskim pravima.

Trgovinski sporazum protiv krivotvorenja (ACTA) potpisan je 1. listopada 2011. godine u Tokiju od strane SAD-a, Japana, Kanade, Maroka, Novog Zelanda, Singapura i Južne Koreje. Nedostatak sporazuma protiv krivotvorenja – ACTA su:

1. ACTA ne pravi razliku između korisnika za koje postoji osnovana sumnja da ne poštuje pravo intelektualnog vlasništva i drugih korisnika. Dovoljno je da nosilac prava tvrdi da određeni korisnik njegovo pravo ne poštuje.

2. ACTA, pored građanskopravne zaštite, nameće državama potpisnicama obavezu krivičnopravne zaštite, povreda prava intelektualnog vlasništva, što je u suprotnosti s Direktivom EU 2004/48. U ACTA-i se ne pravi razlika između kopiranja koje je korisnik izvršio za vlastitu upotrebu i onog za nezakonito stjecanje profita.
3. ACTA predviđa mogućnost da države potpisnice mogu ovlastiti nadležne organe da traže od pružatelja internetskih usluga podatke o korisnicima za koje se sumnja da krše prava sa svojih internet adresa. Trgovinskim sporazumom protiv krivotvorenja - ACTA predviđa se i uspostavljanje agencije za sprječavanje krivotvorenja i besplatnog preuzimanja sadržaja s interneta uz prijetnju sankcijama.

IV. REGULACIJA KAZNENIH DJELA PROTIV INTELEKTUALNOG VLASNIŠTVA U BOSNI I HERCEGOVINI

Bosna i Hercegovina je usvojila i prihvatila sve međunarodne konvencije i sporazume iz područja intelektualnog vlasništva. Najvažniji međunarodni instrument, Konvencija o kibernetičkom kriminalu Vijeća Europe iz 2001. godine, s vremenom se pokazao nedostatnim, tako da su Europski parlament i Vijeće EU-a donijeli Direktivu o napadima na informacijske sustave, kojom bi manjkavosti Konvencije o kibernetičkom kriminalu trebale biti otklonjene. Nakon stupanja na snagu Konvencije o kibernetičkom kriminalu i Dodatnog protokola, u odnosu na BiH slijedila je implementacija odredbi kaznenog materijalnog i procesnog prava Konvencije o kibernetičkom kriminalu u državni i nedržavne kaznene i kazneno procesne zakone. [8] Sadržajem odredbi Kaznenog zakona BiH za razliku od ostala tri nedržavna kaznena zakona (Federacije BiH, Republike Srpske i Brčko Distrikta BiH), nisu implementirane preporučene odredbe kaznenog prava već je to „dogovorno prepušteno“ u nadležnost nedržavnim kaznenim zakonima Federacije BiH, RS i Brčko Distrikta. [9]

Kaznena djela protiv intelektualnog vlasništva, iz Konvencije o kibernetičkom kriminalu, kod kojih se kao sredstvo izvršenja kaznenih djela javljaju računala i računalne mreže, uvedena su Kaznenim zakonom Federacije BiH, u članku 242. (Zloupotreba autorskih prava), članku 243. (Nedozvoljeno korištenje autorskih prava), članku 244. (Nedozvoljeno korištenje prava proizvođača zvučne snimke) i članku 245. (Nedozvoljeno korištenje prava radiodifuzije).

Kazneni zakon Federacije BiH u Glavi XXXII u članku 393. propisuje kazneno djelo oštećenje računalnih podataka i programa, u članku 397. propisuje kazneno djelo neovlašteni pristup zaštićenome sustavu i mreži elektroničke obrade podataka. Kazneno djelo iz članka 6. Konvencije o kibernetičkom kriminalu propisano je u odredbama članka 393. stavak 5. [10]

Kazneni zakon Republike Srpske predviđa krivična djela protiv intelektualnog vlasništva u Glavi 16. [11]
Komparacija odredaba kaznenih zakona Federacije BiH i RS preko kojih su implementirane odredbe članka 2. do 9. Konvencije.

TABLICA I.

Čl. KZ F BiH	Naziv kaznenog djela	Čl. KZ RS	Naziv kaznenog djela
393	Oštećenje računalnih podataka i programa	292a	Oštećenje računalnih podataka i programa
388	Računalno krivotvorenje	292e	Računalno krivotvorenje
389	Računalna prevara	292g	Računalna prevara

Ubrzani razvoj informacijskih tehnologija, posebno Interneta, zahtijeva od zakonodavaca u BiH praćenje promjena u ovom području, kako bi se pozitivno zakonodavstvo prilagodilo novim izazovima. Implementacija Konvencije o kibernetičkom kriminalu otvara značajne mogućnosti u tom pravcu. Međutim, neophodno je da implementacija Konvencije o kibernetičkom kriminalu obuhvaća sve njene dijelove, kako dijelova koji se odnose na norme kaznenog materijalnog prava, tako i onih dijelova koji se odnose na norme kaznenog procesnog prava i norme koje se odnose na postupke i mjere međunarodne suradnje. Ovakav pristup naglašavamo iz razloga jer se u praksi, kada se govori o Konvenciji o kibernetičkom kriminalu uglavnom pažnja fokusira na norme krivičnog materijalnog prava. Međutim, zakonodavac nije u potpunosti implementirao predložene mjere i ovlaštenja Konvencije o kibernetičkom kriminalu kako bi nadležna tijela raspolagala efikasnim mjerama i ovlaštenjima za borbu protiv kriminala kod kojih se kao sredstvo izvršenja kaznenih djela javljaju računala i računalne mreže. Nadležni organi za borbu u Federaciji BiH, imaju na raspolaganju mjere i ovlaštenja koje omogućavaju dokumentiranje kaznenih djela, a one se ogledaju kroz radnje dokazivanja i posebne istražne radnje. Tako nadležni organi imaju ovlaštenja zatražiti i zaplijeniti podatke koji obuhvaćaju i podatke o pretplatnicima na telekomunikacijske usluge, izvršiti pretraživanje i zapljenu računala i uređaja za pohranjivanje elektroničkih podataka i izvršiti presretanje podataka u vezi sadržaja. Međutim, navedena ovlaštenja u Zakonu o kaznenom postupku Federacije BiH nisu u potpunosti precizno određena. Iz tog razloga neophodno je izvršiti potpunu implementaciju procesnih odredbi Konvencije o kibernetičkom kriminalu u Zakonu o kaznenom postupku Federacije BiH kako bi u potpunosti bio u funkciji efikasne borbe. Kako bi se procesne odredbe Konvencije o kibernetičkom kriminalu u potpunosti implementirale u Zakon o kaznenom postupku Federacije BiH potrebne su određene izmjene i dopune zakona. U okviru radnje dokazivanja „privremeno oduzimanje predmeta i imovine“ potrebno je naznačiti da se odredbe ove radnje dokazivanja odnose i na podatke koji su pohranjeni u računalima i s njima povezanim uređajima ili medijima koji služe za pohranjivanje i prijenos podataka. Također, potrebno je propisati da se računalni podaci trebaju predati nadležnim tijelima u cjelovitom, izvornom, čitljivom i razumljivom obliku, kada ovu radnju provodi držatelj računalnih podataka.

Komparativni pregled modela propisivanja kaznenih djela računalnog kriminaliteta protiv intelektualnog vlasništva u kaznenim zakonima BiH pokazuje da različiti modeli propisivanja kaznenih djela nisu jedini i isključivi čimbenik koji utječe na sankcioniranje počinitelja navedenih kaznenih djela. Komparativnom analizom odredaba Kaznenog zakona BiH, Konvencije o kibernetičkom kriminalu i Prijedloga Direktiva, pokazuje slabosti implementacije odredbi iz međunarodnih pravnih izvora. S obzirom na buduće članstvo BiH u Europskoj Uniji, u odredbe Kaznenog zakona BiH potrebno je propisati nova kaznena djela protiv intelektualnog vlasništva kod kojih se kao sredstvo izvršenja kaznenih djela javljaju računala i računalne mreže.

V. ZAKLJUČAK

U ovom radu ukazali smo na određene implikacije intelektualnog vlasništva u informacijskom društvu. Revolucija informacijsko komunikacijskih tehnologija i sve brži rast broja izuma, utjecaj i značaj izuma, kao i ubrzana globalizacija, doveli su intelektualno vlasništvo u središte pažnje. Razvoj informacijsko komunikacijskih tehnologija i njihova masovna primjena u poslovne i privatne svrhe, uvjetovali su napade na intelektualno vlasništvo.

Sustav intelektualnog vlasništva mora uzeti u obzir promjene nastale u troškovima, brzini i kvaliteti distribucije, te pronaći balans između otvorenog i zaštićenog pristupa, koji će osigurati što je moguće veći pristup informacijama, što predstavlja osnovni preduvjet neometanog funkcioniranja društva znanja. S obzirom da su načini zloupotrebe informacijsko komunikacijskih tehnologija svakim danom sve složeniji i savršeniji za otkrivanje, i da je teško ići u korak s tim aktivnostima, potrebno je ulagati napore u to da javnost bude svjesna s kakvim se fenomenom današnje društvo suočava, te je potrebno konstantno raditi na što adekvatnijem odgovoru na različita nedozvoljena djelovanja u ovom području. Potrebno je pronaći ravnotežu između otvorenog pristupa i pravne zaštite te osigurati, koliko god je to moguće, slobodan pristup kako bi se proizvodnja znanja neometano razvijala. Širenje intelektualnog prava u sve sfere društva u posljednjem stoljeću odraz je rastuće ekonomske vrijednosti znanja i informacija, što je potaknulo mnoga pitanja o postojećoj ravnoteži između društvenih i ekonomskih interesa. Ta ravnoteža je pomaknuta u korist medijskih korporacija koje usmjeravaju razvoj intelektualnog vlasništva.

Na osnovu stanja zakonodavstva u BiH, možemo konstatirati da je država usvajanjem odgovarajućih pravnih propisa omogućila odgovornost počinitelja kaznenih djela u vezi s napadom na prava intelektualnog vlasništva. Za kraj, može se zaključiti da, bez obzira na pravnu zaštitu informacijskih sustava, programa i podataka u kaznenim zakonodavstvima BiH, ostaju otvorena mnoga pitanja koja su od važnosti za sveobuhvatno uređenje područja.

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Developing a Communication Application System for Chamwino Small-Scale Farmers in Tanzania: A Participatory Design Research

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***Abstract* – Small-scale farmers in Chamwino Tanzania, lack reliable means of communication for facilitating information flow between farmers themselves and other crop farming stakeholders. This study, therefore, sought to develop a mobile phone application system to support farming decision-making. The study employed a participatory design approach that used interviews, focus group discussions, and brainstorming for data collection and a software developer for the creation of a prototype. Thematic analysis was conducted, and the findings show that farmers require information on farming input, weather, transportation, market, crop farming policies and on agricultural research reports. Thereafter, convergent thinking facilitated the development of a mobile phone application system (mobileCHAPONA). The system enables two-way farming information flow among stakeholders (farmers, extension officers, advisory services and mediators). The system assists in the coordination of stakeholders towards improving production. Also, it is easily usable and adoptable by stakeholders aged between 24 to 44 years old, while elders above 45 years old may require a long run training to cope with innovation. It is expected that in the future, software developers, development practitioners, and policy experts will use the system, and improve it further in a manner that keeps into consideration the ecological perspectives in Sub-Saharan Africa.**

Keywords - Chamwino; system; farmers; information flow; mobile application

I. INTRODUCTION

The software development industry is fast-expanding and is a hot topic in today's world. It provides opportunities for everyone and anywhere of working for a few days and hours and access better tools for business transaction [1]. Thus, several mobile phone applications continue to be developed since the needs of users vary and never end [2].

Chamwino small-scale farmers (SSFs) encounter a challenge of inefficient farming information flow between SSFs (themselves) and other crop farming stakeholders. Chamwino is one of the seven districts of Dodoma region, in central Tanzania. This study intends to develop a mobile phone application system to facilitate crop farming information flow.

The SSFs in Chamwino are characterised by family labour and owning less than five hectares of land. They acquire farming information through physical contact with suppliers of inputs, relatives, friends, traders and sporadically through television and radio. These information flows are inadequate, inaccurate, unreliable and sometimes contradicting, leading SSFs to sometimes take incorrect decisions [3][4]. Consequently, SSFs are forced to use tacit and traditional knowledge, which is often inefficient and obsolete [3][4] and needs to be supplemented with a mobile phone application that can facilitate agricultural information flow.

A successful crop farming business requires support from stakeholders or advisory services (AS) who are responsible for knowledge transfer, farm and business development, basic services and village development, cooperation, and local development [5]. Stakeholders include consumers, agro-based manufacturers, traders, the government, SSFs as producers [6], non-governmental organizations, corporative societies, and agricultural research institutions [7].

The existing software applications provide information on various activities also in the agricultural sector [8][9][10][11][12][13][14][15]. Nevertheless, these applications may be challenged by inefficient two-way farming information flow, poor involvement of SSFs during the design and development processes, and lack of mediators in case of grievances among stakeholders. Therefore, agricultural enabled information system is one of the important tools in crop farming and that needs to be developed considering mass communication technology through design science research (DSR) [16].

A. The Role of DSR in Solving Problem

The design science research (DSR) is a fundamental problem-solving approach that seeks to enhance human knowledge with the creation of innovative artefacts that exploit the available opportunities [17]. It includes both newly designed artefacts and the improvement of applications' relevance in new contexts [17].

Literature suggests the chronological steps in DSR as; problem explication, identification of users' requirements, design and development of an artefact, demonstration or implementation, evaluation and communication [18][19][20][21]. Thus, the development of an ad-hoc mobile phone application may enable efficient farming information flow and empower SSFs and other stakeholders to take prudent farming decisions. Consequently, to achieve this, the following research questions were formulated; *i) Which farming information is required and can be incorporated in the mobile phone application system? ii) What kind of mobile phone application technology can facilitate information flow between SSFs and other crop farming stakeholders? iii) What is the perception of the end-users of the mobile phone application system on farming information flow?*

II. METHODOLOGY

The participatory design research (PDR) was adopted and involved researchers, software developers, SSFs, Extension Officers and other advisory services as crop farming stakeholders. The approach encouraged the SSFs and other stakeholders to be part of the development of system [22]. The PDR is a bottom-up approach that allows users to be co-researchers through the creation of a safe space of interaction and promotes various levels of participation [22]. The approach was chosen because similar studies have used PDR to develop applications [23] [24] [22] [25] and it has been shown to be a good methodology.

The PDR gives the users a voice in designing through interaction with the system [26] [25]. Halskov and Hansen, [25] summarise the five principle aspects in PDR namely; politics, people (users), contexts, methods, and product (see Table I). Thus, engaging stakeholders is an inherent key success factor that may lead to the opening of new opportunities for democracy, sharing economy, and crowd funding spaces [26].

In the case of our study, the plan for PDR was organized - as suggested by Duarte, Lacerda, and Antunes, [22], Halskov and Hansen [25] - into five phases that took mutual learning. Phase one involved the familiarization of all stakeholders, explaining workflow and procedures, working as a team led by researchers and a software engineer. Phase two embedded a focus group discussion (FGD) and interviews, led by researchers to identify the users' requirements. Phase three involved all stakeholders and the designer convergently, clarifying the users' goal and values and the expected outcome. Phase four involved the development of a mobile phone application system performed by a software developer. Phase five encompassed testing the system with the users and further developing the model. The simulation method was performed as suggested by Dresch, Brendel, Degbelo and Kray [18] on assumption that the advisory service, the mediator, and the extension officer already exist, and are prepared to disseminate information and respond to farming related inquiries. Finally, all phases ensured that users' interpretations are considered in the system, simultaneously envisaged, shaped and transcended such that it is beneficial to SSFs and other stakeholders (extension officer, mediator and other advisory services).

TABLE I. FUNDAMENTAL ASPECTS OF PARTICIPATORY DESIGN RESEARCH

PDR Aspects	The main issue found
Politics	People who are affected by a decision should have an opportunity to influence it
People (users)	People or users play critical roles in design by being experts in their own lives
Context	The use situation is the fundamental starting point for the design process
Methods	Methods are means for users of the application to gain influence in the design process
Product	The goal of participation is to design alternatives aiming at improving the quality of life

Source: Halskov & Hansen, [25]

A. Study Area

Chamwino district in Tanzania is located between latitude 40° and 80° south and longitude 35° and 37° and east. It has five divisions; *Itiso, Makangwa, Mvumi, Chilonwa and Mpwayungu* with a total population of approximately 340,000. It has savannah type of climate with the long dry season starting from late April to early December, and a wet season between December to mid-April. It has approximately 8,000 square kilometres of land of which 70% is arable land and the main economic activities are crop and livestock production. Chamwino was chosen because it is frequently affected by food insecurity [3].

B. Selection of participants

A non-probabilistic convenience sampling was employed because the targeted population had to meet certain practical criteria such as accessibility, geographical proximity, availability, and willingness of participating in a study [27][28]. Thereafter, between three to five SSFs and AS were selected in each division through the Village Chairperson or the Ward Executive Officer (see Table II). The inclusion criteria of SSFs involved being a farmer for the past three years, being able to respond to and express oneself on various questions, having participated in any of the community development projects, being able to speak Swahili language, and being the head of household. In addition, other stakeholders or advisory services were selected based on having at least three years' experience in crop farming related activities. These included; Agricultural

TABLE II. SELECTED SSFs, AS AND GENDER IN PDR

Division	Male	Female	Total
Itiso	3	1	4
Makangwa	2	2	4
Mvumi	2	1	3
Chilonwa	2	2	4
Mpwayungu	1	2	3
Sub-total	***10***	***8***	***18***
Stakeholders or Advisory services (AS)			
Extension officer	1	0	1
Input suppliers	1	1	2
Traders	1	1	2
Sub-total	***3***	***2***	***5***
Total	**13**	**10**	**23**

Source: Field Data

Agricultural officer, input suppliers and traders (see Table II).

However, researchers requested volunteers to participate in phases four and five workshops of PDR plan as it involved some costs, and these were conducted at a single centre. Thus, thirteen volunteers agreed and attended the two workshops. However, the challenge was to involve enough participants as it was a farm preparation period and most stakeholders were spending the whole day in the field. Furthermore, lack of economic incentive to motivate participants led others to shy away.

C. *Data collection*

An in-depth interview, FGD, and brainstorming were administered in Swahili language between September and November 2018. The researchers took notes and audio-recorded the conversations after getting the consent from the respondents. Phases four and five included workshops that were convened separately and took two days each. The laddering interview was conducted in phase four and five and it stimulated SSFs, extension officer, mediator and advisory services. However, as partial compensation, workshop participants were offered accommodation, transport, and sustenance.

D. *Data analysis*

Thematic analysis was used and the recorded interviews, FGD, and brainstorming were transcribed and translated into English: they were analysed consistently extracting themes which were coherent to users' requirements. Data analysis in phases one to three provided a deeper description of the user requirements that assisted the software developer and researchers to develop mobile phone application system.

III. FINDINGS

The twenty-three participants were involved in the study: eighteen were SSFs (ten men and eight females) and five advisory service (three men and two female) (see table II). The participants were aged between 24-58 years, with two aged 53 and 58 years old. The participants with less than 24 years were excluded due to inclusion criteria.

A. *Research Question One. What farming information is required and can be incorporated in the mobile phone application system?*

The user's information requirements in convergent thinking dwelt on; input, weather, finance, consultants (experts), health, transportation, destructive and dangerous animals, farming policies, market and agricultural research reports.

B. *Research Question two. What kind of mobile phone application technology facilitate information flow between SSFs and AS?*

The user requirements enabled the development of a mobile phone application prototype that in future, will be connected to the internet through cloud computing for information exchange (see Fig.1). The system will be hosted in a cloud. Thus, crop farming stakeholders work

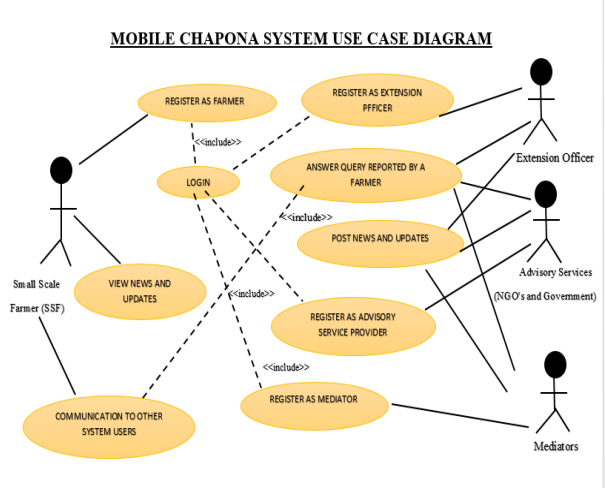

Fig.I: Use Case Diagram: **Source:** Software developer

together through the interface and share diverse information to improve decision making on farming business. Accordingly, the users must possess a mobile phone, specifically a smartphone, that would be connected to the database services, which are stored in a cloud server.

All actors (SSFs, AS, the Extension Officer and mediator) in the system must register in order to access various farming information. The users must have an e-mail address, telephone number and password so that they can be recognised by the system (see Fig. II). Thereafter, each registered actor can access and read various current farming related information (Swahili word "*Habari za hivi punde*" (see Fig. III). In addition, users can upload any new development information in the respective field, respond to the related inquiry and conduct discussion or consultations through preferred mode of communication (see Fig. IV). The system is nicknamed mobileCHAPONA meaning "*the use of mobile phone technology is resourceful*" which is also a welcome interface for end-users to register.



Fig. II: Registration Interface



Fig. III: Current News Interface

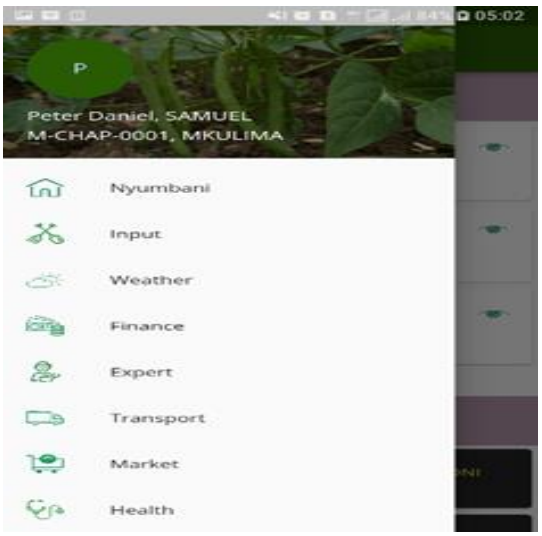

Fig. IV: User Requirements Interface

C. Research Question three. What is the perception of the end-users of the mobile phone application system on information flow?

The laddering interview to SSFs and other stakeholders focused on the features, benefits, and personal held values underlying the prototype. The results reveal that SSFs understood how to access and retrieve information, send messages and images as inquiries, and receive timely feedback when connected to server. The same was performed by the extension officer, the mediator and other advisory services who understood how to respond to queries from other actors in the system. Subsequently, the prototype was found to be easily usable and adaptable to stakeholders aged between 24 to 44 years old, while elder group above 45 years old required a long run training to cope with innovation. However, the inclusion criteria excluded farmers aged below 24 years old. Consequently, there were challenges facing SSFs that were technophobia, lack of e-mail address and password and the inability to recall password when registering, which is important for security purposes.

IV. DISCUSSION OF FINDINGS

The user requirements were incorporated in the developed mobile phone application prototype among stakeholders (i.e. SSFs, AS, the extension officer, and the mediator). The user requirements include information on input, weather, finance, consultants, health, transportation, market, destructive and dangerous animals, crop farming policies, and agricultural research institutions. These are discussed in subsequent paragraphs.

Input information were on pesticides, knife, hand-hoe, axe, rake, hatchet, seeds, ox-plough, tractor, power tiller and fertilizer which are used in farming. Several questions related to these items were considered important in helping farmers taking timely farming decisions. Input information were on pesticides, knife, hand-hoe, axe, rake, hatchet, seeds ox-plough, tractor, power tiller and fertilizer which are used in farming. Several questions related to these items were considered important in helping farmers taking timely farming decisions. Among them: 1. Where can we obtain them? how durable are they? how are they used? who is the manufacturer? how long does it take before needing repair? Are spare parts available or easy to obtain? how good is the input in crop production? And how does the input look like? For example, some arable land cannot be tilled by power tillers or a hand-hoe except tractors and vice versa; some land areas in Itiso and Mpwayungu divisions do not need fertilizers thus, making the supply of the same redundant in the area and consequently, SSFs who are equipped with input information are better-off in decision making than those who are not informed.

Weather information on wind-direction, temperature, humidity, cloudy, draught, and the amount of rainfall is useful in supporting decision-making. Thus, SSFs can plan and on when to prepare farm-field, when to till the land, when to plant, when to weed and when to harvest. For example, if the season is expected to experience draught, then SSFs shall choose draught resistant seeds and suppliers supply the same during the preparation and the planting seasons. The information on incidents (e.g. flood, drought, hot days etc) help SSFs make earlier plans. Furthermore, financial information on the interest rate, which is charged on borrowing, processing credit and loan procedures, permits SSFs and other stakeholders to scrutinize the available opportunities, compare and make appropriate financial decisions.

The crop farming experts' information, which includes NGOs and consultants (private and public), provides professional advisory services to increase skills and knowledge with the goal of improving farming decision. The experts equip SSFs, the extension officer and the mediator with knowledge and skills to enable them to use the opportunities of improving crop farming related activities. In addition, SSFs need health information in

order to take necessary actions before attending health centres. The health centres are distanced with impenetrable roads during the rainy seasons forcing the farmers to use traditional medicines. Poor human health condition deactivate productivity and affects human-life. Thus, access to health information helps stakeholders take early precautions by making an appropriate and a timely decision in saving a life.

Transport information on the mode of transportation and transporters, mileage charges on transferring farm produce to a warehouse or to the market, and other destinations are aimed at assisting decision making of ferrying commodities from the farm-field to the warehouse or the market place. The SSFs can choose an optimal cost. The participants were interested in gaining market information such as the ongoing commodity prices, the quantity demanded and supplied in a specific market, and information on auction markets and market locations.

Information on destructive and dangerous animals such as orangutan, mice, and elephant. These animals cause problems that affect both crop and human life. Thus, information on such animals help stakeholders to take early precautions, which can be for example, developing scaring instruments or repellents chemicals. In addition, crop farming policies is needed by AS, traders and Agricultural Officers. Information on farming policies need to be understood by all stakeholders: unfortunately, SSFs seem not to be much more concerned with policy and practice issues. This is because SSFs are often side-lined in policy formulations and do not know whether they operate within the agricultural policies.

The extension officer, traders, and the mediator need information on agricultural research reports for daily updates. This helps them gain knowledge and skills on farming related activities such as new research development issues and various pieces of advice from both internal and external sources. For example, extension officers need to be equipped with new farming development or research information to provide appropriate advisory to SSFs. However, SSFs had low awareness on research reports and were not informed of the benefits, thus this call for capacity building in rural areas.

Finally, user requirements paired with those which were uncovered in the previous studies [3][4]. This implies that SSFs and AS have some common requirements though each group has its own way of exploiting the existing opportunities. The user requirements enabled the development of a mobile phone application prototype to facilitate information flow between SSFs, the Extension Officer, the mediator, and other advisory services that suit both the literate and illiterate SSFs. The developed application incorporates voice mail features with recorded short descriptions of specific phenomena and images to be uploaded in the system. The system improves trust and transparency, encourages commitment and collaboration, and reduces bureaucracy as noted in the previous related projects [29]. However, there is a need of conducting frequent training to stakeholders particularly the elder group aged 45 years and above to reduce technophobia and let them become familiar with the operating mobileCHAPONA system. In addition, stakeholders with less than 24 years old were excluded because of the inclusion criteria such as being household head, availability and accessibility.

V. CONCLUSION

The user requirements were incorporated in the mobile phone application system prototype nicknamed mobileCHAPONA through PDR which has been overlooked in previous studies [13][14][15]. In addition, we used simulation method that helped to understand the efficacy of mobileCHAPONA system in solving a problem of inefficient timely farming information flow. The simulation helped to realize a timely two-way communication process that has not always been experienced in the previous projects. Consequently, the study provides a nuance on PDR in bringing together the stakeholders in farming value chain in the development phases, which may result in a greater use and further development of the system prototype and replication in Sub-Saharan Africa. In the future this system may benefit all crop farming stakeholders including SSFs to gain knowledge and skills that have been proven in a similar project [30][31][32]. However, the developed prototype is based on a relatively short-term fieldwork, but a longer term can be conducted to deepen understanding of the archetype and make further improvement.

Though we have deployed the mobileCHAPONA system prototype, the sample size that denotes our study should be generalized with caution and the general tendency is likely to be confirmed. Thus, we are currently extending the study to a larger sample of stakeholders to enable us to improve the system. A larger sample will also facilitate further scrutiny of the efficacy of the system. For example, Information flow is only one of the challenges facing the stakeholders, thus more studies are required on AS, Extension Officers and mediators in order to have affirmative advisories and sustain the project. The concrete operation of the system cannot be undertaken now until a server is set up that should be maintained by collaborative and committed institute(s). All the major stakeholders in crop farming value chain should be involved and provided with network in order to realize the reality.

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Smart Specialization within Industry 4.0 Network Strategies

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Abstract **- The article is devoted to the analysis of high-tech sectors development within Industry 4.0 and the features of innovation linkages between them based on network approach. The conceptual base for creating of networks in high-tech sectors based on system integration approach are proposed and the main advantages of given approach are determined. An algorithm for determining the development options for certain inter-sectoral networks, considering the Smart Specialization and international component of national security, has been developed. By empirically examining of Smart Specialization experience a more complete understanding of successful strategies of networked based public policy was proposed.**

Keywords – innovation network; strategy; priorities; smart specialization; technology transfer

I. INTRODUCTION

Under the conditions of transition to Industry 4.0 technologies large-scale application, a chain reaction occurs when changes in some industries cause changes in another. In its scale and complexity, this transformation is a qualitatively new phenomenon. These changes affect all nations and regions, and in order to successfully adapt to these transformations, the broadest and deepest targeted coordination of efforts of all forces and agents at all levels of public administration is necessary.

One of the main characteristic features of the transformation of Industry 4.0 deals with the changes in the basic principles of organization: the networks replace the traditional hierarchical structures as a system that allows to increase exponentially the level of connectivity and cooperation of all parts of economy and society (both consumers and producers), ignoring historical spatial and temporal boundaries.

Under these conditions, states are faced with the task of forming the appropriate specific advantages of a systemic nature. Industry 4.0 allows the country to change its role in global economic competition. This is possible with the full application of its existing resource capacity and the application of innovations within the framework of system strategies.

One of the most effective ways to achieve benefits in Industry 4.0 conditions is to strength cooperation between the business and academic communities in country [1], create innovation spaces based on universities, create mechanisms to promote technological development and strengthen target cooperation between the public and private sectors.

Against this background, the central question that motivates this paper is how Smart Specialization can promote the goals of Industry 4.0 development through the networked based public policy.

II. STUDY OF MODERN TRENDS AND IMPORTANT IMPLICATIONS

We build on this analysis to identify the main ideas and approaches concerning Smart Specialization and its evolution within the modern technological and institutional trends.

The authors of more recent studies have proposed that Smart Specialization should be considered within the development policy and industrial policy [2], which are realized especially through the prioritization of this area of public policy [3].

E.g. in strategical review [4] such points of public policy were proposed:

- identified through, and integrated with, broader capability development, strategic prioritisation and resource allocation processes;
- balanced appropriately between the operational needs of individual agents and broader strategic priorities, as well as between short, medium and long term requirements;
- developed in conjunction with science and innovation community to ensure they are achievable and expressed in manner that is both useful to science and innovation audience and not so prescriptive as to limit novel or alternative solutions;
- risk-informed, evidence-based and developed in logical, transparent and auditable manner.

Given points illustrate an example of system public policy, which is Industry 4.0 characteristic feature.

Smart Specialization within Industry 4.0 study is based on the foresight of emerging technologies and further identification of emerging industries. Such type of analytics deals with the great challenges and opportunities for scholars and policy makers [5].

Study [6] elaborates why and how institutional diversity and integration promote entrepreneurial discovery processes, spillovers and agglomeration effects, and thereby structural change in regions.

Study [8] outlined the links between the policy context, policy design, policy choices and policy intentions were discussed. These approach allows to consider the applied aspects of analysis of policy tools application in technology transfer management within Industry 4.0 conditions [8], using of technological package concept for sector development strategy [9], analysis of strategycal aspects of technology transfer in some sectors [10] and technology transfer management policy [11].

One of the main differences between different approaches to Smart Specialization is its scale understanding. Let us now analyze some of them.

Despite the Smart Specialization is considered mainly for regional level in study [12] it is underlined that national level remains important for both social cohesion and economic development. For Smart Specialization the policy challenge for national state is to learn how to foster innovations of Industry 4.0 by the supply- and demand-side repertoires. Although the supply and infrastructure remain critically important, the state needs to do much more to foster innovations prioritization – for example by creating stable regulatory regimes for long term investment

Another approach is given in [13] and includes the internationalization of smart specialization. Its transformation requires not only endogenous knowledge and technology accumulation building but also coupling with international knowledge and production networks.

It is also important to emphasize cross-border regional innovation systems conception and some implications that are important for the selection of innovation policy instruments [14].

The most important challenges are capturing entrepreneurship and knowledge networks, on the one hand, and embedding their complex interrelationship with wider economic mechanisms, on the other, together shaping the impact of smart specialization policies [15].

Cooperation within and between regions emerges as an important determinant of regional diversification [16]. Research [17] explores the policy framework around the concepts of relatedness and knowledge complexity. Authors show that diversifying into more complex technologies is attractive but difficult for European Union regions to accomplish. According to [18] industrial diversification of new industries can be built on similar knowledge base, draw on shared network, important role in knowledge-intensive industries.

Innovation networks in the priorities sectors and their policy support can be studied within the smart experimentation approach, which was considered in [19].

Smart Specialization that make it particularly suited to the problem of sectoral modernisation in the context of a mature economy [20] and connectivity model application [21].

Therefore the objective of this article is devoted to the analysis of high-tech sectors development within Industry 4.0 and the features of innovation linkages between them based on network approach as the component of public policy, based on Smart Specialization.

The following methods were used to determine the role of innovation networks in Smart Specialization to promote the goals of Industry 4.0 development:

– adapted decision-making methods (optimization of performance indicators, which are used to investigate the innovation role of networks);

– methods of innovation systems and intersectoral high-tech complexes strategic development schemes analysis, which are used to develop the main points of Smart Specialization for national innovation strategy;

– methods for searching of innovation ways of development and integrated economic analysis of development policy (are used to develop the innovation partnership strategies).

The fundamental principles of strategical management of institutional dynamics within the framework of development strategies require constant research, as currently the situation in the innovation sphere is constantly changing. This requires focus on identifying pressing problems and determining the prospects of how network approach can help under Industry 4.0 conditions of technological changes.

III. SMART SPECIALIZATION FOR INDUSTRY 4.0

In the context of institutional transformations, let's note that for effective management of resource flows within Smart Specialization strategy, it is necessary to have clear ideas about modern technologies (new trends of Industry 4.0) and the organizational and economic principles of its development. Understanding the specifics of development of Industry 4.0 technologies is necessary for development of innovation strategies, which should be aimed at organizational and resource support of high-tech industries and innovation communications between them.

The idea of current study is based on the hypothesis about necessity to adapt of institutional mechanism for national security ensuring through Smart Specialization strategy. This can be done through the comparison the level of strategical goals protection with the main trends in the innovation area, which can be done as follows:

- openness of innovation processes, strengthening of network processes of intersectoral technology transfer together with the business processes digitization leading to the formation of huge number of organizations & systems, which have significant synergistic potential;

- unique (specialized) innovation systems development, including national and regional, expanding various forms of innovation integration within the active innovation networks;
- innovation networks formation in national innovation system, which is represented as a complex multi-level and multi-sectoral structure.

These tasks are especially important in the conditions of Industry 4.0 forming, which in turn leads to the formation of new organizational framework for development and innovation processes acceleration.

In Fig. 1 we have shown the scheme of Smart Specialization to promote the goals of Industry 4.0, which is based on two-side analytics and evaluation.

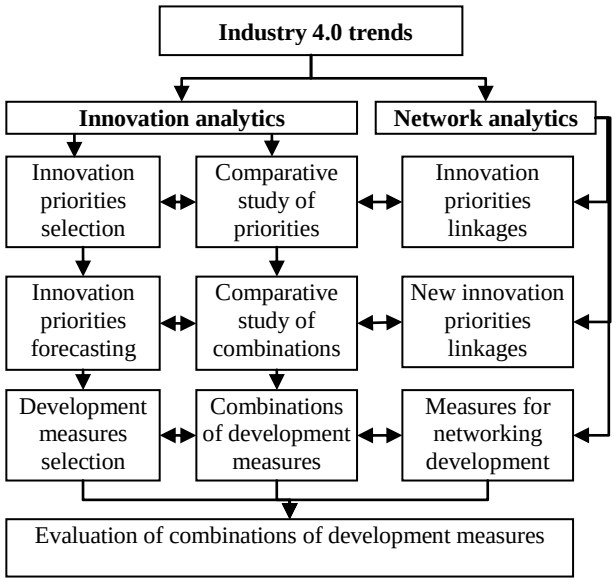

Figure 1. Smart Specialization within Industry 4.0

The elements of given in Fig. 1 scheme are used by many developed countries and corporations for active participation in the fourth industrial revolution. These points are included in the state programs, commercial associations and professional organizations, which aim is eliminating barriers for Industry 4.0 development. In these conditions the main point should be oriented not the classical efficiency achieving, but on adaptability goals (ability to adapt quickly to dynamic markets). This idea forms a new situation of strategic choice, related to redistribution of technology rent and practical planning of innovation-investment processes within the public policy.

Smart Specialization strategy is proposed to consider at such two levels:

1. Management of the technological development within existing sectors and market positions.

2. Designing of new organizational and technological formats for industries and areas of activity development based on innovation linkages.

These levels give possibility to consider national resource base and development priorities and to implement policy with a focus on promising technologies and effects. Thus, the implementation of the objectives of public policy is implemented by the following managerial and analytical mechanisms:

- identification of areas with the highest priority (current and prospective) and localization of competences (human resources, innovation potential, technological excellence, sectoral opportunities);
- creation of set of organizational advantages (unique organizational concept or development model, special configuration of processes, unique innovation culture, local innovations ecosystem etc.).

For the conceptualization of institutionalization the results of Smart Specialization analytics and, the national innovation system should be considered as a system of state, private and public structures (institutions), as well as national institutions and their interaction with the goal of creating, modifying, transferring and using knowledge and technology.

IV. Global Experience in Smart Specialization

This part of study deals with global experience in Smart Specialization analyzing of priorities based on their importance for nations development and national & international criteria using algorithm for selection. The main aspects of the process of development and implementation of technology strategies are considered.

Through the analysis of innovation systems at macro level decision about the priorities networks in optimization with the aim to improve public policy in science, technology and innovation can be provided. The main techniques and decisions can be considered based on foresight-studies.

Today the competitiveness of nation in global space is provided by innovation technological imperative, which demands modernization of production system according to the requirements of scientific and technological progress and postindustrial Industry 4.0 development. Thus, it is necessary to highlight the priority sectors that are material basis for the functioning of most important areas of human life and ensure the development and implementation of advanced technologies.

In some cases such strategic initiatives have even further importance. World experience shows that the greater the lag in the development of a country, the greater is the role of government in infrastructure development, resource mobilization, identifying priorities, reaching proportions and relationships in national economy and national innovation system. Given the fact that the economy is a selection of best possible, there is a need for effective prioritization of socio-economic, scientific-technical and innovation development.

In several countries despite the existence of national regulatory selection process of priorities, resources for its implementation do not meet the real needs. Also unlike the technologies of choice of priorities in other countries, international criterion of development is not considered, which requires an appropriate organizational and economic security.

Today the main policy issue of countries is integration to the global innovation system for using of its potential and achieving long-term economic growth through innovations. Also the creation of education, research and development system components for the foreign investment through the public-private partnerships is in priority areas.

So our study is based on the idea, that innovation system development requires an interrelated definition of performance indicators and priorities, strengthening of intersectoral coordination, changing of operation principles of development institutions, formation of domestic demand for innovation.

To achieve the aim of the research it was necessary to consider the existing experience of foreign nations in innovation development policy, especially identifying the opportunities in international cooperation and international economic activities, based on the selection of innovation priorities and the development of appropriate system support mechanisms.

All these problems have to be solved within the framework of interaction of national and global innovation systems and as a science and industry compound, which is oriented on providing faster and more efficient management in «science – production» cycle in the priority sectors of scientific and technical progress, acceleration of new idea development and its most effective application in practice (transfer).

The development of each priority is based on system approach of social and economic conditions as a result of integration and cooperation of different agents of innovation system (enterprises, research institutions, industry, society). In this context the effectiveness of coordination at cross-sectoral level and innovation network interaction are proposed to be determined based on competitiveness of production and economic development based on innovations at meso- and micro level. Therefore the main factors (determinants) of Industry 4.0 innovations development, which are considered in the Smart Specialization analysis of national innovation priorities, are follows:

- market and resource factors, including consumer preferences;
- relationship between consumers and producers which is often intense within the national system;
- research system that generates scientific and technological innovations;
- technological interdependence in the country which is most significant in the early stages of innovation processes;
- communication and public policy in different areas (for example, scientific and technological policy and defence researches), as well as the conditions for technological and economic activity (as defined within the framework of the policy) such as legislation and regulation;
- education and training system, developing skills, abilities and competencies required for innovation;
- national institutions, that support innovations, such as industry and engineering associations.

V. SMART SPECIALIZATION NETWORK BASED STRATEGIES

Support for the development of technologies at the national level is carried out by many industrialized countries of the world: lists of such technologies are approved and maintained at the state level. By empirically examining, we hope to produce a more complete understanding of successful examples of networked based public policy.

The most widespread and most fulfilled practice of such activities in United States, Russian Federation, EU and Japan. In particular, in EU countries, Euclid program were implemented, Germany and Japan are participating in Delphi program with the participation of government, industry and academia to assess the importance and status in broad number of technologies.

Analyzing institutional coordination, we first note the experience of the United States. The key thesis that some technologies are crucial not only for providing combat readiness, but also as an incentive for economic growth, was ensured by the US law passed by the Congress of PL 101-189 (National Competitiveness Act 1989 Technology Transfer Act of 1989; Public Law 101-189). The US Code defines national security objectives to support national technology and industry. It has been established that the policy of US Congress is aimed at reproducing, within a reasonable time, opportunities for development and production of materials and equipment, including technologically advanced systems, in quantities sufficient to prepare for war, state of emergency or mobilization of the Armed Forces in the case of threat to national security.

According to Smart Specialization strategy state support should include a state system for assessing, identifying and monitoring of such technologies. To such a system it is necessary to involve central and local executive authorities, which have the authority in the field of formation and implementation of scientific and scientific-technical policy, industrial, military-technical and military-industrial policy, and policy in the field of military-technical cooperation. Transfer from military to civilian, but now quite often there is a reverse trend.

The most successful model of functioning of the reorientation of the economy to the innovation-oriented model is the Yazma model of Israel. The model envisaged the creation of funds and the further development of 10 private funds with the participation of the state, each with a capital of $ 20 million or more.

The program was established under the leadership of the Ministry of Industry and Trade of Israel. Funds were required to have at least one Israeli partner and one American or European partner with experience and reputation in the field of venture capital investment.

At the same time, foreign partners undertook to teach Israeli specialists, while the fund itself was managed by an Israeli private asset management company. The sponsored

fund received $ 8 million from the Yozma Fund, which was 40% of the cost of the project. In case of successful implementation of the project, it was envisaged the purchase by the private investor of a share of the state at the initial cost of the state's investment in the project plus a small income accrued on the state's share. In total, within the Yozma program, 10 venture funds were created, almost all of which were closed-ended. The total volume of high-tech exports increased from $ 2.2 billion in 1991 to $ 11 billion in 2000.

US market is characterized by a highly developed investment infrastructure and is by far the largest capital market in the world. The country has a well-developed legislative base, which has more than 80 years of history, uses a wide range of instruments: tax breaks, loans guaranteed by the state loans.

The Small Business Investment Company Program (SBICP) is a unique public-private partnership program, through which, since its inception, more than 100,000 small US companies have been invested in a total amount of $ 48 billion. The PCIMB Management Company is a privately owned venture capital company licensed by the state to provide venture capital companies with equity or long-term loans. Such a mechanism has been introduced in the United States since 1958 in order to simplify the access of small businesses to borrowed capital. The minimum capital required to set up a company for SBICP is US $ 5 million, to be provided by individuals, the remaining capital needed for the development of the project, provided by the state in a triple amount through the sale of targeted government securities. Since the launch of the program, since 1958, 46 billion dollar loans and equity investments have been distributed to more than 99,000 small US enterprises. Most of today's well-known holdings started with this program. For example, they are the following: Intel, Apple Computer, Callaway Golf, Jet Blue Airbus. In addition, this program addresses the issues of the labor sphere, in particular, in 2005, 218,000 new jobs were created, all of which were fully occupied by new ones.

In addition, this program addresses the issues of the labor field, in particular, in 2005, new 218,000 jobs were created, all of which were fully occupied by new employees.

The most famous high-tech clusters in the US are Silicon California, the Boston cluster and the Triangle of Science.

The formation of the first two clusters was not the result of a purposeful government policy, although they benefited from state support, while the last cluster appeared just thanks to this support. The federal cluster policy in the US has historically been minimal and has been implemented mainly through the Administration for Small Business and the Department of Economic Development (EDA) of the Ministry of Commerce.

Basically, the cluster policy was implemented at the state level and, at the first stage, included the identification of a potential cluster by geographic, sectoral and other characteristics, as well as by existing links. At the second stage, work was usually carried out to develop entrepreneurial potential and business and scientific relations within the framework of the identified cluster, for example, through the financing of joint research, development of standard licensing, coordination of seed funding for small innovation enterprises created at universities. As a rule, the role of the state in the cluster policy was to create a research and innovation infrastructure and to stimulate the development of scientific and business relations in the region, and not to direct financing of companies.

Finland has also built one of the world's most effective investment schemes for innovation development programs, based on the SITRA National Fund for Research and Development (SITRA).

The foundation was founded in 1967 by the state and is currently regulated by the parliament of the country. One of the objectives of the fund is the state support of innovation companies in Finland and other countries, including through direct investments or through a fund of funds. The main component of the success of this program is the optimal interaction between the state, science and private business on the basis of common rules and division of responsibilities. The catalyst for the development of venture capital was the SITRA Fund for Sowing Investment (venture capital fund for start-up projects). The total volume of investments made between 1991 and 2003 increased from EUR 50 million to EUR 420 million.

This experience convincingly indicates the importance of the role of the state in coordinating a number of innovation initiatives in priority sectors.

The research carried out allows us to draw a number of conclusions about the main features of the organization of activities to stimulate demand for Industry 4.0 innovation solutions and products through the Smart Specialization, which can be grouped into such groups:

1. Innovation is not an end in itself, but a means of obtaining a new value for the end customer, new ways of solving social and economic problems of customers. Examples of such tasks include strengthening the competitiveness of small and medium-sized enterprises in the technological sphere (SMBA, South Korea), developing the medical field of "comfortable aging" (HAPPI Healthy aging, France etc.), increasing the competitiveness of enterprises (e.g. RIS-3, France, Ron-Alps region).

2. Stimulating the demand for innovation is a system of measures for building effective interaction of all stakeholders at all stages of the life cycle of innovation product in innovation networks: from identifying and detailing the needs of customers in innovation solutions for public procurement procedures.

3. Stimulating the demand for innovation is not implemented as a set of individual activities, but as systemic actions in the format of projects or programs that cover all or most of the measures aimed at developing and implementing solutions that are needed by end users, as well as popularizing the most effective practices of such policy. In such projects and programs there is always an active coordinating center – the organizational structure

responsible for implementing the key tasks of project or program. We also have investigated that in the most cases a specialized organization is created as a such structure.

VI. CONLUSION

We opened this paper by noting that institutional mechanism for Industry 4.0 through the Smart Specialization strategy can be considered as matching of cooperation mechanisms with the main innovation trends. The foregoing discussion has attempted to new trends of Industry 4.0 and the organizational and economic principles of its development. Understanding the specifics of development of Industry 4.0 technologies is necessary for development of innovation strategies, which should be aimed at organizational and resource support of high-tech industries and innovation communications between them.

The main factors (determinants) of Industry 4.0 innovations development, which should be considered in the Smart Specialization analysis of national innovation priorities, were discussed. By empirically examining of Smart Specialization experience a more complete understanding of the main points of successful strategies of networked based public policy was proposed. The main features of the organization of various public policy activities to stimulate demand for Industry 4.0 innovation solutions and products through the Smart Specialization were studied.

The study of global experience in Smart Specialization analyzing of priorities based on their importance for nations development and national & international criteria using algorithm for selection leads us to the conclusion that Smart Specialization should be based on network cooperation between the agents from the public and private sectors. The evidence from our studies suggests a variety of factors related to management of network cooperation within the Smart Specialization for Industry 4.0 technologies development.

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Digital transformation scoreboard – Case of Slovenia and Croatia

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Abstract - **Implementation of digital technologies leads enterprises and governments towards digital transformation. While some enterprises are successful in their digital journey, many still remain behind. Digitalization and digital transformation are of key importance for increased efficiency, improved value proposition, innovation and overall growth of the economy as well as wellbeing of the society. For that reason, decision makers and policy makers need to understand current situation of digital transformation in enterprises to set up proper actions and policies for its expansion. The impact of digital transformation is measured with various digital indicators and assessment techniques on country and enterprise level. Based on the open data provided from different reports on digital transformation this paper summarizes current state of digital transformation in enterprises in Slovenia and Croatia. Furthermore, we provide comparison between analyzed countries and EU average.**

Keywords – digital transformation; enabling conditions; Slovenia; Croatia; scoreboard

I. INTRODUCTION

Growing market pressures from customers and competition are forcing enterprises to act fast if they want to survive and thrive in a fast-pace changing business environment. Digitalization of both competition and customers in today's business environment is a dominant factor acting as an opportunity and also as a threat for enterprises [1]. When new digital technologies are implemented into business environment, processes get standardized [2], new value is made [3], which in turn brings new revenue streams and new or improved value proposition [4]. And even though the enterprises recognize the threat of becoming obsolete, the number of those enterprises that prepare to respond is worryingly low [5], [6].

Nowadays it is all about the digital transformation. But as Kane [7] puts it - the issue is not only about implementation of cutting-edge digital technologies, but more and more about aligning the enterprises' culture and people with digital strategy [8]. Technology is affecting conditions under which enterprises conduct business, but the value that technologies bring to business comes from business being conducted in new ways, all enabled by digital technologies [9]. It is a crucial [2], ongoing, evolutionary and continuous process driven by changing business environment that increases enterprises options for survival and success [10].

The results of digitalization and digital transformation vary vastly, not only between enterprises but also between different countries [11], which puts whole economies under threat of not being able to compete in a global setting.

Building on this fact, we have analyzed the results presented on Digital transformation scoreboard [12], [13] and compared local scores of neighboring countries Slovenia and Croatia to other EU countries to try and present the strong points and weaknesses.

This paper is organized as follows: the next section presents current state of digital transformation of Slovenian and Croatian enterprises by analyzing and compiling the results provided by European Commission in the annual Digital transformation Scoreboard report. We focused on the enabling factors for digital transformation. Results are followed by discussion where we elaborate on provided results. Last, we provide a conclusion in which we touch on possible actions to improve digital transformation in Slovenia and Croatia.

II. CURRENT STATE OF DIGITAL TRANSFORMATION OF SLOVENIAN AND CROATIAN ENTERPRISES

Digital transformation Scoreboard framework consists of several categories, which are divided into enabling conditions and outcomes of digital transformation. This study will focus on enabling conditions for digital transformation, because according to Probst et al. [12] the enablers are indicators for the level of digital transformation in enterprises. As shown in Figure 1, the digital transformation conditions in digital transformation scoreboard framework are presented in five categories: digital infrastructure, investments, and access to finance, supply and demand of digital skills, e-leadership, and entrepreneurial culture. Each of these categories consists of several digital transformation monitor indicators derived from different publicly available sources (Eurostat, Global Entrepreneurship Monitor, and Global Talent Competitiveness Index).

Based on the data from EuroStat [14], and Global Talent Competitiveness Index [15] Slovenian and Croatian results were compared to European Member States average (EU average), while based on the Global Competitiveness Index [16] the data about where Slovenia and Croatia rank among the European Member States is provided. Furthermore, Global Entrepreneurship Monitor [17] does not provide all data for some EU countries and therefore we were not able to calculate the EU average. Consequently, only the comparison between Slovenia and.

Dimension	Digital Transformation Monitor indicators	Source	Last update	Last year available	
Digital infrastructure	Enterprises using DSL or other fixed broadband connection	Eurostat	14/12/2017	2016	Enablers
	Internet bandwidth	Global Competitiveness Index	11/05/2017 (Ed. 2016-2017)	2016	
	Percentage of enterprises who have ERP software package to share information between different functional areas	Eurostat	14/12/2017	2017	
	Percentage of enterprises using Customer Relationship Management to analyse information about clients for marketing purposes	Eurostat	14/12/2017	2017	
Investments and access to finance	Business enterprise R&D expenditure in all NACE activities from high-tech sectors	Eurostat	28/11/2017	2015	
	Direct investment in the reporting economy (inward) in the Information and communication sector (sector J) (NACE Rev. 2)	Eurostat	28/11/2017	2017	
	Total Tax rate (percentage of Commercial Profits)	Global Competitiveness Index	11/05/2017 (Ed. 2016-2017)	2016	
	Venture Capital Availability	Global Competitiveness Index	11/05/2017 (Ed. 2016-2017)	2016	
	Ease of Raising Money Through Local Equity Markets	Global Competitiveness Index	11/05/2017 (Ed. 2016-2017)	2016	
	Ease of access to loans	Global Competitiveness Index	11/05/2017 (Ed. 2016-2017)	2016	
Supply and demand of digital skills	Innovation output (derived by aggregating two output pillars: Knowledge & technology output and creativity output)	Global Talent Competitiveness Index, 2017	16/01/2017	2016	
	Ease of finding skilled employees	Global Talent Competitiveness Index, 2017	16/01/2017	2016	
	Enterprises that employ ICT specialists and had hard-to-fill vacancies for ICT specialists	Eurostat	14/12/2017	2017	
	Persons employed, which were provided a portable device that allows a mobile connection to the internet for business use	Eurostat	14/12/2017	2017	
e-leadership	Percentage of enterprises that provided training to ICT/IT specialists to develop/upgrade their ICT skills	Eurostat	14/12/2017	2017	
	High-Level Skills: Workforce with tertiary education	Global Talent Competitiveness Index, 2017	16/01/2017	2016	
	Enterprises giving portable devices for a mobile connection to the internet to their employees	Eurostat	14/12/2017	2017	
Entrepreneurial culture	Activity: Total Early-Stage Entrepreneurial Activity (TEA)	Global Entrepreneurship Monitor, 2016	04/02/2017	2016	
	Self-Perceptions: Entrepreneurial Intentions	Global Entrepreneurship Monitor, 2016	04/02/2017	2016	
	Societal Values: Entrepreneurship As A Good Career Choice	Global Entrepreneurship Monitor, 2016	04/02/2017	2016	

Figure 1: Digital Transformation Scoreboard, Composition of framework Enablers dimensions. Adopted from Digital transformation scoreboard 2018 [13]

Croatia is provided. The findings are presented in the following section.

Digital infrastructure

As shown in Figure 1, the digital infrastructure dimension consists of four indicators: enterprise using DSL or other fixed internet broadband connection, percentage of enterprises who use an ERP software package to share information between different functional areas, percentage of enterprises using customer relationship management to analyze information about clients for marketing purposes, and user internet connection bandwidth. First, we obtained data regarding the kb/s per user for each EU member state. Based on those data we ranked all EU member states and found out that Slovenia is ranked on the 16th place and Croatia is ranked on 25th out of 28 EU member states. The comparison between Slovenia, Croatia, and EU average for the remaining three indicators is presented in Figure 2. According to Figure 2, the Slovenia and Croatia are below EU average according to two indicators. The first indicator where both countries are below EU average is a percentage of enterprises using customer relationship management to analyse information about clients for marketing purposes. As regards to percentage of enterprises who use an ERP software package to share information between different functional areas only Slovenia is below EU average while as regards to the enterprises using fixed broadband connection only Croatia is below EU average.

Overall, digital infrastructure dimension conceals huge discrepancies between EU Member states. Slovenia score (48) is at the same level as the EU average score (48), while Croatia (24) is far below EU average [13].

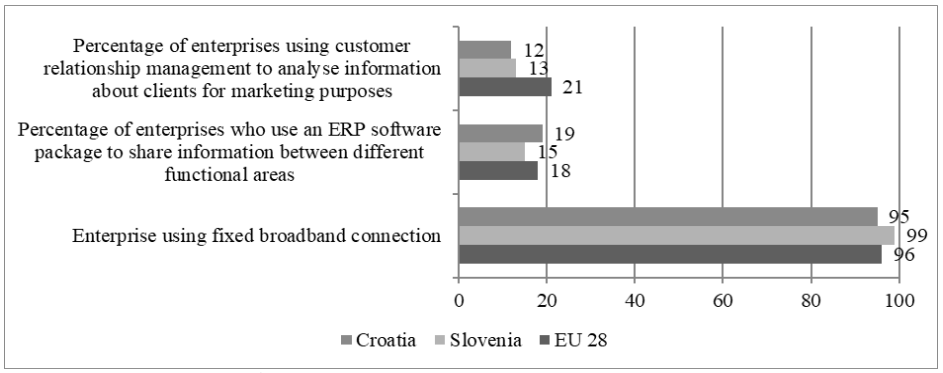

Figure 2: Digital infrastructure – comparison between Slovenia, Croatia, and EU average

Investments and access to finance

Business enterprise R&D expenditure in all NACE activities from high-tech sector[14] calculated as percentage of GDP shows that Croatia expenditure is at 0,39% of GDP while Slovenia is at 1,51%, which is closer to EU 28 average at 1,75% of GDP. The other investments and access to finance components on venture capital availability, ease of raising money through local equality markets, and ease of access to loans are presented on Figure 3.

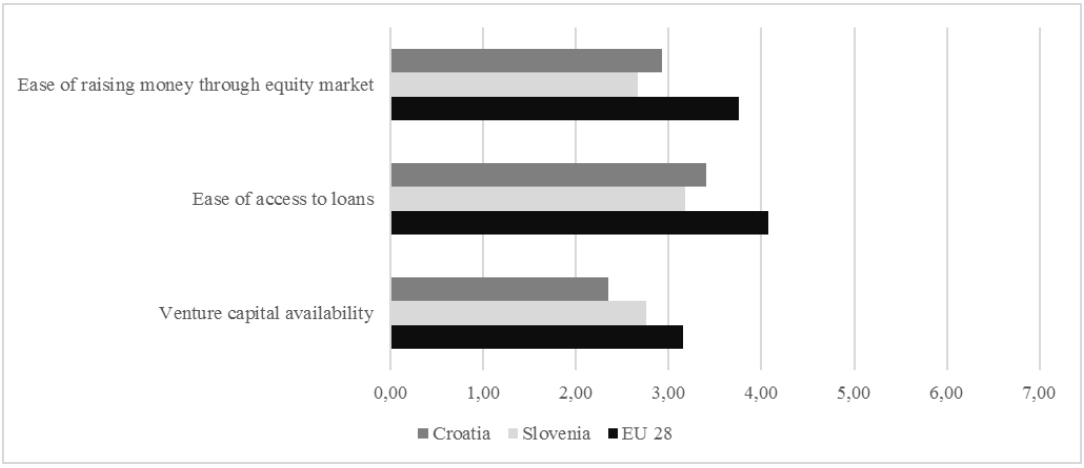

Figure 3: Investments and access to finance – comparison between Slovenia and Croatia

Total tax rate (percentage of commercial profits) and direct investment in the reporting economy (inward) in the information and communication sector (sector J) are provided in Figure 4. If we compare Slovenia and Croatia, we can see that Slovenia enterprises have higher R&D expenditure and the venture capital availability for them is better, while Croatian enterprises have easier access to loans and they can easily raise money through equity market. Nevertheless, according to Figure 3 and Figure 4, the investments and access to finance for digital transformation in Slovenia and Croatia are lower compared to EU 28 average.

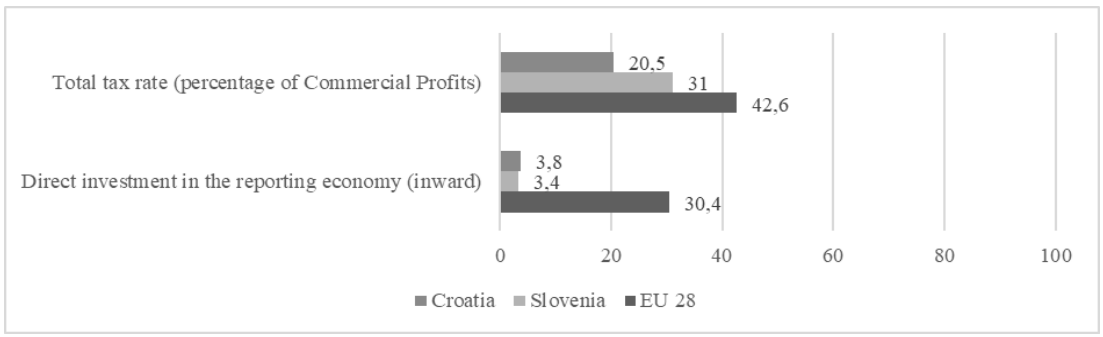

Figure 4: Investments and access to finance - comparison between Slovenia, Croatia, and EU average

Overall, Slovenia and Croatia are significantly lagging behind almost all other EU countries in investments and access to finance for digital transformation. While the EU average score is 46 the performance score for Slovenia is 19 and for Croatia is 14 [13].

Supply and demand of digital skills

Supply and demand of digital skills dimension is explained by innovation output (derived by aggregating two output pillars: knowledge & technology and creativity output), ease of finding skilled employees, enterprises that employ ICT specialists and had hard-to-fill vacancies for ICT specialists and persons employed, who were provided with a portable device that allows a mobile connection to the internet for business use. The comparison between Slovenia, Croatia, and EU 28 average is provided in Figure 5. We can see that Slovenia is below EU average in three categories, while Croatia only in two categories. Nevertheless, according to European Commission [18] Slovenia (34%) is right below EU average (45%) in supply and demand of digital skills for digital transformation, while Croatia is even further below EU average with 32% [13].

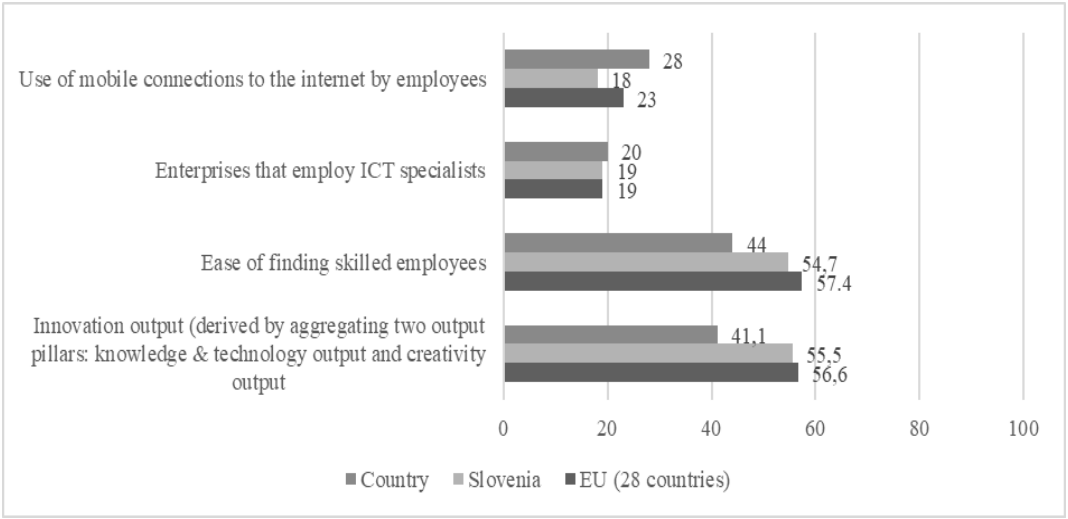

Figure 5: Supply and demand of digital skills - comparison between Slovenia, Croatia, and EU average

E-leadership

E-leadership dimension is explained by percentage of enterprises that provide ICT/IT specialists with training to develop/upgrade their ICT skills, high-level skills: workforce with tertiary education and enterprises giving their employees portable devices for a mobile connection to the internet. Figure 6 presents the comparison results between Slovenia, Croatia, and EU average for all three indicators. We can see that both, Slovenian and Croatian enterprises are above EU average according to two indicators (enterprises that provide ICT/IT specialists with training to develop/upgrade their ICT skills, enterprises giving their employees portable devices for a mobile connection to the internet), while the share of workforce obtaining a degree for tertiary education is under the EU average.

Overall, in the e-leadership dimension, Slovenia scores (6) above EU average (55) while Croatia with 45 is right below the EU average [13].

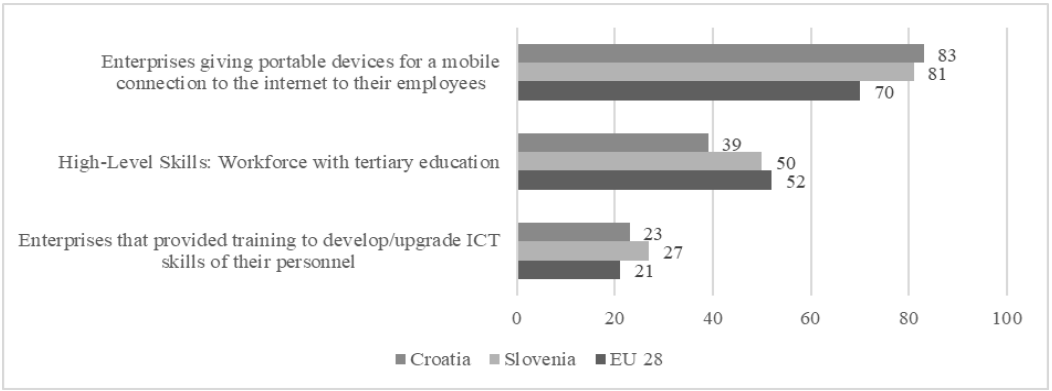

Figure 6: E-leadership - comparison between Slovenia, Croatia, and EU average

Entrepreneurial culture

The entrepreneurial dimension of digital transformation scoreboard framework consists of three indicators: activity: total early-stage entrepreneurial activity (TEA); self-perceptions: entrepreneurial intentions; and societal values: entrepreneurship as a good career choice. The EU average was not possible to calculate due to missing data for some EU countries. Therefore, Figure 7 presents only the comparison between Slovenia and Croatia. We can see that Croatia is performing better than Slovenia in all three indicators.

Overall, Slovenia and Croatia are among the best-performing countries in entrepreneurial culture dimension (with scores 79 and 91 respectively, while the EU average is 68), which could be a result of "recent active implementation of policies conducive to the creation of a business-friendly environment"[13].

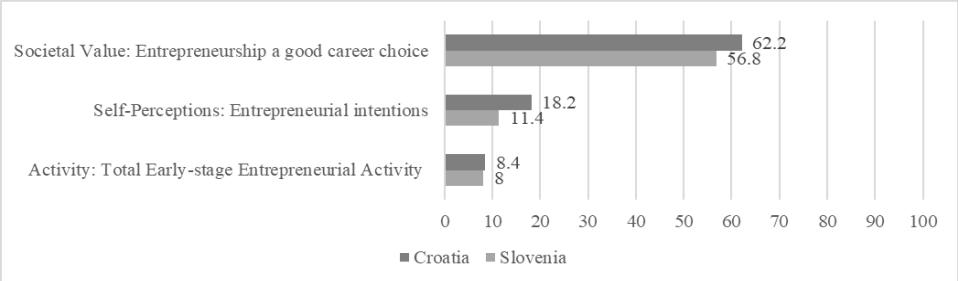

Figure 7: Entrepreneurial culture - comparison between Slovenia and Croatia

III. DISCUSSION

In the last decade we witnessed a large uptake in importance of digital transformation initiatives and the effects they have on enterprises. European Commission uses various measures such as Digital Economy and Society Index (DESI), Digital Technology Integration Index (DTII), Digital Transformation Enablers' Index (DTEI), and now also digital transformation scoreboard framework to track progress of EU member countries' and their enterprises.

We can see from the report that EU average score for digital transformation is 49.2, while for the Slovenia and Croatia is 40.0 and 30.7 respectively. This indicates that both countries are below the EU average, Slovenia ranging on 20th place and Croatia ranging on the 25th place among 28 EU member states. The index scores by dimensions that were chosen for the evaluation in this study are presented in Figure 8.

Detailed observations reveal that Slovenia scores above the EU average in two out of five dimensions, namely e-leadership and entrepreneurial culture, while Croatia scores above EU average only in entrepreneurial culture dimension. Both countries have significant opportunities for improvement, Slovenia in two dimensions (supply and demand of digital skills and investments and access to finance), while Croatia in three dimensions (supply and demand of digital skills, investments and access to finance, and digital infrastructure).

As the investment and access to finance is regarded as one of the most important factors driving the digital transformation Slovenia and Croatia should be worried about the significant gap between their scores (19% and 14% respectively) and EU average score (46%). A rather low performance in R&D expenditure and commercial profits makes this area a key challenge for both countries. Second area that can be seen as a main point of improvement for both countries is the supply and demand of digital skills. For instance, according to the recent data the innovation output could be further increased. Besides before mentioned areas, another key challenge for Croatia is digital infrastructure as the country ranks on the 25th place in Internet bandwidth (kb/s) per Internet user.

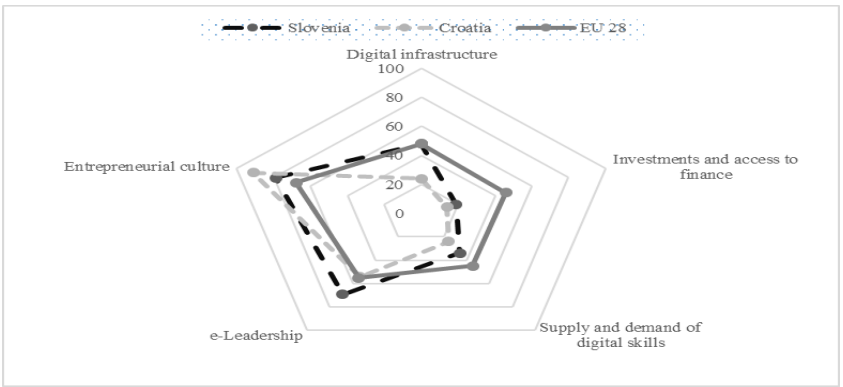

Figure 8: Digital transformation Index scores by Enablers' dimensions – comparison of Slovenia, Croatia and European average

IV. CONCLUSION

In this paper we examined enabling conditions for digital transformation in Slovenia and Croatia and compared them against other EU countries. Current state in both discussed countries demands action from policy makers to secure more stimulative environment. Policy makers in both Slovenia and Croatia should consider strong entrepreneurial culture of enterprises and enable better access to finance. That could create a strong push in helping Slovenia and Croatia achieve better overall digital transformation score.

There are many open opportunities for educating enterprises, especially small and medium-sized enterprises for tackling challenges brought by digital transformation. Supporting environment is proving to be very important, which is the reason behind EU establishing digital innovation hubs (DIHs). This project is now also supported by Slovenian government, who established DIH Slovenia – DIH will now take on a role of the primary educator and promotor of the importance of digital transformation for enterprises in Slovenia.

We noticed that data used for Digital transformation Scoreboard 2018 was changed in comparison to data used in Digital transformation Scoreboard 2017 report. We regard the improvement as valuable but recommend that data used should be more coherent, hoping that in the next report we will get data collected at the same time point from the same statistical sample.

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The Transition of Croatian Seaports into Smart Ports

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***Abstract* - Currently, the most advanced cargo-related business process management seaport model is a "smart port", in which all parts of the seaport operations and transportation are closely connected through various networks. Different seaports are in different phases of system implementation that allows uninterrupted data flow and interconnections. For example, some Croatian cargo seaports can be considered "ports in development", meaning they are currently only trying to simplify business processes. The Ministry of the Sea, Transport and Infrastructure plays an important role in the development of Croatian seaports, as it has recognized the importance of digitalization and stakeholder connectivity (shippers, freight forwarders, maritime agents, etc.), and has taken concrete measures to achieve digitalization and connectivity. Initially, it is necessary to enable system integration and stakeholder connectivity within the seaport, and subsequently connect the seaports with each other. The first step in the transition of Croatian seaports into smart ports is the development of both the Port Community Systems and the National Single Window. Later on, the goal should be to introduce the appropriate smart technologies, which should result in various benefits e.g., accelerated cargo manipulation.**

Keywords – smart ports; smart technologies; interconnected platforms; Croatian seaports

I. INTRODUCTION

Mobility and transport have always played an important role in economic and social development. With the increase of cargo volumes, seaport cargo handling procedures need to be performed in quicker and more efficient manner. The seaport is a multidimensional system combined between economical function, infrastructure system, geographical space and trade [1]. The smart seaport can be defined as "all parts of the port terminal operations, warehousing, logistics, yard and port transportation are closely connected through the wireless network or special network, providing all kinds of information for daily production supervision, related government departments and port shipping enterprises" [2]. According to Kamolov and Park, a transition to a smart port, takes a lot of time. To achieve such transition, smart technologies should replace the traditional technologies, and the processes should be automated [3]. According to Dong Xisong et al., smart ports are based on the modern electronic information technology, which represent a service system for transport in seaports [4]. In this way, services such as collecting, processing, issuing, exchanging and analysing the use of information are provided to the participants [4]. According to the SMART-PORT research project (Action Plan towards the smart port concept in the Mediterranean Area), which was co-funded by the MED transnational programme of European territorial cooperation, several factors affect the choice of port. These factors can be divided into: port connectivity regarding the common platform; the level of electronic information exchange and the costs related to port operations [5].

Certain Croatian cargo ports are classified as open ports for international traffic, and they are of significant (international) economic interest to the Republic of Croatia. Such ports are ports of Rijeka, Zadar, Šibenik, Split, and Ploče. Since the cargo throughput in the above-mentioned ports is economically significant, various seaport stakeholders are trying to improve their business performance, to make them more competitive. Different technologies are used in smart ports, and the usage of those technologies depends on different factors and resources used in port operations, such as infrastructure, cargo handling, security, etc. According to Jens, Delenclos and Rasmussen, many ports have adopted different intelligent port technologies, but leading seaports, such as Hamburg, have connected multiple individual systems to a single interconnected platform [6]. This type of interconnected platform integrates data from sources such as sensors, mobile devices and databases of different seaport stakeholders.

Not all ports are in the same phase of implementation of technological systems that will enable digitalization. That is the reason why some steps need to be taken, from the initial connecting of the stakeholders within the seaport to the cooperation between seaports. A smart port can ultimately be a fully automated port where all devices are connected by a so-called Internet of Things. However, most seaports have only achieved a certain, partial level of integration with the business environment. Deloitte Port Services claims that if the seaport does follow the market

trends, but on the other hand it does not have the defined and anticipated strategies, the seaport business will not develop and improve. Becoming a smart seaport means embracing the following: developing solutions to address the current and future challenges which seaports face, including spatial constraints, pressure on productivity, fiscal constraints, security risks and sustainability [7].

II. INTERDEPENDENCE BETWEEN STAKEHOLDERS AND DIGITAL-BASED SERVICES

Boston Consulting Group claims that a smart port technology includes a variety of digital services, which consists of built-in sensors, truck pre-order systems, and platforms for data exchange [6]. Seaports should base their decisions on their role in regional and global trade, as each seaport has its own specific commercial and operational needs. According to Jens, Delenclos and Rasmussen, the following division of stakeholders based on the management of smart ports technologies exists [6]:

- Infrastructure - port authority, port operators and terminal operators: smart sensors help them track, manage, and maintain their physical infrastructure
- Cargo handling - port authority, port operators, terminal operators, shipping lines, logistics companies: solving problems with the increased amounts of cargo
- Intermodal traffic - port authority, port operators, terminal operators, shipping lines, logistic companies, cargo owners, rail operators, barge operators: the technology provides improved organizational system of operations which includes cargo trucks and trains
- Customs and Collections - customs, terminal operators, port authority, port operators, shipping lines, cargo owners: cargo handling, payments, trade licenses, import and export permits, and customs clearances are performed in an easier way
- Safety and Security- port authority, port operators, terminal operators, shipping lines, logistic companies, rail operators, barge operators: they alert the staff if an unauthorized incursion is detected, and some ports put additional protection systems through which they are reporting, such as network connected biometric scanners
- Energy and environment - port authority, port operators, terminal operators, shipping lines, logistic companies, rail operators, barge operators: help the ports work sustainably

In the time of globalization, when the borders between countries have disappeared, and the volume of cargo and dimensions of ships has increased, the port authorities have increasingly started to face a different set of challenges. Competition between seaports is becoming more intense, and only those that successfully respond to such challenges succeed in maintaining their competitive position. Therefore, some port authorities introduce smart technologies, although this is not enough if the technology is not adapted to the needs of the port stakeholders themselves. There is a need for co-operation of all stakeholders: from local businesses to governments. According to Deloitte Port Services, Center of Expertise, “port authorities in Europe and North America are working hard on fully automated container terminals, “greenification” of ports and port related economic activities in the port areas” [8].

As supply chains become more integrated, hinterland operations become more pronounced. Port authorities should focus on improving hinterland connections by taking the lead in drawing up a joint investment program for the necessary infrastructure improvements; adding that a port authority can facilitate the application of technology and enable better insight into traffic flows, helping enterprises to further optimize their supply chains and make them more flexible. "The port authority of the future is assisting companies through port community systems" [8].

According to Botti, the port is in a continuous process of evolution that affects the supply chain stakeholders, but also the country where the port is located [9].

III. CROATIAN PRACTICES AND INITIATIVES WHICH LEAD TOWARD SMART PORTS

The port development is divided into four stages: loading and unloading port; industrial ports; logistics / supply chain port and smart port [7]. While the first stage relates only to loading and unloading operations, the last stage refers to what is increasingly present in developed ports - the digital integration that makes the seaport smart. Such seaport shifts its business to become a service provider, and focuses to the connection of all stakeholders who contribute to seaport operations. Therefore, smart ports represent the last development stage where the digitalization of port activities is at the forefront and where new services replace traditional practices.

Logistics companies require easy access to information and port data transparency, and such technology allows freedom of data exchange among different smart devices. The data are collected and analysed to facilitate the exchange of information.

Seaports have a wide variety of smart-port technologies to choose from, but the key strategic issues they face should guide the selection process (e.g., an individual port’s needs can be driven by its location, role in trade, or level of competition) [6]. In this respect, seaports can be divided into four categories [6]: emerging ports, local trade hubs, intermodal ports and city-based ports (Table 1). Croatian cargo ports cannot be strictly categorized, and should focus on numerous aspects of the aforementioned seaport categories. Their main objective should be to simplify the business processes. Furthermore, they should also aim to optimize traffic across transport modes (intermodal gateway) and to minimize impact on surroundings (city-based port).

TABLE 1: A PORT'S INDIVIDUAL NEED DRIVE TECHNOLOGY STRATEGY

Type	Focus	Applicable solutions
Emerging port	Ease of doing business	-Port Community System -Single Window -X-ray scanning -Biometric access control systems
Local trade hub	High productivity	-Smart cargo-handling systems -Equipment management and control -Gate automation -Safety management solutions
Intermodal gateway	Optimized traffic across transport modes	-Truck appointment systems -Traffic-monitoring systems -Integrated rail and barge platforms
City-based port	Minimized impact on surroundings	-Asset health monitoring -Environment and energy -Management systems -Port-wide platforms

The Ministry of the Sea, Transport and Infrastructure has recognized the importance and advantages of digitalization and stakeholder connectivity (such as forwarders, maritime agents etc.), in maritime transport. These advantages are the business facilitation, the reducing of administrative mistakes and impediments.

Within this, three projects have been developed that will solve the administrative problems faced by stakeholders in the logistics chain of freight transport, thereby facilitating data control. The first project refers to the establishment of a National Single Window, an information platform for data exchange and processing through the cooperation of the Ministry of the Sea, Transport and Infrastructure, the Customs Administration of the Ministry of Finance, the Port Authority of Rijeka and the Port Authority of Ploče [10]. Besides that, a new service CIMISNet will significantly improve data exchange, reduce administrative procedures among Ministries, all Port authorities, Ministry of the Interior, the Customs administration, Coastal Shipping Agency, Croatian Bureau of Statistics etc. Security in cross-border traffic will also be improved in accordance with Schengen rules [10].

According to Duvallet, Sadeg and Belfkih, many challenges in the smart port development exist, which are also present in Croatian cargo ports: "heterogeneous technologies: the large equipment list and standards used in the port, produce and exchange a large amount of data; large variety of data types: a large amount of data (AIS data, logistic data, etc.) is used in the port" [11].

In the port of Ploče, the integration of PCS system with other systems (TOS, CIMIS, etc.) is already present. The goal is to develop a port logistics center and enable the automated data exchange based on the concept of Single Window [12]. Data exchange using CIMIS system (Croatian Integrated Maritime Information System) has already been tested and it is now necessary to define the data exchange structure that will be standard to all PCS systems regardless of the port where they are used; the use of the PCS system must be applied in all Port authorities in the port areas, with necessary adaptations [12]. This is the main objective of the project "Design and implementation of a Port Community System", with the aim of providing PCS ICT solutions in ports of Rijeka and Ploče, based on the existing solution in port of Ploče, as well as their integration into the National Single Window, CIMIS system, e-Customs and the existing parts of other individual application systems currently being used.

Anticipated PCS ICT solutions will enable the optimization of business processes and timely and reliable data exchange, as well as simplified and accelerated logistics processes among all users/stakeholders.

The PCS will be initially implemented in the ports of Rijeka and Ploče, after which other Croatian ports of international importance (Zadar, Split, Šibenik and Dubrovnik) will be included, with necessary system adaptation.

IV. CONNECTED TECHNOLOGIES AS A PREREQUISITE FOR COMPETITIVENESS OF CROATIAN SEAPORTS

Smart systems based on ICT technology and integrated logistics systems for information exchange between maritime, urban and road systems enable improved port operations. By adopting modern ICT solutions, there is a reduction in costs, and in the long run, there will be a return on funds that were initially invested in the new ICT infrastructure [9].

According to Heilig and Voß, "Information systems have become indispensable to the competitiveness of ports, facilitating communication and decision making for enhancing the visibility, efficiency, reliability, and security in port operations under various conditions" [13]. Providing value-added information services and analytics is increasingly important to maintain a competitive edge and to meet regulatory requirements.

Shanghai International Port (Group) Co., Ltd. and Accenture have conducted the research in the area of smart ports (Figure 1) [14]. They have also emphasized

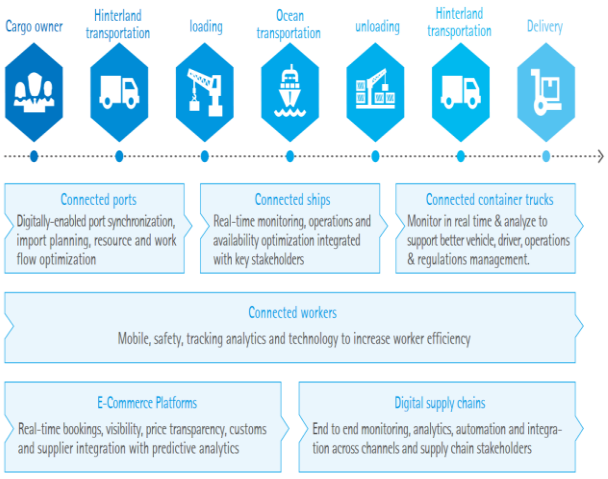

Figure 1: Openness and innovation to achieve interconnection in the value chain of ocean cargo

the importance of connected technologies among seaports, ships, container trucks, connected workers etc.

According to their research, "The most direct and effective way for traditional industries to embrace innovation is by introducing innovative forces; The trend is toward a port ecosystem that is open, interactive, highly connected, data driven and smart and collaborations between ports, governments and research institutions are essential" [14].

The advantages of smart technologies are also emphasized in the port of Rotterdam: at the same time, it is possible to gain insight into the business of all stakeholders and make the process more efficient. "Digitally optimized berthing can improve safety as well as efficiency. The guidance can reduce wait times, enable faster loading and unloading, and allow ships to come and go more quickly—and shaving an hour from the berthing process can save ship operators USD 80,000" [15]. The case study of the Hamburg smart port "has proven that given the right approach, investing in IoT will yield results", and the stakeholders associated with logistic services have already noticed a reduction in time spent in the port for increased operational efficiency [16]. Therefore, the impact of Internet of Things technology in ports as well as development of smart applications will improve port operations. At last, positive effects on business processes will be visible throughout the entire supply chain [17].

Several already existing and worldwide adopted smart technologies can be applied to Croatian ports such as smart cargo handling equipment, which reduces operating costs by up to 10 percent and minimizes idle and unnecessary energy use [6]. In addition to the economic and security component, it is important to emphasize the ecological business aspect in smart ports. A motion-sensitive terminal lighting system is one of the smart technologies. It illuminates only when vehicles are nearby – the port of Valencia reduces energy consumption by 80 percent [6]. Port of Hamburg uses similar smart illumination at the port roads.

Table 2 shows the advantages of using smart technologies in seaports by comparing two situations: *as-is* (current state) and *to-be* (future situation).

TABLE 2: DURATION OF THE CONSIDERED ACTIVITIES WHEN USING SMART ICT

Activity	**Duration (as-is) (min)**	**Duration after using smart ICT (to-be) (min)**	**Smart ICT used**
Truck check-out	15	0,5	RFID
Locate container	15	1	WSN

The as-is situation refers to "a number of manual steps, such as stopping the truck, delivering the hard copy of documents to the gate officer, and waiting for the pass before restarting the truck" [18].

After applying RFID technology, "the activities are almost totally automated, since, when the truck approaches the access gate, the RFID allows registering and controlling the container, thus allowing opening the gate" [18].

Port of Rijeka represents an intermodal port, and a multi-purpose port as well, where the port activities are performed at several locations and terminals. The port of Rijeka has many advantages such as the geographical position, the depth of the sea, the resources, and therefore has become the maritime transit centre of Croatia. In addition to these characteristics, a major role in the success of the port is played by its traffic connections with the rest of the country as well as the surrounding countries. According to Abbes, seaports benefit from their strategic positions, but it is necessary to ensure adequate capacities to meet the potential demand [19]. As a port is more connected to international maritime routes, it will attract more global operators. Therefore, the port of Rijeka could be a competitive and a key connection if digitalization is increased.

Port of Ploče is also a port of special significance for Croatia. Recently, new investments have been made in a new container terminal, bulk cargo terminal, and port information system. Port of Ploče has recognized the advantages that this investment could bring: "the increase in port traffic, economic multiplier effects on the local community and the narrow gravity area of the port of Ploče, with the neighbouring Bosnia and Herzegovina will have positive economic effects by increasing the competitiveness of their goods due to modern transhipment facilities in port of Ploče, as well as reduced transport costs for their goods due to new capacity in port of Ploče" [20].

V. CONCLUSION

Smart technology solutions enable ports to become smarter in terms of information flow. Operations such as tracking, and data collection are used to make the best decisions and improve business processes. Currently, attention is directed at data providing services, rather than, for example, hauling operations. Therefore, smart ports are the stage in which the digitalization of port activities is at the forefront and where new services replace or increase traditional port services. Shareholder cooperation also plays a very important role in achieving sustainable business as well. There are numerous ports that turn to sustainable business procedures, bringing together smart technologies.

One of the main objectives of Croatian cargo seaports should be to simplify the business processes as well as to optimize traffic across transport modes (intermodal gateway) and to minimize impact on surroundings. The Ministry of the Sea, Transport and Infrastructure has also recognized the importance and advantages of digitalization and stakeholder connectivity: the business

facilitation, the reducing of administrative mistakes and impediments.

In port of Ploče, the objectives are: integration of PCS system with other systems (TOS, CIMIS and others); development of ports logistics center and enabling the automated data exchange based on the concept of Single Window. A well digitalized port allows access to a common business application system intended for port management. There is no doubt that this is a strategic move in which the efficiency of business is at the forefront.

The port of Rijeka possesses many advantages such as its position and the depth of the sea at the terminals, but adequate capacities are essential to meet the potential demand. Therefore, PCS ICT solution in port of Rijeka will enable the optimization of business processes, timely and reliable data exchange as well as simplified and accelerated business processes among all stakeholders.

The transition of Croatian seaports into smart ports is definitely possible. The first step toward the transition is currently in progress: the development of both Port Community Systems and National Single Window, with the aim of simplifying information exchange among the stakeholders. Each seaport faces its own problems or opportunities, and the transition can be a long and demanding process. Therefore, in Croatian ports, the goal should be to introduce as many smart technologies as possible, which will create numerous benefits, for example accelerated cargo manipulation.

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Students' Perception of Studying in Digital Environment and Preparedness for Workplaces in Digital Economy - Current State and Perspectives

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Abstract - **In order to utilise modern technologies in efficient, effective and reliable ways within tertiary (higher) education, it is necessary to fulfil certain framework conditions. Modern technologies need resources, infrastructure and human resources who will utilise and implement them in economically justified way. Also, it is absolutely necessary to integrate them in curriculums, while learning outcomes obtained by utilizing those new solutions must be evaluated and at, both, the national level and the international level. Necessary measures for the implementation of those improvements require long-term strategic planning, positive changes in the business environment and the allocation of optimally adequate financial funds. Therefore, the main challenge of this scientific paper is to analyse and, based on the achieved results, evaluate tendencies of utilisation and further possibilities of utilisation of modern technologies in the teaching process and in the learning process. Whereas, the main focus was put on perception of studying in digital environment and consequent preparedness for workplaces in digital economy. With scientific questionnaire authors have included students and lecturers at selected higher learning institutions in the Republic of Croatia. Thus, in the context of this paper, analysis is used to evaluate the current state and synthesis is used to gain proper perspectives.**

Keywords – **Digital Environment, Digital Economy, Workplaces, Students, Studying**

I. Introduction

Beside the role of information and communication technology (abb. ICT) in a reform of tertiary education and in a creation of knowledge-based economy within developing countries, integration of these ICTs in tertiary education has direct benefits for universities, faculties, professors, lecturers and students. Universities that enable the use of ICTs for teaching purposes, learning purposes and administrative purposes will probably attract more students, solve problem of lack of qualified staff, increase satisfaction and motivation of staff, develop extra skills of staff, enhance overall organizational effectiveness, improve public image of the institution, build strategic alliances with external organizations and increase revenues.

Fig. 1. [4] shows the share of Internet users who used common digital technologies or those who are engaged in chosen indicators related to: content creation, cloud computing, e-banking, e-government, online courses, online purchases, seeking health information and social networking. For example, in Fig. 1. there is the comparison of mentioned indicators for one of the most successful countries (Belgium) and OECD average. In Belgium, cloud computing, e-banking social networking and online courses were more widespread among individuals than in OECD average, while less individuals created (online) content and sought (online) health information.

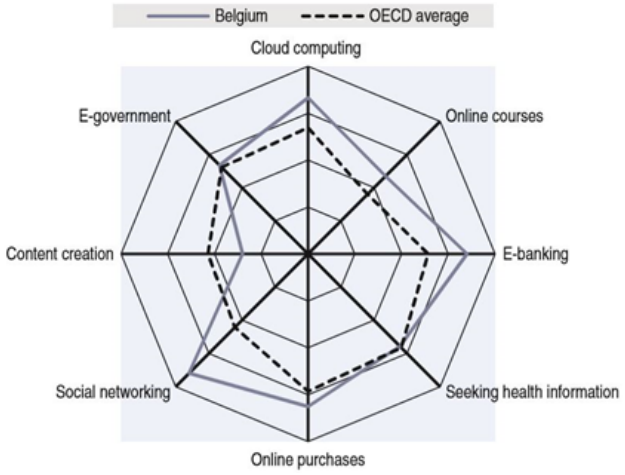

Figure 1. Use of digital technologies by Internet users, as the percentage of Internet users aged from 16 to 74

Likewise, Fig. 2. [4] shows the comparison of the chosen indicators of various digital (computer, ICT, Internet) skills, positions offered to ICT specialists, tertiary (education) level (graduates in ICTs, graduation rate) in one of the most thriving countries (Finland) and OECD average. Even though graduation rates and positions offered to ICT specialists were in accordance with OECD average, in Finland, there was much larger share of businesses that provided training to develop ICT skills and individuals with a high level of computer skills. That suggests that Finland has invested and continues to invest in skills that are needed to boost productivity and growth in digital economy, thus providing other countries with the outstanding example.

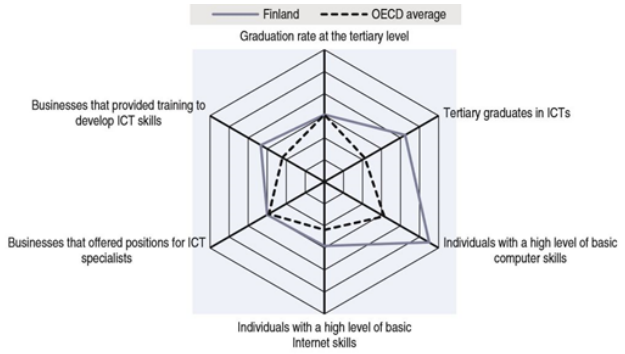

Figure 2. Overview of digital skills, tertiary (education) level and positions, as the percentage of all graduated students, persons aged from 16 to 74, companies with 10 or more employees

Additionally, digital technologies can help to encourage economic growth, including positive overflow effects within and between sectors. Technologies, smart applications (including data analytics) and other innovations in digital economy can also improve services and help with rising to policy challenges in the widest sense, including education, finances, insurance, health care, transportation, energy, agriculture, fishing and other sectors. So, digital technologies contribute not solely to innovations in goods and services, but they also contribute to innovations in processes, business models and organizational arrangements. [1] [2]

This short overview of chosen countries (Belgium and Finland) in comparison with OECD member countries made it perfectly clear how important digital skills were for persons who were just about to enter the workforce, but especially for persons who are already in the workforce.

All of 32 OECD member countries and 6 partner countries who have participated in OECD survey related to policy and forecasts of digital economy, have stated that they possess their own national digital strategy or program, except for United States of America that is decentralized. Almost 2/3 (two thirds) of national digital strategies are standalone strategies, while others are the integral part of wider national strategy, e. g. national strategy of innovation. Most European OECD member countries have aligned their national digital strategies with digital agenda for Europe, European strategy of single digital market, strategy Europe 2020, action plan for e-government of European Union or their combination(s) (Framework 1.3.). More than 2/3 (two thirds) of all countries had national strategy before the current one. Currently, on average, national digital strategies have a timeframe for implementation of 7 years and there are half way through the implementation, either with the budget that is directly related to a national digital strategy or more indirectly through the budget of ministries and agencies that are involved in its implementation.

Aims of policy for the development of digital economy and society, that largely implement national digital strategies, are the high priority in all countries. Out of 15 aims in total that were related to national digital strategies, 68% of aims had a high priority, 15% of aims had a medium high priority, 14% of aims had a medium priority, while only 3% of aims had a medium low priority or low priority.

From one standpoint, it can mean that most of those aims are high priorities for governments, while from other standpoint it could indicate the inability to determine priorities among those aims in many countries. Strengthening of e-government services and further development of telecommunication infrastructure took the highest place in the year 2017. Yet, e.g. re expected priorities in the following 3 to 5 years, further development of telecommunication infrastructure falls 3 places, what indicates that those aims are dynamic and interchangeable when it comes to country's priorities. Likewise, there is a number of countries that mention these aims as part of national digital strategy along with some extra aims that are not included in ranked priorities, but are often mentioned as aims of national digital strategies.

II. State and Perspectives of Education For Digital Economy - Students' Perception

Focus of Digital agenda for Europe is the creation of single digital market, impairment of interoperability framework between ICT products and services, encouraging reliability and security of Internet, fast and ultrafast Internet access, research and innovations, development of digital literacy, skills and competences, along with ICT-related benefits to EU countries. Therefore, Digital agenda for Europe is the list of aims that should, with the help of technology, bring real changes in human lives.

What is students' perception, as one of the main groups that will soon enter the workforce and in the situation that they understand the need for and the meaning of digital economy, has been examined by authors via questionnaire research method and online questionnaire that was answered by 190 students (61,69%) out of a total of 308 students who were asked to complete it. Plus, out of those 308 students, 160 students (51,95%) were from Faculty of Economics, while 148 of students (48,05%) were from Faculty of Electrical Engineering, Computer Science and Information Technology, that are both located in Osijek, Republic of Croatia, Europe.

This, fully and completely students-based questionnaire, entitled "Questionnaire about perception of students and studying in digital environment" was consequently filled in by students at higher years of study in economics and electrical engineering.

Gender-wise, there were 56,8% males and 43,2% females among respondents, what presents roughly gender-equal sample.

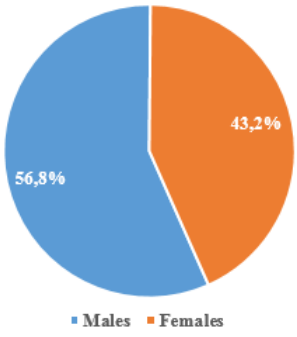

Figure 3. Questionnaire sample according to gender

Based on reviewed literature, strategic documents authored by European Union, OECD and national economies, it can be preliminarily concluded that digital education is a precondition for a life in digital world and digital economy of today. [3]

Both tendency and need for digital education is visible from the questionnaire, based on the question: "How necessary it is to be educated digitally?"

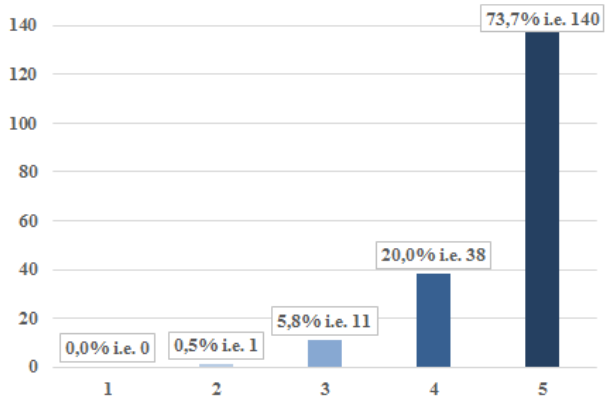

Figure 4. Necessity of digital education

According to answers it is visible that 73,7% of students are well aware of the importance of digital education as of today what is completely in sync with question put, while 99,5% of students are in sync with question put.

When it comes to the question re traditional education style, students' opinions, however, do differ. So, 35,8% of students deem that traditional education style is not satisfactory at all as education style, while the majority of students deem that it is, after all, satisfactory. Of course, accentuated is the need for combined education style that implies the combination of traditional style and contemporary, digital education style.

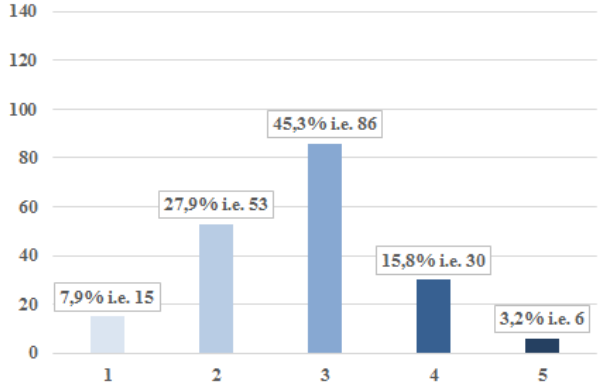

Figure 5. Satisfaction with traditional education

Regardless of students' habits, a large number of them deem that education properly enriched by means of various ICTs is the future and that it is increasingly taking over primacy in education system as well as within tertiary education in general.

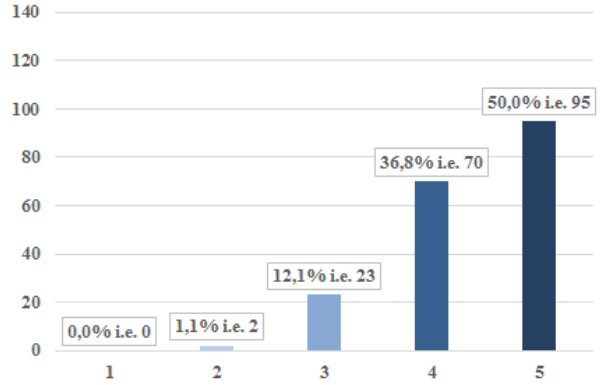

Figure 6. Digital education (enriched by ICT) as future of tertiary education

Questionnaire has revealed that 98,9% of students deem that digital education enriched by ICT is the future of tertiary education and that is necessary to make additional efforts in order to make substantial benefits of those contemporary tendencies, wherever and whenever possible, available to all students.

Based on mentioned considerations, the question is put on what is the current situation in use of ICT within tertiary education and students' preparation for digital economy.

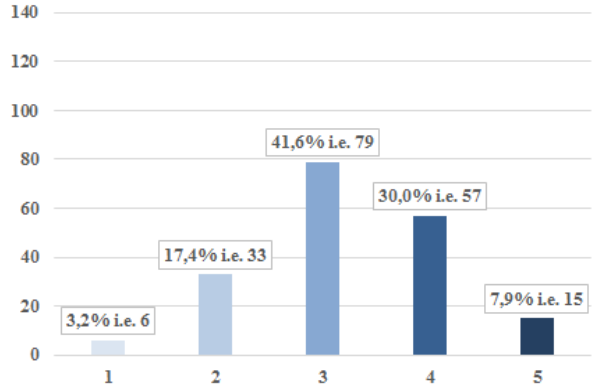

Figure 7. Students' estimate on use of ICTs in their tertiary education

As per questionnaire, 37,9% of students deem (have experience) that ICTs are used in teaching process at tertiary institution, while 41,6% of them deem that ICTs are both used and not used in teaching process. Somewhat over 20% of them deem that ICTs are not at all used in teaching process.

There are many reasons why use of ICT is at this level, yet, for sure, one of reasons is the availably and the reliably of ICT infrastructure at students' home tertiary institution.

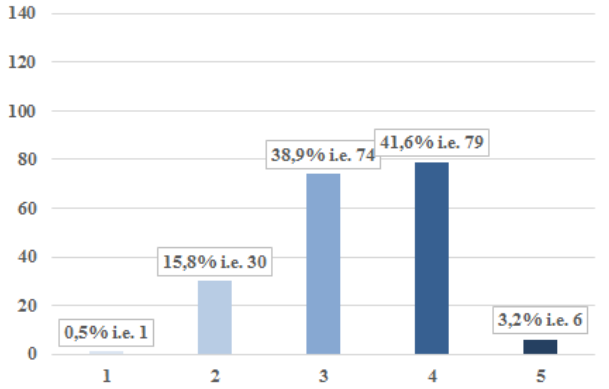

Figure 8. Current ICT infrastructure in students' home tertiary institution

According to the results, it is visible that 44,8% of students deem that current ICT infrastructure in home tertiary institution is highly satisfactory or satisfactory, while 38,9% of them deem that it is somewhat satisfactory. From a total number, 16,3% of students deem that ICT infrastructure is not satisfactory, that is most probable reason behind non-usage of ICT in teaching, as it was presented and elaborated in the earlier phase of questionnaire analysis.

A total of 71,6% percent of students deem that knowledge in the domain digital economy will surely or probably help them in future employment or self-employment, while 9,0% of them deem that this knowledge will not be useful to them, what is surely data that raises new questions and prompts for further research.

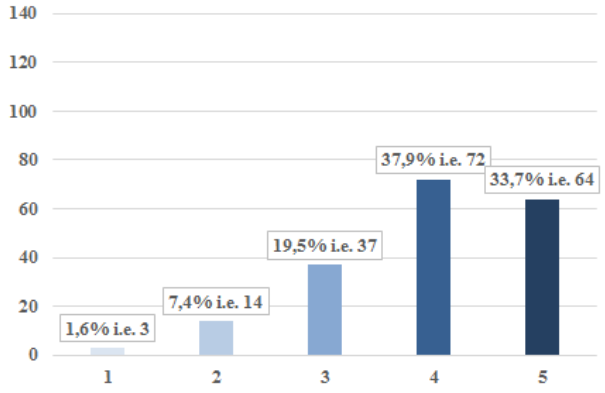

Figure 9. Students' estimate on how much will knowledge in the domain of digital economy help them in future employment or self-employment

Subjective students' assessment has shown that 63,7% of them (supposedly) possess very good or excellent digital skills, while 4,2% of them deem that they have not got digital skills.

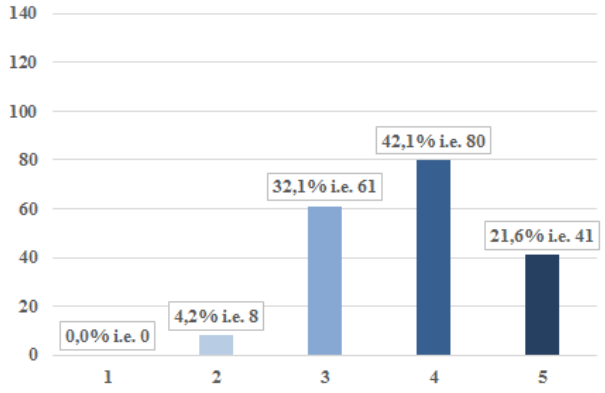

Figure 10. Students' assessment of their possessed digital skills

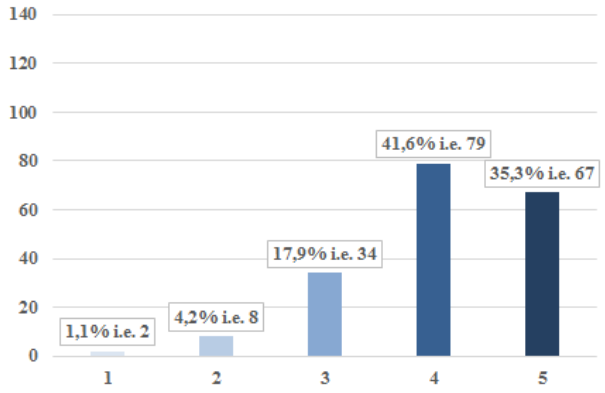

Figure 11. Tertiary institutions should create more opportunities for non-formal education related to digital economy

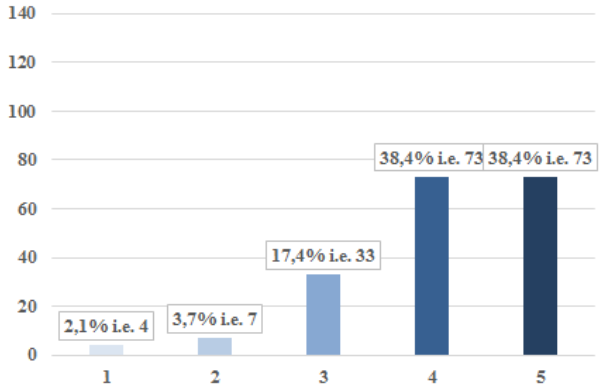

Figure 12. Tertiary institutions should create more opportunities for formal education related to digital economy

III. Conclusion

Some countries consider that their accomplishment contributes to the achievement of aims at higher levels, such as growth of Gross Domestic Product (GDP) (Brazil, Denmark, Germany, Israel, Japan, Mexico, Slovenia, Sweden), jobs (Denmark, Germany, Latvia), productivity (Finland, Russian Federation, Switzerland), competitiveness (Estonia, Latvia, Netherlands, Russian Fed.), quality of life and welfare (Estonia, Lithuania, Netherlands, Russian Fed., Turkey), democracy and transparency (Sweden, Switzerland), inclusiveness (Israel, Norway, Slovenia, Sweden) plus fight climate change and encourage sustainable development (Sweden, Switzerland). [4]

Based on these macrocategories, it is possible to perceive perceptions of student population, of current economic tendencies as well as of problems and opportunities in tertiary education under influences of digital environment, economy and education. Additionally, in accordance with the questionnaire conducted for the purpose of this paper, it is possible to observe and recognise numerous and various signals and perceptions of students:

- Students are aware of (increasingly digital) environment within which they live and study
- To be educated digitally is the key, as almost all students deem
- Tertiary education enriched by contemporary ICT is the future
- Students are satisfied with the current traditional education, yet they deem that the key is in introducing contemporary ICT within teaching process
- More than half of students see their tertiary institution as the one that has non-satisfactory ICT infrastructure for educating students in the context of digital economy
- Most of the students deem that they possess average to high digital skills, however they do deem that they will need additional skills acquirable through (non-)formal education
- Accordingly, it can be concluded that students are aware of the current situation and of the importance of digital skills and related tertiary education for their future establishment within the workforce as well as for personal differentiation with regard to their environment.

To sum up, questionnaire results have confirmed that students do perceive that they are indeed studying in (increasingly) digital environment, education and economy. Yet, when it comes to their preparedness for workplaces in digital economy, while they (supposedly) possess above-average digital skills, they have some reservations re digital (economy-related) skills, what will definitely be further researched by the authors.

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The potential of ICT-enabled social innovation

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Abstract - **Although social innovation is an old paradigm, social innovation courses appeared in the curricula in the approximately last ten years. By doing so educational institutions acknowledged the existence of new approaches to obstacles that the world is facing. The courses regarding the social innovations give the students valuable knowledge and skills related to solving different social problems, increasing the motivation for being active in the society, and raising awareness about specific topics that need attention. An important role in implementing social innovation have ICT technologies. The role of the ICT is multiple: (1) administrative (members of the certain social initiative collaborate on the project through different ICT tools that enable communication and information organization), (2) disseminative and educational (the topic of the social initiative is disseminated through different tools and social media), and sometimes (3) topical (it the topic of social innovation project is directly connected to specific ICT technology). Based on the roles that the ICT takes upon in the process of social innovation implementation, the authors present ICT solutions that could be included in the realization of a social innovation course for business students at the graduate level.**

Keywords - social, innovation, ICT, education

I. INTRODUCTION

In times of increasing overlapping of public, private and civil sector, the term social innovation became one of the gladly used buzzwords reflecting the processes that are emerging throughout the world. As an important part of the local entrepreneurial eco-system Faculty of Organization and Informatics in Varaždin is ready to provide its students with hands-on experiences and bring awareness to the social problems and the potential of social innovation. The first step in that direction was the introduction of a course Social Entrepreneurship to the undergraduate program Economics of Entrepreneurship which is now being executed for the third year. In the anonymous survey 70% of students who finished the course Social Entrepreneurship expressed a desire to broaden the knowledge and gain more practical experience in that area. The next step in the same direction would be to introduce the elective course Social Innovation to the graduate program Economics of Entrepreneurship.

The aim of this paper is to explore how the ICT can be of assistance in development and implementation of social innovations and further on which ICT skills should be encompassed in a social innovation course at the graduate level of business education. In order to answer these questions, the second part of the paper describes the meaning of social innovation and the complementary concept of social entrepreneurship. The third part of the paper presents the literature review of the competencies that should be acquired through a social innovation course. The fifth section identifies the importance of the ICT technologies for social innovations and gives recommendations for the inclusion of ICT in the social innovation courses. The final section concludes the paper.

II. SOCIAL INNOVATION AND SOCIAL ENTREPRENEURSHIP

Different authors give us different perspectives on social innovations and social entrepreneurship. However, with time and efforts made by researchers and policymakers, the concept of social entrepreneurship became more structured in comparison to the term social innovation, especially in the EU context. According to the Commission [1], the term "social enterprise" encompasses two types of businesses:

1. "Businesses providing social services and/or goods and services to vulnerable persons (access to housing, health care, assistance for elderly or disabled persons, the inclusion of vulnerable groups, child care, access to employment and training, dependency management, etc.); and/or
2. Businesses with a method of production of goods or services with a social objective (social and professional integration via access to employment for people disadvantaged in particular by insufficient qualifications or social or professional problems leading to exclusion and marginalization) but whose activity may be outside the realm of the provision of social goods or services."

According to [2] referenced in [3], social innovation is the development and implementation of new ideas realized through products, services and models in order to meet social needs. This approach is broad and could encompass a variety of innovations that would be considered only as very useful innovations before the era of the buzzword social innovation. On the other hand, Mumford [4] states that social innovation refers to the development and implementation of new ideas about how people should organize interpersonal activities, or social interactions, to meet one or more common goals.

Christensen, Baumann, Ruggles, & Sadtler [5] introduced the term catalytic innovations that refers to a fundamentally new approach to social problems that creates system-changing solutions, and in order to be system-changing they have to be durable and have a broad impact. Following that line of thought, Westley and Antadze [6] defined social innovation as a complex process of

introducing new products, processes or programs that profoundly change the basic routines, resource and authority flows, or beliefs of the social system in which the innovation occurs. Thus, in order to determine whether something was a social innovation, it can only be done post hoc, when the process proves that it is sustainable and scalable. Thus, the social innovation definition is more encompassing when it states that social innovations represent novel solutions to social problems which have potentially transformative effects.

Social entrepreneurship innovations must not only be new and cost-effective, but the social value has to be delivered in a way that is financially and in other ways accessible to its intended beneficiaries [7]. Even though social innovation sometimes includes technological or scientific solutions, many social problems could be solved with more social versions of social innovation such as gathering the stakeholders on the same page or by creative use of existing resources [5].

III. SOCIAL INNOVATION COURSES

As it can be seen from the previous section, the literature has struggled with the definition of social innovation, and thus with the belonging description of what social innovators do and what they need to know to actually do it. Following the complexity of social innovation, the learning outcome of the one-semester course Social Innovation simply cannot be that all the students participate in development and implementation of social innovation and thus the course should strive to something more manageable. Since the learning outcome of the course Social Entrepreneurship is not necessarily becoming a social entrepreneur, the analogy applies to the social innovation courses. Due to the time constraint of the course and the fact that social innovation process as any innovation process is not linear in its nature, the courses should use the available time to equip the students with knowledge and skills that would make them more likely to engage in social innovation.

Previous research provides us with the guidelines what these knowledge and skills are for social entrepreneurship courses. Social entrepreneurs face three main challenges [8]: the complexity of accountability since social entrepreneurs are accountable to multiple stakeholders; achieving a double bottom line by balancing social and commercial objectives; management of complex identity since the organization has to be legitimate both in the for-profit and not-for-profit sector. However, social entrepreneurs in Croatia are concerned with issues related to the social context and community rather than with commercial goals such as efficiency and financial independence [9]. Thus, the introduction of social entrepreneurship topics in the business curricula should contribute to the more successful achievement of a double bottom line.

Based on the thorough literature review and the research of their own Miller et al. [7] made a list of competencies required for social entrepreneurs which have to facilitate identification, evaluation and exploration of opportunities: ability to challenge traditional way of thinking, communication skills, creativity, sense of moral imperatives, ability to identify social problems, management of financial capital, ability to sell, conflict resolution skills, capacity to measure outcomes, cultural awareness, ability to commit to a collective purpose, time management, flexibility, humility, taking responsibility for actions, fundraising and donor cultivation, etc. Among the aforementioned competencies, there was also the management of logistics and technology. Research [7] shows that the five most common competencies taught in social entrepreneurship courses are managing strategy development, managing financial capital, the capacity to measure outcomes, innovativeness and creativity and identification, evaluation and exploitation of opportunities.

Social innovators also face specific challenges [10]: they require a deep understanding of social problems, how they are rooted in existing institutions, values and ideas and social practices. A second is inherently political in nature since social innovators are changing social systems and often lead to the redistribution of privilege. Thus, social innovators often take upon the roles of problem solvers as well as politicians to overcome the resistance to change.

Since the course Social Innovations which we are developing is an elective course that follows the course Social Entrepreneurship, we see it as a continuation of the previous with complementary learning outcomes that are often neglected in the social entrepreneurship courses. Competencies that are rare in the social entrepreneurship courses' syllabi including our course are developing volunteer support, managing administrative work, developing social skills, conflict resolution skills and confidence to succeed at challenging tasks [7]. In addition, the research shows that social entrepreneurship practitioners [7] put more emphasize on marketing and selling, sense of moral imperatives, and challenging traditional ways of thinking in comparison to existing social entrepreneurship courses.

Social innovation, as well as social entrepreneurship, is cross-disciplinary and the courses bearing these names exist across different domains such as business, public affairs, sociology, non-profit management, urban studies, disability studies, etc. The paper aims to explore what role ICT plays in the development and application of social innovation since the transfer of ICT competences is at the core of the Faculty's mission. Additionally, according to the Faculty's strategy, one of the three missions is a contribution to the society which covers different social innovation projects [11].

IV. THE IMPORTANCE OF ICT FOR SOCIAL INNOVATIONS AND SOCIAL INNOVATIONS COURSES

Today it is almost impossible to conduct any project without the Information and Communication Technology (ICT). Social innovations are often implemented as different initiatives and projects which means that ICT has an important role in implementing social innovation. The research team at the Faculty of Organization and Informatics (FOI) which is focused on entrepreneurship and decision making has gained experience in the implementation of socially-innovative projects, mostly funded by the EU funds. The projects are presented in Table 1, together with their belonging social impact and a list of ICT tools that facilitated the realization of the projects.

TABLE I. SOCIALLY-INNOVATIVE PROJECTS IMPLEMENTED IN COOPERATION WITH FOI RESEARCHERS

Project	Type	Funding	Social impact	ICT tools
Ivanscica for better tomorrow, 2013	National	European Commission: IPA, Youth in action Programme	Finding solution for revitalization and development of different social activities at the top of mountain Ivanscica which is placed between two different cities and counties which makes this process difficult	Learning management system Moodle, Facebook, Messenger, MS Office, Dropbox, Expert Choice, Wordpress
Go, go, NGO!, 2015-2016	International	European Commission: Erasmus+	Increasing the level of structured level in local government units, Increasing the motivation of young people to involve in different social activities (as organizers or participants), Increasing the funds for non-governmental organizations in local government units	Learning management system Moodle, Facebook, Facebook Ads, Messenger, MS Office, Dropbox, Viber, Wordpress, Adobe Connect, MS Publisher
One, two, … and action!, 2013	International	European Commission: IPA, Youth in action Programme	Motivation of young people to participate in elections for European parliament, Creating the city monograph regarding the 25th city anniversary, Filming a documentary movie regarding the 25th city anniversary	Learning management system Moodle, Facebook, Messenger, MS Office, Dropbox, Corel Video Studio Pro X6, Joomla, Gimp, MS Publisher
Being young in EU – how to start?, 2013	International	European Commission: IPA, Youth in action Programme	Project deals with the overall indifference and apathy and wants to serve as a sort of a wake-up call for young people. In the first stage, the problems that young people face were identified. In the second stage, participants made video material representing each of the chosen problems and how they affect people in Zlatar. In stage three, during the partners meeting in Zlatar, workshop participants from Zlatar discussed each theme and generated possible solutions.	Learning management system Moodle, Facebook, Messenger, MS Office, Dropbox, Joomla, Corel Video Studio Pro X4
3P – Plan it, start it, promote it!, 2015-2016	National	European Social Fund	The increase of entrepreneurial aspirations of high school and higher education students, The increase of enterprise culture capacity of high school and higher education educators	Dropbox, Facebook, WordPress, Video Studio Pro X8
Pop-up rural socially-innovative hubs, 2018-2020	National	European Social Fund	Service learning of students in interdisciplinary teams who work as consultants for potential social and commercial entrepreneurs in rural areas	Google Drive, Skype, Viber, Facebook, Teamwork

Based on this experience gained on several social innovation projects such as national projects Ivanscica for better tomorrow [12], [13], 3P– Plan it, start it, promote it! [14], and Pop-up rural socially-innovative hubs [15]; international projects: Go, go, NGO! [16], [17], One, two, … and action! [18], and Being young in EU – how to start [19], [20]); we propose that the role of the ICT in social innovations is multiple:

(1) administrative (members of the certain social initiative collaborate on the project through different ICT tools that enable communication and information organization),

(2) disseminative and educational (the topic of the social initiative is disseminated through different tools and social media), and sometimes,

(3) topical (it the topic of a social innovation project is directly connected to specific ICT technology).

After discussing the three leading roles of the ICT in implementing the social innovations, we will be able to elaborate the ICT part of the new course, since the course – in a practical way – presents the implementation of different initiatives and projects similar to previously mentioned ones (Figure 1).



Figure 1. From real social innovations projects to course "Social innovations"

A. Administrative role

The most straightforward role of the ICT in social innovations is the administrative role, which can be realized in two ways: communication and information organization. Comparing to simple Plan-Do-Check-Act paradigm (also known as Deming cycle) [21], each social innovation can be considered as project that requires several aspects: (1) detailed analysis of the social problems that are addressed, (2) detailed plan of social innovation implementation (3) implementation of the social innovation and (4) evaluation of the results that are achieved by implementing the social innovation. It is obvious that each of those four phases requires both, good organization and documentation (information organization) and communication between the actors that are planning and implementing social innovation. Those two processes, communication and information organization can be organized the best using the appropriate technologies. There are many technologies that can be helpful:

- for information organization: different platforms such as Google docs, Dropbox and others;
- for communication: emails, instant messages services such as Facebook Messenger, Viber, Skype, WhatsApp, Hangouts and others;
- for both: advanced systems such as Alfresco Share, Learning Management Systems Moodle, Teamwork and others.

B. The disseminative and educational role

The second role of ICT is disseminative and educational. Even if it seems easy, the dissemination of the social innovation project is everything but not that. The success of social innovations often depends solely on the dissemination, especially in case of crowdfunding campaigns. All social innovations are focused on some social problem. Often, society is not familiar (enough) with the problem, or they know something about it, but the knowledge is superficial. Therefore, social innovators have to create appropriate disseminative products in order to spur the public interest and encourage the inclusion of the stakeholders into the project. At the same time, the disseminative products are also educational. There are many ICT platforms that can be helpful in achieving the disseminative role of social innovations. Some of them are:

- webpages – separate webpages for a specific social innovation project or the content that can be incorporated into existing webpages of social innovators (often the more affordable choice);
- social networks (social media) – there is a colloquial statement among active Facebook users, "If it is not on Facebook, it didn't happen". Similarly, the statement can be applied to other social networks. The content can be disseminated through a separate social innovation project's page (profile), or as a part of a page (profile) of the social innovation project's initiator. Some social networks provide enable the creation of different promotion campaigns (paid posts);
- crowdfunding platforms – they enable both the collection of the finances necessary to implement social innovation as well as serve as a promotional tool of great potential.

The content published on those platforms can include text, figures, animations, videos, blogs, vlogs, forums, chatrooms, and others. Additionally, it is important to have a good strategy for publishing the content.

C. Topical role

The last role of ICT in social innovation implementation is topical. This is related to the case when ICT is a big part of the innovation itself, and social innovation could not exist without it. Some of the examples are:

(1) Pigeon Air Patrol was a project in which the pigeons flew across London with the air quality sensors in their little backpacks. As the birds spread out across the city, people could check the air quality readings relayed from each sensor by tweeting their location to the Pigeon Air Patrol Twitter account [22],

(2) System e-citizens (in Croatian e-Građani) which enables the full range of public administration services for citizens that do not have to be implemented "in the old way" anymore (issuing the personal documents, informing about students grades, checking the medical information and prescriptions …) [23],

(3) Transition to the new DVB-T2 and H.265/HEVC TV system.

V. THE ROLE OF ICT IN THE DESIGN OF SOCIAL INNOVATIONS COURSE

Social Innovations would be a one-semester experiential learning course realized through the team-based projects. Experiential learning is the process of accumulating knowledge through direct experience [24], [25]. Research suggests that it is important to include stakeholders in the design of education [26]. Thus, every team would collaborate with a social venture or an NGO. The fieldwork should result in first-hand experiences that cannot be gained in a classroom setting. The course is an elective course at the graduate study program Economics of Entrepreneurship, and the participants are business students. Thus, the students are ICT users who have the necessary knowledge for administrative and disseminative/educational role of the ICT.

However, basic knowledge is not enough in the digital era and the students need to be encouraged to improve their e-competences through Social Innovations course. At the beginning of the course, students will form several teams. The teams will analyze a specific social problem, collaborate with a social entrepreneur or an NGO and through that collaboration design and implement concrete social innovation projects (some of the projects will be also proposed by the educators). Depending on the project, they will get the support for acquiring the ICT competencies which they need.

ICT education will include:

- Using the platforms for information organization and communication with the advantages and disadvantages of each platform and instructions on how to select the appropriate platform for their projects. The messages that they need to take from this experience is the importance of documentation in one place, the importance of simple and understandable documentation organization, documentation availability to the project team members and the importance of back-up,
- Using the platforms for dissemination and education: simple websites (ex. Wordpress and Wix), conducting the Facebook ads,
- Using the crowdfunding platforms – Indiegogo, Kickstarter, GoFundMe, Kiva, Zopa,
- Creating the digital content that will be disseminated – the main accent here will be on creating short and attractive videos which will be

used in social innovation project in terms of dissemination and education,

- For the topical role of the ICT, we can present students with the resources that are available at the Faculty of Organization and Informatics such as 3D printers, and introduce them to the computer science students who can help them in the development of mobile apps etc.

Most of the above-mentioned solutions support both, desktop and mobile devices.

There are many other ICT solutions that can be used in terms of some ICT role regarding social innovations. The list of them increases rapidly [27]. However, the plan is to use the solutions students are familiar with at least at some level considering the type of the students (area of business) and the time available for the course. Additionally, students are already familiar with some other specific software that can be useful for the implementation of social innovation projects – they learned about them on other courses. Some of them are MS Office tools, decision support systems (ex. Superdecisions for making multi-criteria analysis) and different tools for statistical analysis (ex. R-studio).

At last, it is important to find the balance in using the ICT solutions. Otherwise, the risk of using too many solutions might appear. Two main preconditions of using the ICT solutions are: they are really needed (they will contribute to the success of social innovation), and users know how to use them.

VI. CONCLUSION

Teaching materials for courses that deal with social innovations are usually fragmented and organizing the course content is a challenge especially when the course includes project-based learning and students work on different topics. The main aim of this paper was to summarize which ICT tools could be of value to the students working on their social innovation projects. Three roles of ICT were identified in the course Social Innovation: administrative, disseminative and educational, and topical. For each role, the belonging tools are presented. The list is by no means exhaustive, but it gives an indication of the many tools that can be presented to the business students depending on their project needs.

Students often express the desire for more meaningful education which is in accordance with the desire for more meaningful jobs expressed by Millennials. The specific feature of the course Social Innovations is that their e-competences will not be tested isolated from their concrete application. Their e-competencies will be reflected in the results of the whole project which encourages students to acquire life-long learning skills and adapts them to the conditions of the real working environment.

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Ontology literature review as guidelines for improving Croatian Qualification Framework

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***Abstract* – Development of information systems dealing with education and labour market using web and grid service architecture enables their modularity, expandability and interoperability. Application of ontologies to the web helps with collecting and selecting the knowledge about a certain field in a generic way, thus enabling different applications to understand, use, reuse and share the knowledge among them. A necessary step before publishing computer-interpretable data on the public web is the implementation of common standards that will ensure the exchange of information. Croatian Qualification Framework (CROQF) is a project of standardization of occupations for the labour market, as well as standardization of sets of qualifications, skills and competences and their mutual relations. This paper analysis a respectable amount of research dealing with application of ontologies to information systems in education during the last decade. The main goal is to compare achieved results according to: 1) phases of development/classifications of education-related ontologies; 2) areas of education and 3) standards and structures of metadata for educational systems. Collected information is used to provide insight into building blocks of CROQF, both the ones well supported by experience and best practices, and the ones that are not, together with guidelines for development of own standards using ontological structures.**

Keywords* – *ontology, education, e-learning, Croatian Qualification Framework

I. INTRODUCTION

Communication between two or more dislocated information systems via web implies their ability to automatically interpret exchanged information. Use of ontology enables clear and unambiguous access to structured knowledge, while allowing enough freedom in conceptualizing and creating the final software product. [1] analyses the role of ontologies in the semantic web and the corresponding data structures, such as Linked data and Big data. Authors investigate advantages and problems of development of ontologies, their sharing and reuse, and analyze tools and techniques that enable their development and use. In general, ontologies are still not widely implemented in practical applications. Although there are differing opinions on the need to further implement them, there is a common agreement about the need for unanimous semantic, understanding and formal representation with the aim of connecting heterogeneous systems with large amounts of data.

CROQF (Croatian Qualification Framework) is based on EQF (European Qualifications Framework) and on QF-EHEA (Qualifications Frameworks in the European Higher Education Area). Main task of CROQF is to classify qualifications based on the criteria set for certain levels of learning achievements. The purpose is to integrate and coordinate national qualification systems and to improve transparency, accessibility, mobility, and quality of qualifications in relation to the market labor and civil society. It should allow effective integration of education programs and labor market requirements. One of the ways of linking labor markets and education systems is to provide support by a common language called ESCO (European Skills, Competences, Qualifications and Occupations taxonomy) standard [2], shown on Fig. 1.

ESCO should improve the exchange of information and enable cooperation between education systems, public and private job search platforms, as well as among different countries. ESCO standards should enrich and upgrade tools and applications so that they provide better options for compatibility, up-skilling and information exchange. A detailed breakdown and description of ESCO taxonomies are shown in the Chapter II and on Fig. 3.

This paper analyses the research done in the last decade in the area of application of ontologies to e-learning and education systems. Analyzed papers were identified among publicly available resources by keywords: ontology, e-learning and education. A total of 33 publications and papers (30 in journals and 3 conference papers) were analyzed. From the overview of analyzed papers by year, shown on Fig. 2, one can conclude that the subject of ontologies in education has been continuously researched.

Chapter II describes the three dimensions used for classification of papers: purpose and coverage with basic

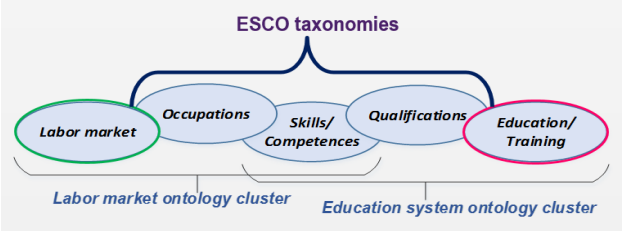

Figure 1. ESCO standards connect education and labour market systems

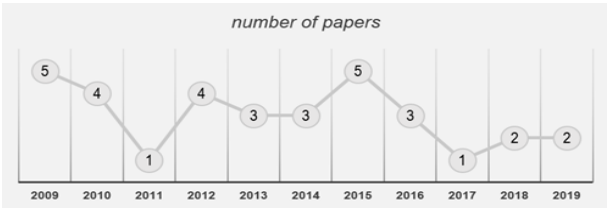

Figure 2. Overview of analysed papers by year

functionality of education system, ontology content for education system and application scenarios of ontology implementation. An overview of all papers with a summarized description of ontology content with purpose and coverage of these ontology in education systems is shown in Chapter III. An overview of papers according to application scenarios of ontology implementation, as well as purpose and coverage of these ontologies in education is given in Chapter IV. Chapter V concludes our analysis and emphasizes the problem of lack of basic concepts, such as learning outcomes, which connect the labor market system with the education system.

II. CLASSFICATION

Our domain of interest is the education ontology cluster (shown on the left-side of Fig. 1). The analysis of papers was performed over the following dimensions (main topics): *Purpose and coverage*, *Content* and *Application scenarios* [3] [4] [5] [6].

A. Purpose and coverage

What is it for? The purpose of ontologies covering e-learning systems can be classified according to the following characteristics [3]:

- *Curriculum modelling and management* covers institution's processes and organization for development, design, and implementation of each degree program's organization, structure, content, assessment of outcomes, and pedagogy.
- *Describing learning domains* incorporate subject-domain ontologies (providing substance for learning process) and task ontologies (activities, exercises, case studies, projects, simulations, and assessment items).
- *Describing learner data* is related to an individual learner (learning profile, completed content and performance data).
- *Describing e-learning services* - collaboration between heterogeneous e-learning systems. Ontologies are used for searchable, accessible, and sharable learning resources (services such as IEEE LOM, Dublin Core, and SCORM).

B. Content

What is in it? Fig. 3 shows detailed set of ontologies from Fig. 1, their connections and applied standards (taxonomies). According to ESCO interoperability map [4] and main relationships and classifications from [5] the following domains were identified:

- *Education Ontology* includes information about levels and fields of education. Fields of education are based on FOET (Fields of Education and Training) taxonomy and level of education on standard ISCED (International Standard Classification of Education).
- *Competency Ontology* defines the proven ability to use knowledge, skills and personal, social and methodological abilities. ESCO defines DigComp (Digital Competence Framework) which provides a vocabulary of digital competences at the European level.
- *Knowledge Ontology* contains the body of facts, principles, theories and practices that is related to a field of work or study (e.g. CS2013 – Computer Science Curricula 2013, from https://dl.acm.org/citation.cfm?id=2534860).
- *Skills Ontology* defines the ability to apply knowledge and use know-how to complete tasks and solve problems. The task of CROQF is to define the National skills classification.
- *Qualification Ontology* is described in terms of knowledge, skills, responsibility and autonomy and should be attainable though a variety of educational and career paths.
- *Occupation Ontology* includes information about occupations and workplaces. An integral part of this ontology is ISCO (International Standard Classification of Occupations). Occupation ontology is outside of this paper's scope.

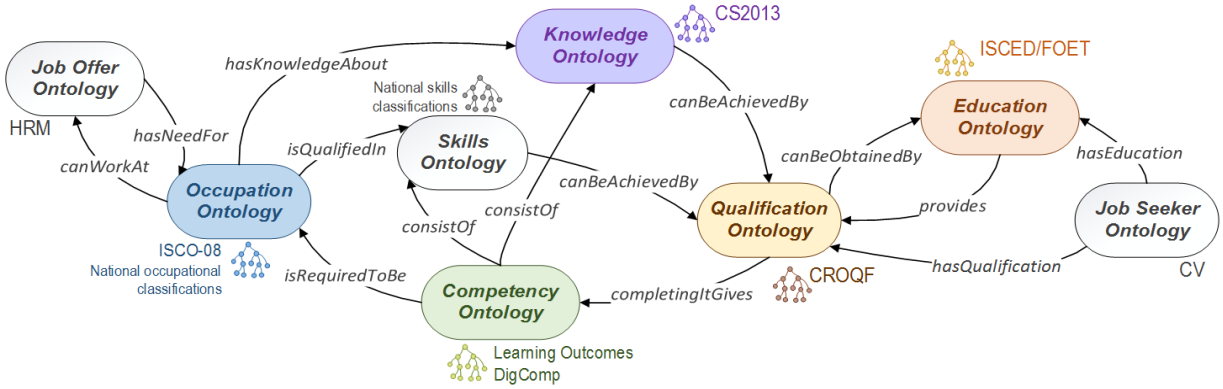

Figure 3. Ontologies cluster for occupation and education systems

C. Application scenarios

How do ontologies help? Four main categories of ontology application scenarios are given in [6], showing a wide range of ontology representations, from semantically lightweight to semantically rich ones, such as:

- *Neutral ontology for authoring,* where individuals develop their own ontologies for authoring operational data with different applications. Individual organizations or companies use ontologies as translators for various proprietary software systems.
- *Ontology as specification*, domain-specific ontology created to be implemented manually or by partially-automated software tools. This level of ontology application automates documentation, maintenance, reliability, knowledge use and reuse.
- *Common access to information,* where ontology information is used by multiple agents, as a mutually agreed basic standard for information conversion and mapping, thus facilitating interoperability and effective knowledge (re)use.
- *Ontology-based search,* where an ontology is used by a structuring device (e.g. search engine) as information repository allowing better access to information. This ontology application scenario allows using the same ontology for multiple systems as a way of concept-based structuring of information.

D. Two types of analyses

The analysis is performed by grouping the available literature according to the topics covered, in relation to the topics (dimensions) of interest:

1. *Purpose and coverage* in relation to *Content* (Chapter III with Table 1), and
2. *Purpose and coverage* in relation to *Application scenarios* (Chapter IV with Table 2).

During the both analysis a special focus was placed on *Curriculum modelling and management*, and *Describing e-learning services*, which are parts of *Purpose and coverage* dimension, as well as the main functionalities of processes implemented within the CROQF.

Skills, *Competences* and *Qualifications* ontologies, which belong to dimension *Content,* are integral parts of both the ESCO and the CROQF standards, so the research results that include these ontologies are a valuable asset that can be used for development of CROQF.

Furthermore, the knowledge about *Application scenarios* of ontology implementation obtained from researched papers can be used to provide insight into the building blocks of CROQF.

III. PURPOSE AND COVERAGE VS CONTENT

Table 1 show frequency of articles according to the two main topics covered (*dimensions*), each shown as a hierarchy of *characteristics*. The hierarchies contain a relatively large number of characteristics in order of their influence to be quantified as precisely as possible during the phase of analysis. One paper's scope may cover more than one characteristic, therefore the same reference may be found in more than one place within a single table.

TABLE I. PURPOSE AND COVERAGE VS CONTENT

Content	**Purpose and coverage**			
	Curriculum modeling and manag.	*Describing learning domains*	*Describing learner data*	*Describing e-learning services*
Education Ontology	[19] [22] [25] [36]	[7] [8] [13] [24] [26] [30] [34] [35]	[7] [8] [12] [16] [28]	[9] [17] [18] [20] [21] [23] [33] [38]
Competency Ontology	[32]	[11] [29]	[15] [19] [21] [25] [37]	[9]
Knowledge Ontology	[22] [24] [30]	[12] [14] [27] [32] [39]	[8] [14] [15] [16] [23] [27] [39]	[11] [31]
Skills Ontology		[10]	[10] [13]	
Qualification Ontology				[11]

As shown in Table 1, ontologies *Knowledge* and *Education* are mentioned in a large number of papers (30 of 33 papers analyzed), as opposed to *Skills, Competences* and *Qualifications,* mentioned in only 11 papers, and consequently researched to a lesser extent.

Ontology-based system for educational and *Curriculum modeling and management* [22] [36] with semantic repository and predefined semantic queries. An approach to achieve optimal sequence of learning the contents of a course and taking tests is researched in [19]. In [25] a technique for developing an individualized learning path that meets user's requirements is described. It uses revised Bloom's taxonomy to specify concepts of a domain ontology: courses, lessons and their sequences. Besides development process of an educational ontology [32] emphasizes the importance of specifying competences in terms of learning outcomes. A semantic web-based system, *Gescur* [22] [24], is used for managing the education curriculum, data about institutions, knowledge areas and subjects.

A Java ontology integrated toolkit, used to create an ontology-based application that specifies the *Describing learning domain* is described in [26]. Development of an ontology-based e-learning support system [7] [30] [35] includes specification of curriculum, syllabus and subject ontologies, as well as discovery and sharing of knowledge based on subjects' ontology (teachers and students). [24] demonstrates the use of semantic web system *Gescur* for improvement of education process quality. An intelligent approach to compose optimal learning groups with members having different domain backgrounds is described in [13]. [34] deals with interoperability problem and ontology mapping between educational domains elements (syllabus, courses, materials, exams) and pedagogical resources. Modeling of a particular knowledge area with concept maps was created by experts and with the guidance of teacher judgment in [39]. In [8] and [27] authors define the main knowledge domain concepts and relations in form of graphs, maps or

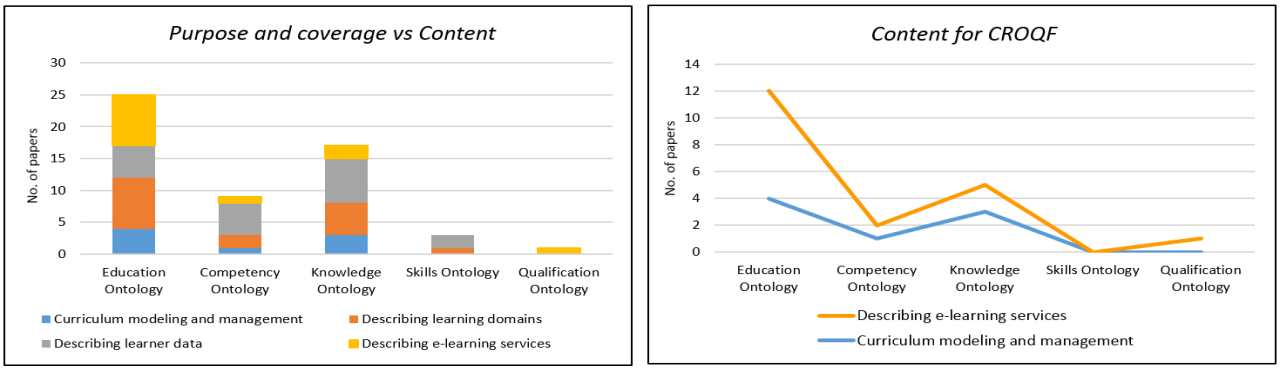

Figure 4. Frequency of articles for *Purpose and coverage* dimesion in relation to *Content* dimension

diagrams. An ontological representation of cognitive skills is described in [10].

Educational domain modelling and *Describing learner data* in [8] are a basis for personalized e-learning. A method for tracking students' active learning and self-leading learning is proposed in [7] and [12]. Ontology-based e-learning systems [16] [28] make adaptations and improvements to the learning process by analyzing students' learning performance and courses' ontology. Knowledge-based systems which assists learners in achieving desired knowledge and goals are described in [13] [15] and [19]. A domain ontology offers learners a personalized choice of registered courses and materials [21] [25] [37], in order to achieve personalized competences. To improve the content and structure of personalized course knowledge [14] [23] use ontology-based metadata for describing both the entire domain and specific learning objects.

Metadata standards of the D*escribing e-learning services* domain, such as LOM, Dublin Core and SCORM, are used to develop different educational systems: *PASER system* [9] supporting educational process; *GrEd* [17] used for education in Greece; *LO management model* [18] used to find correlation between learning styles and LO characteristics; *SMILE system* [20] enabling semantic ontology mapping for interoperability of learning resource systems, and a framework for building an adaptive Learning Management System [21]. MOODLE system is used in [33] to classify learning objects and to develop modern semantic learning management system. Education objective metadata repository in [9] provides a system-wide consistent competency vocabulary. [11] and [23] describes e-learning at the workplace and link between learning and work performance, as well as the communication between individuals.

An overview of papers frequency across the *Content* dimension hierarchy (shown on the left side of Fig. 4) shows that a large number of papers cover the *Knowledge* and *Education* ontologies, specifically their following elements: syllabus, courses, materials, exams, and pedagogical resources. On the other hand, *Competency*, *Skills* and *Qualification* ontologies, relevant to CROQF, are covered in a small number of papers. The breakdown across functionalities *Curriculum modeling and management* and *Describing e-learning services*, which are relevant to CROQF (right side of Fig. 4), shows the same trend.

The experiences gathered from the current research on the education systems are a valuable reference for the task of designing basic concepts of CROQF. The ontologies that not adequately researched should be developed from the beginning, from conceptualization to formal application.

IV. Purpose and Coverage vs Application Scenarios

Regarding different application scenarios, which can be divided according to the level of maturity of implementation of ontologies, lower levels of maturity have received a greater focus. As shown in Table 2, scenarios *Neutral ontology for authoring* and *Ontology as specification,* representing lower levels of maturity, have been researched in 22 papers, as opposed to *Common access to information* and *Ontology-based search*, which were mentioned in 14 papers.

Curriculum modeling and management is presented in [22] [25] [32] [36] as conceptualization of education ontology. In [24] ontology structure is used by *Gescur* web–based system to execute semantic queries. [33] presents the design of curriculum ontology and syllabus ontology in detail with implementation of mapping rules with the aim of connecting different entities that contain different formats of syllabi. Web applications in [17] and [19] use ontologies to: define vocabularies, share common

TABLE II. Purpose and Coverage vs Application Scenarios

Application scenarios	**Purpose and coverage**			
	Curriculum modeling and manag.	*Describing learning domains*	*Describing learner data*	*Describing e-learning services*
Neutral ontology for authoring	[22] [25] [32] [36]	[8] [30] [32] [35] [39]	[13] [23] [25] [39]	[23]
Ontology as specification	[24] [30]	[7] [10] [11] [13] [14] [24] [27] [34]	[7] [10] [19] [27] [28]	[11] [18] [31] [33]
Common access to information	[19]	[12] [26] [29]	[15] [16] [21] [37]	[17] [38]
Ontology-based search			[8] [12] [14]	[9] [20] [21]

understanding of information structure among people or software agents, and enable reuse of domain knowledge.

Describing learning domains by conceptualizing educational knowledge structure, resulting in concept maps, is given in [32] [35] and [39]. Domain-specific ontology is created for adaptive learning path implementation [7] or for multidisciplinary learning group composition [13] [14] and [34]. Knowledge and content structuring, using collaborative ontology design methods, is presented in [27]. In [25] and [26] the ontology of student activities is designed to store information about their learning process and results. An agent platform, described in [12], supports various personalization levels by using machine-understandable representations of educational domains and learners' characteristics.

An approach to learning where learning objects are based on students' specific needs results in them developing a unique learning style. *Describing learner data* [23] [25] [39] deals with determining, managing and monitoring such learning objects, as well as tracking students' time spent learning different content. In [13] authors propose a flexible e-learning self-evolving system, so that enrolled trainees can become trainers at the end of the process. [10] [19] and [28] describe different ontology-supported methods of processing contents of e-learning systems. Improved methods of student assessment during learning process used by educators are described in [12] [14] [16] and [37]. Results of assessment can be used to adjust syllabus concepts, such as *body of knowledge* and *area/unit of knowledge* taxonomies.

Describing e-learning services using [23] ontology and LOM standard to create a concept tree of learning objects and detect the student's previous knowledge level. Application of semantic web techniques to services of e-learning system, such as searching context relevant learning resources by means of decision trees and ontology mapping, are described in [18] and [33]. An ontology-based learning management system was used to manage e-learning knowledge in [31]. [9] and [21] present intelligent systems with ontologies, metadata repositories and knowledge-based modules that use queries and reasoning on learning metadata.

An overview of papers frequency across the *Application scenarios* dimension hierarchy (shown on the left side of Fig. 5) shows that a large number of papers cover *Neutral ontology for authoring* and *Ontology as specification*, which shows that the current research is focused on specification and conceptualization of subject-domain ontology. From the perspective of CROQF-related ontologies, such results are encouraging, because they constitute a solid basis for their development. A small number of papers that covered *Common access to information* and *Ontology based search*, points out the complex task of ontology development, implementation, use and reuse. The breakdown across functionalities *Curriculum modeling and management* and *Describing e-learning services*, which are relevant to CROQF (right side of Fig. 5), shows the same trend. Consequently, work on the CROQF will be a demanding and long-lasting job.

V. CONCLUSION

The main recommendation for the process of establishment of EQF and national qualifications, CROQF in our case, is for them to be related to learning outcomes. Development of a methodology for description, use and application of learning outcomes has the aim of increasing transparency, understanding and comparability of qualifications. Web technology and ontology-based systems can ensure semantic interoperability between characteristics used to describe learning outcomes, such as skills, competences and qualifications, which would help to reduce the communication gap between EU countries and between domains of employment, education and training.

The research described in this paper is focused on ontology-based systems in education. Literature is analyzed with respect to two aims: representation of ontologies relevant to CROQF (*Skills*, *Competences* and *Qualifications*), and maturity of ontology-based software implementation.

Analyzed papers, as expected, contain many references to the *Education* and *Knowledge* ontology which support the learning process. However, the most important aim of the education process, learning and learning outcomes, and the appurtenant ontologies *Skills*, *Competences* and *Qualifications,* are researched to a much lesser extent. They represent an upgrade of the e-learning process and a connection with learning outcomes and qualifications. Their further analysis is recommended, as well as research into the possibilities of their implementation in both the CROQF and EQF.

For maturity of ontology-based software implementation, majority research is focusing on low-level ontology implementations, such as modelling of interest domains, and less on a holistic approach aimed at integrating heterogeneous systems and achieving their interoperability. In addition to further research ontology-based systems and their application to CROQF, additional

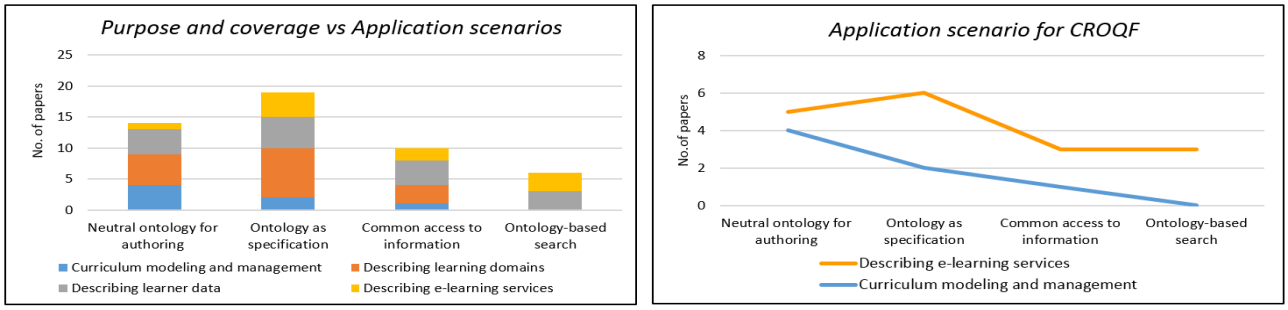

Figure 5. Frequency of articles for *Purpose and coverage* dimesion in relation to *Application scenarios* dimension

work should be done developing web services and applications for facilitating interoperability and effective knowledge use and reuse.

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E-Government Ecosystem: A new view to explain complex phenomenon

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***Abstract*—Different kinds of e-governmental services have taken into use in several countries all over the world. The transition is often driven by the seen benefits in, e.g., efficiency, money savings as well as empowerment of citizens. Different e-governmental systems have been studied and analysed by using different theories and models; however, the current models often do not succeed to take a citizen—the customer—into account enough. This study propose of using an ecosystem viewpoint to define and explain this phenomenon and presents the concept of 'e-government ecosystem'. The concept is based on philosophical foundation on citizenship. In addition, an existing maturity model is extended and future research areas proposed.**

***Index Terms*—e-government, socio-technical view, ecosystem, citizen-oriented, digital society, e-government maturity model**

I. Introduction

Throughout history, governments have sought more efficient and better ways to govern. It is no wonder that technological development has also been seen as possibility to reach this aim. IT in government has been a subject in literature since 1970's, but the term e-government was born in the late 1990's when internet changed the world of computing [1]. E-government is a shorter form of electronical government, which refers to the use of of information and communication technology (ICT) tools and applications to enhance government. [2], [3]

Digitisation of governmental information system has been a trend for decades. Public sectors all over the world have been shaken by various attempts to reinvent the government, but it seems that expectations of change are now anchored into e-government especially in Europe [4]. For example European Union has in the e-government action plan 2016-2020 promoted the use of information and communication technology (ICT) as a way to governments to become more efficient and effective and constantly improving public services. [5] The guiding vision of the European Union's e-government action plan is:

> *"By 2020, public administrations and public institutions in the European Union should be open, efficient and inclusive, providing borderless, personalised, user-friendly, end-to-end digital public services to all citizens and businesses in the EU. Innovative approaches are used to design and deliver better services in line with the needs and demands of citizens and businesses. Public administrations use the opportunities offered by the new digital environment to facilitate their interactions with stakeholders and with each other."* [5]

In the EU level, the goal is to transform the governments and create a Digital Single Market, that would support ideas of user-centric and transparent government, and cross-border mobility, which have been selected to be the top-level benchmarks of e-government [5], [6]. Currently many countries have varied levels of e-government implemented. In the EU commission's bench-marking top countries in e-government have managed to make public services available online, mobile friendly, transparent and available for other countries as well [6].

Globally levels of e-government vary even more than within the EU. Nevertheless, the level of the e-government is globally rising and governments are striving to keep pace with the technological innovations in order to enhance government and to create better societies. [7]

It is often highlighted that e-government is a citizen-centric action that delivers many benefits to the citizens [5]–[7]. Citizen-centricity implies, that the needs of the citizens are the starting point for the redesigning government and its processes [8], [9]. Paradoxically, many e-government systems and applications are suffering from low adoption rates [2], [4], [10], perhaps due to a mis-match between developed services and goals and requirements of citizens and stakeholders [11]. This prevents government and citizens from gaining promised benefits and decreases these systems public value. [2], [4], [10]

Thus, although research about e-government has been done for decades and from perspective of many fields there seems to be a problem in understanding the role of the citizens as part of the e-government. As citizens seem to be the key factor in e-governance, there should be more focus on the issue. We claim that neglecting citizens' role is partly a problem arising from too narrow view to these complex systems. Thus, we propose a new view of *e-government ecosystem*.

The rest of the paper is structured as follows. Section 2 reviews e-government field, Section 3 focuses on the role of the citizens, and Section 4 presents the definition of e-government ecosystem. Finally, we conclude in Section 5.

II. Background of the e-government field

The field of e-government research emerged in the late 1990's. At first, it was a field of practitioners trying to cope with the new challenges created by the use of internet as a medium in government. Since then a large number of the conferences have been practitioner oriented. [1] and traditionally e-government research relies on managerial perspective [12], [13].

Managerial orientation can for example be seen in interchangeable use of terms e-government and e-governance. Calista and Melitski [14] describe these terms as separate but yet complementary terms. E-government, they define, *"provides governmental services electronically, usually over the Web, to reduce the physical character of customer transactions by recreating them virtually"* whereas *"e-governance envisions employing the Web and Internet to overhaul how the state conducts its democratic dealings by using networked interactions with citizens to foster transparency and participation"*. [14, p.101–102] Thus, there is a small division between the two. E-government is a system of digitised services for citizens whereas e-governance can be characterised as more comprehensive set of measurements to govern democracy by means of information and communication technology.

Since e-government can be defined as a system, it is no wonder, that it is often perceived as a technical system. This can be a reason for why e-government research often focuses on technical solutions and is rather technologically deterministic [4], [13], [14]. Technological determinism refers to idea, that technology alone effects how the system works and thus, the consequences of implementation can be estimated prior to implementation. This idea has been challenged for example by socio-technical approach which takes into account the social system (people using the system) and their influence on the technical system and vice versa. [15], [16]

In general level goals of e-government can be divided into three: more efficient government, better services to citizens, and improved democratic processes [1]. Assumed benefits vary a lot from the cost-effectiveness and efficiency of government itself, to improvement openness and transparency and in the most recent phase of the development, the empowerment of citizens [17]. Many of these benefits are hard to measure and there is not a lot rigorous research done about how these benefits actually occur and if they even occur.

One of the most used bench-marking tools in e-government is the maturity model of United Nations (UN), that is used to measure level of e-government globally in UN member countries. It is based on four stages that reflect the state of e-government in a country [18]. The model and its stages are presented in Table 1.

The model of the UN [18] is a classical model based on the sophistication of technology and level of communication between users and organisations as well as between organisations. For example Moon [19] has used similar approach in their e-government framework that also takes into account both internal and external communication as well as levels of sophistication in terms of technology.

These kinds of linear and broad descriptions are useful when describing the e-government, although in reality the phases are not so clear [14]. They often leave out the broader implications or affects that e-government has. For example, UN's model [18] does not take into account the societal effects, but focus merely on possible applications of technology. However, these kind of constructions highlight the notion that e-government cannot be stated to be one piece of technology, and it should be tread as it is — a set different stages of applications that serve the purpose of more efficient government and (in the best case scenario) democracy and its processes. It must be noted, that there is also a growing body of research about e-government that takes into account the citizens. For example there is a lot of research done about citizens attitudes and how to influence them [2], how to manage citizens' uncertainty [10], how citizens should be viewed as stakeholders [20], and how success could be measured from citizens perspective [17]. However, none of these views takes into account the holistic system of e-government.

As a problem of e-government seems to lie on the social side of system implementation, more holistic view could be more fruitful way to approach the issue. Thus, we have to refrain from focusing solely on the managerial aspects or perceiving it as merely as a technical system. We suggest that in order to acknowledge the role of different actors, especially citizens, we need to consider e-government from new perspective.

TABLE I
STAGES OF E-GOVERNMENT (ADAPTED [18]).

Stage	Description
Emerging information services	Government websites provide information on public policy, governance, laws, regulations, relevant documentation and types of government services provided. They have links to ministries, departments and other branches of government. Citizens are easily able to obtain information on what is new in the national government and ministries and can follow links to archived information.
Enhanced information services	Government websites deliver enhanced one-way or simple two-way e-communication between government and citizen, such as downloadable forms for government services and applications. The sites have audio and video capabilities and are multi-lingual, among others.
Transactional services	Government websites engage in two-way communication with their citizens, including requesting and receiving inputs on government policies, programmes, regulations, etc. Some form of electronic authentication of the citizen's identity is required to successfully complete the exchange. Government websites process non-financial transactions, e.g. e-voting, downloading and uploading forms, filing taxes online or applying for certificates, licenses and permits. They also handle financial transactions, i.e. where money is transferred on a secure network to government.
Connected services	Government websites have changed the way governments communicate with their citizens. They are proactive in requesting information and opinions from the citizens using Web 2.0 and other interactive tools. E-services and e-solutions cut across the departments and ministries in a seamless manner. Information, data and knowledge are transferred from government agencies through integrated applications. Governments have moved from a government-centric to a citizen-centric approach, where e-services are targeted to citizens through life cycle events and segmented groups to provide tailor-made services. Governments create an environment that empowers citizens to be more involved with government activities so as to have a voice in decision-making.

III. The Role of the Citizens, Government and E-government

Understanding the unique nature of citizenship in a e-government is imperative, if we wish to move towards more holistic view of eGovernment. Many philosopher have pondered citizenship, so we draw some influences from their work, then we define the ideal role of citizens in e-government ecosystem.

A. Philosophical background for citizenship

The Philosophical foundation for citizenship can be traced to ancient times Greece. However, in this paper we look more modern time Philosophers to understand the role and concept of citizenship. The social contract is theory which justifies the states authority over the individual citizens. There are several philosophers that can be seen as social contract theorists, but in this paper three philosophers whose thoughts we are leaning on are John Locke, John Ralws and Jürgen Habermas.

Even though Habermas is not commonly counted as social contract theorist—like Locke and Rawls are—he is famous and influential sociologist and philosopher that has focused on public discussion and rational policy making, issues what are essential to consider whilst seeking justified e-government ecosystems in democratic states.

For Locke [21], a state is the tool to seek the good of mankind in world that without commonly created rules and authority would be violent and cruel. The nature of law thus is changed to social contract made voluntary between people and this contract protects the of life, health, liberty and possessions [21]. Thus social contract does not give authority for state to do use uncontrolled power but secure the rights of the citizens. That is only justification for states authority over individuals and states should always keep that in mind or it has broken the social contract it is based on. From Lockean perspective it is crucial that e-government will be securing the life, health, freedom and possession[1] of citizen and the focus should be in serving citizens not governance of them.

Rawls' [23] idea about Veil of ignorance is thought experiment developed for determining the morality of rules of society. The participant of the experiment has to distinguish themselves from their knowledge of current socio-cultural situation and their other personal attributes and create rules for society from behind the "veil of ignorance", a place where they do not know where they found themselves in the created society. Rational behind this idea is that people cannot know what is their position in society they are creating and thus they will try to make it fair as possible to all member of society.

We claim, that people if they would be behind this "veil of ignorance" they would create e-government systems that would be good for citizens instead of creating faceless governing system to meet up the needs of government. Reason for our belief is not that we believe that people are solely benevolent, but also the selfish people would agree with this approach as most people are those that are governed and only small minority is governing. Thus, both rational selfish and benevolent people would aim to citizen-centric direction and thus it seems to be most rational—and even ethical—choice

If Locke is demanding the state that protects citizens and Rawls fairness of society, Habermas is one that calls for rationality and open discourse for all members of society. Habermas [24] has present concept of the rational discourse that is public communication about issues at hand. Habermas originally described the legislative processes but also governmental information systems—here e-government—are also stated to be such that those should be included in rational discourse because they have such big impact on society [25].

There are preconditions for rational discourse by Habermas [24]. First, all members of society should have possibility to participate discourse. This means that the citizen cannot be neglected. Secondly, all subjects of legislation—here also stakeholders of processes and governmental ISs—must have possibility to see implications of legislation and changes before they can have the agreement on it. Thirdly, the consensus is needed before the legislation/changes can be made. Fourthly, the strategic games are not allowed in rational discourse. Strategic games are mode of discourse where best argument is not winning but decisions are based on bargaining and thus those who posses more bargaining power has leverage against other. This however removes the ethicality and leave no more than excuses of the strongest. Thus, we see that citizens should be heard and their rational needs fulfilled when developing e-government ecosystem and services that are part of it.

B. Role of citizens in e-government

Citizenship is not like an employment or a business relationship of producer and customers, but has more unique characteristics that should be taken into account. Since, they are at the core of the e-government success, their role with its uniqueness should be acknowledged in the design and implementation of e-government much more than it is currently done.

We argue, that the reason for low-adoption rates and failures in e-government lies in the current view that e-government has on citizens. In lower maturity stages of e-government citizens are seen as rather passive instances, whereas in higher stages they are viewed as politically active individuals who are willing to take on duties originally orchestrated by governmental officer and professionals. This is a big change that deserves more attention and should be viewed from more socio-technical perspective as it affects the both citizens and governments.

In other words, we should be re-negotiating the social contract as e-government is changing our societies rapidly. Although citizen-centricity aims to acknowledge citizens, it actually assumes citizens' needs rather than bases the development on the actual needs. To base the new social contract on the needs of citizens, we need to discuss it. Thus, we need to have a rational discourse about the topic. In this discussion e-government applications, such as democratic forums, are valuable tools of democracy [26].

[1]Note: This is lexical order and thus life is more important than health, health more important that freedom. [22]

Thus, citizen-centricity as an approach is not quite as sufficient view. We argue, that the citizen-centric view should be replaced with citizen-oriented view, that is not based on the assumed needs of citizens, but on actual needs and values that they have. Whilst citizen-centricity notes that individual should be in core they can still be objectified — even it may be good willed. On the contrary citizen-oriented approach demands that needs of individual are heard and they have possibility to have active role whilst developing e-government for them. Hence, the citizen-oriented view has similarity with Habermas's [24] rational discourse where it is prerequisite that all stakeholders are able to participate in process.

Adopting the citizen-oriented view would guide the design and development of e-government towards understanding how the e-government impacts the lives of individuals and what kind of system they would like to use. In other words, what kind of value they need from that system. Thus, it would mean that e-government is build based on the needs and of the citizens — the users of the system. Acknowledging needs of the users of a technical system is a cornerstone of socio-technical view on information systems [27]. Although, it has been developed for organisational purposes, its view on human-beings as subjective individuals who are a part of a holistic socio-technical system [16] could be beneficial in the context on e-government as well.

It must be remembered, that the development of e-government should also be fair to even the most vulnerable. Thus, we should always considered the needs of the ones in more weakest positions as well. This aspect is actually incorporated in the current strategy of e-government for example in the EU [6] and the UN [7]. However, it must also be remembered, that acknowledging needs does not mean that needs should not be guessed or decided for, but based on actual needs.

In summary, the view on role of citizens should be shifted towards more active perspective, since the role of citizens is active in the last stages of e-governance maturity. Instead of focusing on assumed needs, it would be preferable to find out actual needs and aim to have a rational discourse about the topic. This would hopefully clarify the reasons behind the low-adoption rates in e-government, but also base the future solutions on the needs of the citizens who are willing to use them. Alas, it is impossible to find a solution that would be needed by each and every single citizen. However, treating citizens as individuals who can have a say in a democracy would be true empowerment. Thus, citizens' view should be incorporated in the e-government discussions and development.

IV. E-government Ecosystem

A. (Non-biological) ecosystem

The describing term of 'ecosystem' has been used as in multitude of ways in the fields studying technology. Research has been done about software [28], information systems [29] as well as IT [30] and ICT ecosystems [31], just to mention a few. The popularity of the term 'ecosystem' to explain non-biological systems can be traced back to the work by James F. Moore [32], who used the metaphor of an biological ecosystem to explain the complex and interrelated relationships between different actors in business world, in the 1990s. The concept was known before his work and used by, for example, Zeleny [33].

Yet after Moore's work, the concept of 'business ecosystem' has been used applied in a wide range of different kinds of artificial systems to system to explain their complex relationships (c.f. [34]). For example, software ecosystem depicts a set of organizations functioning as a unit in a shared market for software products and services [28].

According to Moore [35, p. 26], a business ecosystem is *"an economic community supported by a foundation of interacting organisations and individuals—the organisms of the business world"*. Often, there is a platform, of any kind, which acts as a central point for the business ecosystem [36]. A decade after presenting the concept, Moore report the concept has been found useful in several disciplines to understand modern business organisations such as law, management and sociology [37].

One of the central concepts for the ecosystem view is value. For example, Iansiti and Levien [36] define, in their seminal paper, that the keystone organisation, the one being in charge for the well-being of the business ecosystem, is responsible for creating and sharing *value* in the ecosystem. They note that creating too little value does not attract or retain members of an ecosystem. Similarly, capturing too much of created value, leaves too little for other ecosystem participants to share.

B. Towards e-government ecosystem

Based on the discussed problems in the current views to e-government systems, we draw from the literature of business and software ecosystems for presenting a new view to the discussion: an ecosystem point-of-view of e-government system. In the following, we will first define the term 'e-government ecosystem' and discuss its benefits and limitations. It is followed by a characterisation of a maturity model for e-government ecosystems.

We define an **e-government ecosystems** as a *complex socio-technical system incorporating citizens, organizations, companies as well as governmental agencies, which uses electronic platforms to create and distribute value to its participants*. A single e-government ecosystem can include several information systems if they are connecting to each others through shared data set. Thus, it describes all the stages in United Nation's maturity model [18].

In addition, the definition emphases *'complex socio-technical system'* (cf. [38]). That is, e-governmental systems are rarely simple nor trivial; instead, they include several data sources, stakeholders, interfaces, and users. In addition, the requirement of privacy and security are crucial for the technical system. Furthermore, the systems are likely change their surrounding societal system.

The definition shares similarities with, e.g., definitions of software ecosystems (c.f. [39], [40]); however, there are noteworthy differences. First, the e-government ecosystem does not focus only on e-government platform, but views it from

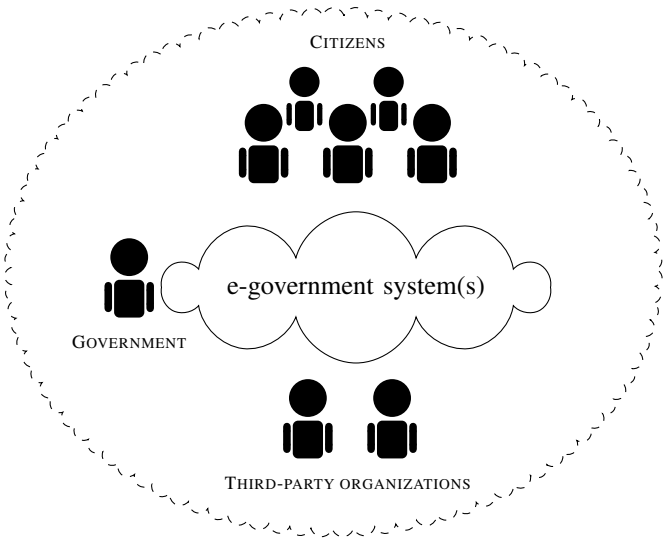

Fig. 1. An illustrative example of a general e-government ecosystem

the wider socio-technical perspective, thus taking into account also people that are in interaction with the platform. Second, it does not juxtapose the roles of citizen to the role of user, but rather views citizens as users who should be able to participate in the development of e-government.

Thus, our view is that the e-government ecosystem is that it is a socio-technical system that is orchestrated by the government, but which also includes citizens and other user groups such as companies and their representatives. This is illustrated in Figure 1. These social systems (citizens, other users, governmental officials and vendors) and technical system (interconnected e-government systems) should be seen as inseparable from each other. Together they for the ecosystem, that is—or at least should be—self-organising in a sense, that the needs of citizens should guide the development of technical systems. It is noteworthy that also governmental officials and software vendors often are also citizens.

Furthermore, a e-governance ecosystem, in our view, is often a result of an evolution process (cf. [41], [42]). There are clearly different stages in an ecosystem's evolution path. Therefore, we extend the e-governance maturity model (see Table I) into e-governance ecosystem model. The ecosystem maturity model is described in Table II. The model adds a new, fifth, stage in the previous model as well as defines the stages from the citizens viewpoint.

Finally, the defined concept offers valuable view to the phenomenon. It aims to make a complex phenomenon more approachable through using a well-researched metaphor to include citizen into e-government development. Use of this metaphor highlights the holistic view and takes into account different stakeholder as well as societal impacts.

Obviously also this view has its limitations. First, the term 'ecosystem' might lead the discussion too much towards either business ecosystems and profits, or biological ecosystem and its metaphor. However, the e-governance ecosystem is not about (economical) value capture or about predators and preys' mutual competition. Second, the ecosystem approach might help researchers and practitioners characterise the complex system, yet it does not provide or guarantee ethical and equal treatment of citizens. Thus, further work is needed to improve the model and any practices related to it.

TABLE II
STAGES OF E-GOVERNMENT ECOSYSTEM FROM CITIZEN'S POINT-OF-VIEW

Stage	Description
Emerging information services	Citizens are aware of governments websites and the information is easy to find. Citizens also have non-electronical ways to express the need for certain information.
Enhanced information services	Citizens are aware of governments websites and their services. The information and forms are is easy to find and use. Citizens have electronical ways to express the need for certain information and services.
Transactional services	Citizens are and capable to use transactional services offered by the government. Services are easy to find and use. Identification is simple, but yet secure. Citizens have two-way communication with the government about their needs of information and services.
Connected services	Citizens have easy ways to communicate with the government. Searching and transferring information is effortless for the citizens as well as managing it. Although systems and services are complex, government has understandable information about services available. There are multiple channels to citizens to express their need for information and services.
Participatory ecosystem	Citizens have and are participating in the creation of their e-government ecosystem. Citizens have ways to participate in governmental development including the development of technical governmental systems in multiple ways. The system adapts to the personalised needs.

V. CONCLUSIONS

This research proposes that e-government should be viewed from the more holistic perspective because of its complex nature and key position that citizens hold in the success or failure of e-government. To shift the view from managerial view and technological determinism towards view that acknowledges the unique relationship of government and citizens metaphor of e-government ecosystem is proposed.

E-government ecosystem could help to understand the complexity of these socio-technical systems. Furthermore, analysing these system from ecosystem-point-of view emphasises the active role of citizens alongside other stakeholders. As needs of citizens should be seen as a starting point of socio-technical development, this view could help to solve challenges of technological diffusion that forms a barrier for gaining the benefits of e-government.

Thus, findings of this research are that the current view on the e-government might be the cause of the problems in gaining the benefits. By using more holistic view of e-government ecosystem we could truly adopt the citizen-centric view that is currently lacking in the research and development of e-government. This study is still in a work-in-progress; however, it proposes an approach to include citizens into the discussion

of e-government as active actors, which in democratic countries should be the ultimate goal of e-government initiatives.

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Assessment of High Performance Computing Services Potential of SMEs

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***Abstract* - High Performance Computing (HPC) enables solving complex problems that would be otherwise impossible to compute with ordinary desktop computers in an acceptable time. HPC services, offered in cloud, could foster new products and/or services development, faster time to market and optimization of production processes for Small and Medium sized enterprises (SME). However, cloud HPC services adoption among SMEs is still scarce and not all SMEs are viable to use HPC. The goal was to assess the cloud HPC potential among SMEs, select the viable SMEs and support them in implementation of the technology. For this purpose we have developed a web-based multi-criteria assessment tool to measure the potential of the SMEs to use cloud HPC services. In this paper we present the analysis of the 61 assessed organizations, among which 38 were SMEs. The analysis offers a limited insight into the state of the European SMEs and other organizations, but is important for understanding the needs and opportunities, that the cloud HPC services offer.**

Keywords – High Performance Computing; Cloud computing; Potential assessment; SME

I. INTRODUCTION

High Performance Computing (HPC) refers to computing performance needed for solving complex computing problems that could not easily (or timely) be computed by typical desktop computers. It is generally used for solving large scale problems in science, engineering and business [1]. So far HPC was mainly reserved for the large companies and research institutes, who could afford high costs that are associated with HPC. From the industry perspective the HPC is predominantly used in manufacturing sector with financial sector just behind it [2]. On the other hand, adoption of cloud computing services is high among companies, including SMEs [3], therefore there is an opportunity to make HPC services available in the cloud and thus make it affordable for the SMEs [4]. However, adoption of HPC services in the cloud is still weak [5]. The problems lie not merely in the price, but also in the lack of knowledge, and competences that are needed to first identify the potential and then know how to use HPC. An important step is being made in the sense of identifying the potential uses of HPC, transformation power that it has in the sense of business models for the whole business ecosystem (companies, ISV, HPC infrastructure providers, experts etc). Cloud HPC service does not encompass only IaaS, but includes also modeling services, software adaptation (parallelization), implementation and maintenance. The business models need to be changed from the existing IaaS, PaaS and SaaS to a more elastic approach to providing licensing (from classical licensing to adaptable pay per use licensing according to the actual needs), furthermore there is a need for a "Simulation Workflow as a Service", that would be accessible through a »one-stop-shops«, as are being developed and tested in the EU project Fortissimo [6]. These kinds of holistic services can become of interest to other industrial segments, also for the SMEs [7]. More precisely, the European Commission roughly assesses that the manufacturing SMEs would benefit best from the cloud HPC services. They represent about 2 million SMEs (of the whole 24,5 SMEs) [8].

A. SME sector in the EU

According to Annual SME Report [8], in 2017 there were 24,6 million SMEs registered in the EU countries, 22,9 million of those were micro, 1,4 million small, and 0,2 million medium sized enterprises. In total the SME sector is accounted for 4.156 billion EUR added value, and employs 94,8 million people in the non-financial sector. In other words, SMEs employ two thirds of population and generate 56,8% of the entire added value of non-financial sector. Between 2013 and 2017 the SME sector recorded 7,1% employment growth, added value increased by 15,1%. Both, large companies and SMEs have surpassed the financial indicators from 2008, but not in all EU member states. There is also a significant gap between large and SME sector, especially due to weak internationalization among the SMEs. SMEs can be found in all industrial sectors, nevertheless medium SMEs are more internationally oriented compared to small and micro companies.

Similarly to internationalization, SMEs lag behind in the field of digital transformation. They have adopted basic digital business support technologies (ERP, social media etc.), but are lagging behind with adoption of advanced digital technologies (i.e. robotics, internet of things, big data & analytics, block chain, artificial intelligence) [9]. European commission has specifically stressed the importance of cloud and HPC technologies in communication »European Cloud Initiative – Building the competitive data and knowledge economy in Europe« [10]. The initiative sets out to provide a European scientific, industrial and public organizations data infrastructure for storing and managing data, fast

connectivity and data transfer, and HPC for data processing by the year 2020. Return on investment of HPC is very high, meaning every invested euro yields on average 867 EUR of revenue and 69 EUR in profit. EU is in fact leading in the use of HPC resources, but currently owns no so called supercomputer that is among top 10 in the world. While possessing only 5% of all HPC resources, EU currently consumes one third of the world's HPC resources [11]. Therefore, one of the main goals is to set up an EU HPC infrastructure for EU research, industry and other organizations. In September 2018 the European parliament supported the "EURO HPC JU" (euorhpc.eu) initiative for setting up an »exa-scale« supercomputer (by 2022/23).

In parallel to the infrastructure investment and development, there are lots of activities on the forefront of HPC services offered in cloud [12, 13]. On the European level, within the initiative »ICT Innovation for Manufacturing SMEs« (i4MS), which main goal is to support manufacturing SMEs in adoption of key enabling technologies, funding is available to develop and test possibilities for cloud HPC services. Manufacturing SMEs are specifically identified as the ones that could benefit most from digitalization, especially by "cloudifying engineering services, by combining HPC resources, computational tools, and cloud computing platforms" [14]. Through the i4MS initiative European Commission supports the following four key areas: robotics, cloud HPC simulation services, laser technology applications, and intelligent sensor-based equipment. By developing and supporting new business ideas, particularly the use of HPC services in manufacturing SMEs, the initiative aims to foster the new economic growth and competitiveness by reducing development times for innovative products with better performance. The results of these initiatives are fostering engineering and the processes of prototyping within the manufacturing workflow. In previous experiments we haven't seen the desired results from an integrated information workflow and simulation loop based on online factory data though [14].

An important part of the i4MS funds are invested in adoption of cloud HPC services by selecting experiments for showcasing the best practices, develop, test and demonstrate the use of infrastructure and the business model as a "one-stop pay-per-use shop" [6]. Experiments include all actors (SME, Innovation centers/clusters, experts, code providers) throughout the value chain of an innovation ecosystem (in projects like for example CloudFlow, Fortissimo, Cloudifactory). One of the important goals of the initiative is the "development of a sustainable business model, which is crucial for the successful adoption of these services" [15]. Therefore, general criteria for selection of an experiment are: demonstration of HPC needs for new product development in manufacturing industry; end-user driven, address a real use-case, and demonstrate the use of HPC and high potential to benefit from cloud technology [16].

For the purpose of assessing potential to use the cloud HPC services, we have developed a multiple-criteria model based on multiple criteria decision analysis MCDA [17] and validate it on a set of experiments, conducted in CloudFlow, Fortissimo, and Fortissimo II projects. Within the Sesame project the web questionnaire was developed to elicit knowledge from the SMEs (HPC4SME assessment tool). To this date there were over 90 experiments conducted in the CloudFlow, Fortissimo, Fortissimo II projects, and over 60 SMEs potential assessed with the HPC4SME assessment tool, set up within the Sesame project. Main goals of the project were selecting appropriate SMEs who could benefit from the cloud HPC services, raise the awareness of the HPC technology among manufacturing SMEs by showcasing the successful experiments, and set up the central access point to HPC services and thus enlarge the HPC market.

Aim of this paper is to present the analysis of 61 organizations that have completed the online assessment. Special focus of analysis will be put on the 40 SMEs. The insights will enable us to define the further research steps, assess the quality of the questionnaire and answer the following research question: Are European small and medium sized enterprises ready to take on the cloud HPC services? We believe that this research will contribute to identification of SMEs who could benefit by using cloud HPC services, identify the main obstacles to cloud HPC services adoption, and provide policy implications for SMEs adoption of digital technologies, like HPC, big data analytics, artificial intelligence, internet of things etc.

II. RESEARCH METHODOLOGY

The general approach, used in this research, is a mixed strategy of design science research [18] and survey, described in Figure 1.

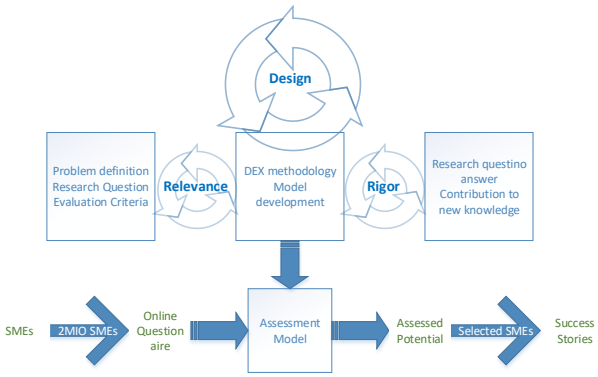

Figure 1. Research framework

As shown in Figure 1 in the first step of research we have developed the multi-criteria assessment model using design science research approach. The main goal is to develop an IT artefact (construct, model, prototype, instantiation) that will demonstrate practical relevance, and is fundamentally rooted in problem-solving paradigm [18]. In our case the IT artefact is a qualitative multi-criteria model that we have developed using DEX methodology [19] and was tested on experiments conducted in the CloudFlow project. In the second phase we designed a questionnaire by which we could elicit data from the SMEs. The questionnaire was tested with the companies already collaborating in the experiments of Fortissimo projects. The questionnaire was made available online and during the second part of 2017. To date we

have engaged 61 organizations to assess their cloud HPC potential.

A. *Instrument and Data Collection methods*

Predominantly the manufacturing SMEs were targeted through various media outlets (i.e. project partners and their dissemination activities, conferences, workshops, LinkedIn, Twitter, and Facebook), but anyone who wished to assess their potential was welcome. A feedback was provided to each registered respondent in the form of a detailed report on their current and future cloud HPC potential. The main data gathering method was online questionnaire (HPC4SME Assessment Tool, network.sesame.net), which consisted of 32 questions, divided into three sections: 1) Readiness, with this group of questions we tried to get understanding about the current state of knowledge and adoption of HPC services in organization; 2) Cloud, this group of questions provides insights in understating and experiences of cloud technologies and services; and 3) HPC, which refers to a group of questions assessing computational needs, understanding and experiences with HPC. Since questions can be difficult to understand, each question is further explained and an option of "ask an expert" is available. Questions are measured on the discrete qualitative scale that is directly connected to the multiple-criteria model. Top level of the model is presented in Figure 2. For example, to a question »How would you rate the applicability of simulation in your sector?« respondents could have selected one of the suggested answers: »Great Potential«, »Applicable« in »Not Applicable«. The scales are descriptive in order to be easy to understand, and ordered from less desirable to most desirable value (i.e. "Not Applicable", "Applicable", "Great Potential").

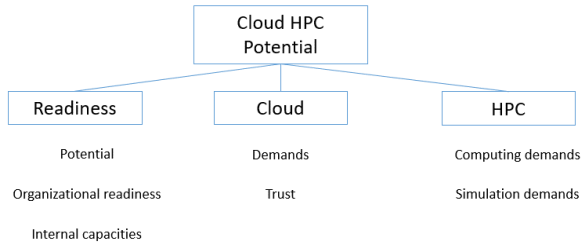

Figure 2. Top Level of multiple-criteria assessment model

The multiple-criteria model was developed on the basis of experiments in the CloudFlow and Fortissimo projects, and had been updated several times. Details on the multiple-criteria assessment model development can be found in [17].

B. *Data Analysis*

Data were collected through an online questionnaire and exported to DEXi multi-criteria model [17] to assess the cloud HPC potential. The model consisted of 32 basic criteria (that corresponded to 32 questions in the questionnaire) and 21 aggregated criteria. Evaluation was conducted using the DEXi methodology which assumes deriving the aggregated criteria by using the criteria function defined as a set of simple "if-then" rules [19]. The final values are thus derived from lower laying criteria values in line with the defined criteria function. The final value can be assessed even with missing values and provide transparent reasoning of every derived criteria value. When all aggregated criteria had been calculated, the values of all the 61 organizations can be analyzed.

III. RESULTS

Analysis is based on the 61 organizations, who filled in the assessment questionnaire voluntarily. Among the assessed organizations there were 62% of SMEs, 16% of large enterprises, 1% of research institutes, the rest are universities, associations, competence centers and government institutions. We have followed the current EU recommendation [20] for size of the company, by which all the large companies in our samples just fall outside the SME definition. However, the companies that can afford own HPC infrastructure are usually very large companies, research institutes and government institutions. On the other hand, those companies are the ones that would potentially benefit from the services greatly, therefore we are including them in the analysis but report the results separately. The main limitation of the research is the sample, which offers only limited insights into the state of cloud HPC potential among European SMEs. The fact that we have managed to engage only 38 SMEs shows that awareness among that population is still very low.

Majority of organizations originate in Slovenia, Serbia, Bulgaria, following by Spain and Greece, Germany, United Kingdom and Croatia, Poland, Italy, Austria, France, Norway, North Macedonia, Israel and Ireland (Figure 3).

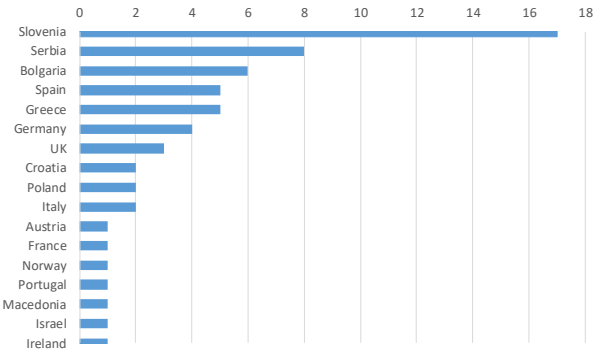

Figure 3. Assessed organizations by the country

In Figure 4 we present the distribution of cloud HPC potential assessment for all organizations, SMEs and large companies. Nearly 40% of all organizations were assessed as "Magic quadrant – Ready", 36% organizations were assessed as having "Low potential" to use cloud HPC services, 24% are assessed to be "Close to Magic Quadrant". Regarding the SMEs alone, about half are assessed as "Magic quadrant – ready", what means that they could immediately benefit from using cloud HPC. Two of the assessed SMEs are not ready to use the services yet, seven are considered to be close to the "Magic quadrant" and 11 have "Low potential" of using

the services. Only two (out of ten) large companies are assessed to be ready to use cloud HPC services, the rest are low potential of close to magic quadrant.

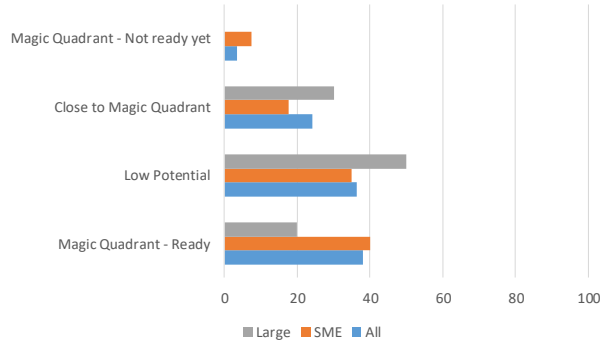

Figure 4. Cloud HPC Potential assessment for all 61 organizations, 40 SMEs and Large companies

Analysis of internal and external organizational factors are presented by the aggregated criteria "Readiness", according to the analysis, most organizations (70%) are ready to take upon new business opportunities. 77% of organizations had identified HPC opportunities within their sector, 68% reported their organizations to be ready to take on HPC. There is no difference between the types of organization (SME, large, institution, etc.).

Further we analyzed the potential to use HPC (Y axis) in the cloud (X axis) (Figure 5). Both aggregated criteria were assessed on a four level scale (»No potential«, »Low potential«, »Fair potential«, »High potential«). Each point in Figure 5 represent individual SME, the color of the point represents the overall assessment (orange – Magic quadrant – ready, green – Magic quadrant – not ready yet, blue – Close to magic quadrant, and red – Low potential).

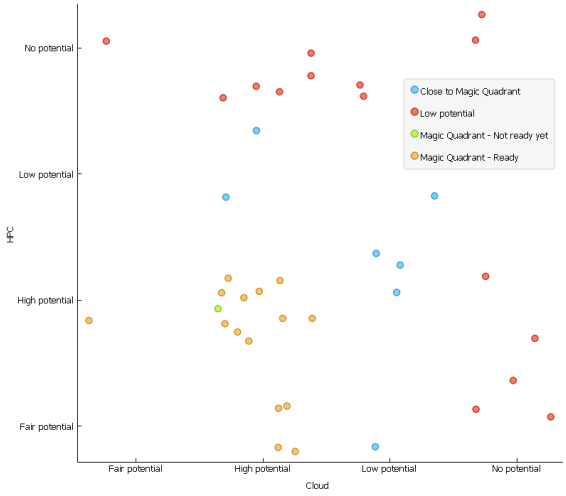

Figure 5. HPC and Cloud assessment for SMEs

According to responses, overall 70% of all responding organizations could access HPC services through cloud, and as much as 13% of them cannot use cloud to consume those services (due to various reasons: complex simulation processes, confidentiality of data and/or results). Assessment of possibility to use the cloud environment for the SMEs revealed that 60% have high cloud potential, 5% fair, 35% low or no cloud potential. Regarding computational needs and possibilities to employ HPC, 45% of SMEs are assessed as "High potential", 21% of SMEs as having "Fair potential", 34% as low or no potential. Comparing to overall assessed organizations, the SMEs, who took part in the study, show higher potential for using cloud HPC services.

IV. Conclusion

In this paper we addressed the problem of assessing the cloud HPC potential of European SMEs. The availability of high-performance computing for SMEs is crucial for new product and/or service development, competitiveness and economic growth. Unfortunately the readiness of this sector to adopt high-end digital technologies, like HPC, is still weak. EU is putting a lot of effort in making sector of manufacturing SMEs aware of the benefit of digital technologies. One of the problems is to identify those SMEs who could benefit from using HPC services and support them in the process of HPC implementation and business model transformation. For this purpose we have developed an online survey, which provides an input data to the multi-criteria assessment model, implemented in DEXi program. By HPC4SMEs Assessment Tool we can identify the current potential of a specific SME and analyze its future potential. Furthermore, the collected data provide an important insight into the state of European SMEs regarding the ability to use cloud HPC services.

In the paper we have presented the assessment of the main three groups of criteria (readiness, HPC and Cloud) and the overall cloud HPC potential assessment. In spite of huge engagement of project partners, we have to date acquired only 61 responses, 38 of which were SMEs. These organizations have not previously been involved in projects, but had already been aware of HPC benefits. This study had revealed that SMEs in general are not yet familiar with the potential of cloud HPC services, which is corroborated by the fact that only 38 of SMEs from across the EU took part in the assessment, and only half of those were assessed to have potential of using the services.

The limitation of the study is the small sample of SMEs, which is a good indicator that in the future we need to be doing a lot more to raise the awareness among them. Interestingly, 21 other organizations took part in the assessment, which shows that organizations, such as large companies, universities, associations, and institutes are interested in cloud HPC services as well.

In the future we will conduct another round of European survey, by which we plan to reach a larger number of SMEs. This will give us a better insight into what kind of strategies we need to take in order to better prepare the European market for the opportunities offered by digital technologies.

Acknowledgment

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cooperating in collecting data and testing the multi-criteria model.

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The role of university technology transfer process in Digital Economy

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Abstract – Commercialization of scientific research is a challenging task for every university. Successful commercialization depends on the well-established university technology transfer (UTT) systems at universities that will enable the effective technology transfer process of transforming scientific research results into viable products and services on the market. Intellectual property rights have an important role in technology transfer process. In the light of emerging digital economy, intellectual property rights are faced with many challenges. In this paper the main factors for efficient technology transfer systems will be discussed as well as different models of technology transfer process. The technology transfer system of the University of Rijeka will be presented.

Keywords – UTT; commercialization; IPRs; digital economy

I. INTRODUCTION

Today, scientific research and research and development (R&D), especially at universities, are more open, collaborative, and geographically dispersed. Development of research and innovation activities has emerged since research and development activities are at the same time more globalized and more localized and include the participation of different actors.

Evolution in the geographical distribution and dispersion of innovation, facilitated by Information and Communication Technology (ICT), resulted from and contributed to more cross-border collaborations in innovation between different actors across the world, both for private sector and public institutions (universities, research institutions, etc.).

In general, technology transfer process in the light of digital economy development has become one of the main drivers of innovation and open innovation. Technology transfer process covers all activities needed for successful translation of scientific research to the market.

University technology transfer (UTT) has an important role in the development of knowledge-based economy and the key contributors of technology transfer are university researchers. Technology transfer is a legitimate part of the University purpose, alongside the core activities of teaching and scientific research [1].

In order to fully understand the concept of university technology transfer process it is necessary to consider the intellectual property rights since they present the basis for technology transfer process.

It is very important to protect creativity of the human mind and at the same time to provide incentives to those who are engaged in the scientific research process.

Intellectual property should be seen as a powerful tool for continuous research and technological innovation growth within universities and not only as legal concept it is currently perceived. Moreover, it is also very important to understand and deal with intellectual property protection challenges in a digital economy.

Public research (from universities or research institutes) still presents the most important source of cutting-edge technologies. Academic research produces important results in all scientific fields for the benefit of the whole mankind.

For the purpose of research within this paper the focus will be on the university technology transfer process.

II. UNIVERSITY TECHNOLOGY TRANSFER MODELS

Almost every University today is engaged in technology transfer process. University technology transfer is playing a significant role in fostering economic development [2] through commercialization of its research results.

The catalyst for starting the university technology transfer process usually comes from the research support provided by the government or industry [3].

In order to commercialize University research results it is important to have a well-established technology transfer model. The extent literature on university technology transfer led to a construction of so-called traditional university technology transfer model which was widely

implemented by large number of universities. However, technological development made university technology transfer process more complex what opened a discussion on relevance and efficiency of this model. Over the years and due to, among other, digital economy development certain shortcomings of the traditional university technology transfer model appeared and some of them will be explained in this paper.

The traditional or linear university technology transfer process starts with the discovery process made by the university scientist (university researcher) in any scientific discipline [4].

In traditional university technology transfer process, the university scientist discloses his invention to the university Technology Transfer Office. TTO, after the invention disclosure, evaluates the invention and decides to patent the invention or not.

During the invention evaluation, TTO must consider the commercial potential of the invention as well as public and private sector interests.

In case when University decides to invest in the invention then the patent application will be prepared and applied. If the patent protection for invention is granted the task of TTO is to market the technology in order to find and match its technology with a suitable commercialization partner and provide revenues for University.

The negotiations on license agreement is the next step when finding a commercialization partner and when agreement is negotiated the technology is officially transferred (commercialized). When technology is adapted and used the university technology transfer process is finalized.

The literature overview on traditional university technology transfer model shows that this model has its limitations since in practice it doesn't provide with accuracy the complexity of technology transfer process. Oversimplification of the process, one-size-fits-all approach and too much emphasis on patents are the most important limitations.

In the era of digital economy development these limitations appear as potential obstacles for university technology transfer process realization since digital technologies require new or adapted technology transfer concepts and approaches. For example, a one-size-fits-all traditional university technology transfer model does not foresee the differences of technology transfer process across different disciplines and insists that all invention disclosures at universities must follow the traditional commercialization route. As a result, this approach can result in an outcome that university inventions fail in the technology transfer process.

Traditional university technology transfer model puts a strong emphasis on patents as main outputs of the transfer process and overlooking other means of commercialization and revenue gaining.

Patent protection is one of the successful university technology transfer strategy, but in practice other means of IP protection should be taken into consideration (trademark protection, copyright, etc.).

Patent-based indicators for measuring the university technology transfer success can be misleading in a way that other efficient technology transfer channels of university inventions might be compromised or overlooked [5].

III. TECHNOLOGY TRANSFER SYSTEM AT UNIVERSITY OF RIJEKA

There are two main preconditions for successful technology transfer system: infrastructural and regulative preconditions.

University of Rijeka is composed out of 10 Faculties, 1 Academy and 4 University Departments [6]. Beside its constituents, University of Rijeka has established the Science and Technology Park (Step Ri) in 2008 and Technology Transfer Office (TTO) in 2009 which are closely collaborating on technology transfer activities and projects.

University of Rijeka Science and Technology Park (Step Ri) was established in 2008 by the University of Rijeka in order to become the premier science and technology hub, facilitating the commercialization of research and development and to foster cooperation between the scientific community and industry [7].

University of Rijeka Technology Transfer Office was established in 2009. It is an organizational unit of the University of Rijeka, presents an important link between academia and industry and acts in synergy with Science and Technology Park.

Regarding the regulative preconditions for technology transfer system University of Rijeka prepared, adopted and implements several strategies and policies:

- University of Rijeka Strategy 2014-2020;
- University of Rijeka Innovation Strategy;
- University of Rijeka Intellectual Property Management Policy;
- University of Rijeka Regulation on Intellectual Property Management.

These documents, especially Intellectual Property Management Policy and Regulation on Intellectual Property Management, serve as basis for regulation of mutual relations between University researchers as inventors and University. The agreement between

researchers and University defines rights and obligations between the parties (especially the part related to IPRs protection costs, shares of ownership over IP rights, financial rewards, etc.).

The mission of University of Rijeka TTO is to extract the fair market value of the University intellectual property and to stimulate creation of future viable IP by using the best business practices for the benefit of the University, its constituents, staff and community.

The role of University of Rijeka TTO is to screen, evaluate, protect and, in collaboration with Step Ri Science and Technology Park, commercialize IP generated at University.

University of Rijeka TTO has defined its operational procedures regarding IP protection and commercialization. The protocol is consistent out of several steps:

- expression of an interest from the researcher/inventor;
- signing an NDA between TTO and researcher/inventor;
- invention disclosure;
- invention evaluation;
- invention protection with appropriate form of IP protection; and
- IP commercialization.

In Table 1 are presented technology transfer indicators for the University of Rijeka.

TABLE I. TECHNOLOGY TRANSFER INDICATORS AT UNIVERSITY OF RIJEKA

	Indicator	Value
1	**Number of patent applications**	**7**
2	**Number of granted patents**	**3**
3	**Number of trademark applications**	**1**
4	**Number of registered trademarks**	**2**
5	**Number of industrial design applications**	**-**
6	**Number of registered industrial design**	**1**
7	**Number of license agreements, MTAs and other TT agreements**	**4**
8	**Number of spin-off companies**	**4**

Source. University of Rijeka TTO (internal data), 2018

From the data presented in Table 1. It can be seen that University of Rijeka is active in technology transfer activities. Even though the University of Rijeka TTO operates for a decade these numbers cannot be considered as modest. It is important to emphasize that 4 spin-off companies were created, and these companies are still active on the market.

As it is for every newly established unit it takes time for the capacity building of TTO staff, to implement all relevant activities for, among other, awareness raising and educational activities on importance on IP protection and commercialization among university researchers and administrative staff, to assure funding for technology transfer activities and projects, to create and implement relevant IP documents and policies, etc.

University of Rijeka Technology Transfer Office, as other universities' TTOs in Croatia, at this moment follows the traditional model of technology transfer process and it will definitely need to adapt their processes and IPRs protection and management to the future changes that digital transformation will bring.

IV. IP CHALLENGES IN A DIGITAL ECONOMY

Digital technology is probably the most important and transformative technology of our time. Because digital is fundamentally an information and communication technology (ICT), intellectual property rights lie at its heart. Economic and technological changes mean that an appropriate and enabling IP framework has become one of the prerequisites for prosperity [8].

New technologies are transforming IP management and enforcement. Innovation is guided by the increased need for interoperability inherent in communication technologies and platforms, the Internet of Things (IoT), machine to machine (M2M) communication and the industrial Internet. This means that patents in the context of standards continues to be a hot issue. Also, intelligent machines and devices such as robots and satellites can themselves produce information that results in IP assets. This raises questions of creation, invention and ownership [9].

From the university perspective in the era of emerging digital economy intellectual property rights face many challenges. The challenge is not only the technological progress that became very complex, it is the issue of ownership of intellectual property over newly created digital technologies.

The problem lies in a fact that traditional model of technology transfer process is outdated, and that universities' IP portfolios were built based on this model. Also, it is very important that legislative part of IP protection is able to follow and respond to the emerging technological development.

There are several IP protection and management challenges in the digital economy that should be

considered such as: data protection and exploitation, development of strategic IP portfolio together with access to complementary knowledge, understanding and management of the growing importance and value of trade secrets as alternative to patenting, ownership over IP concept in the digital era, etc.

Technological and societal changes will present future challenges for the IPR system management. Technology development will create both new uncertainties and new interface between IP and competition policy. It is important to make sure that the IP framework will be flexible enough to facilitate, rather than obstruct, the capacity for digital technology to deliver growth. Even though the European Commission's "Digital Agenda for Europe" highlighted the need to simplify copyright licensing across the EU, the Commission was expected to issue a communication proposing the future direction of IP strategy.

In order to be prepared to face the challenges and succeed in the digital economy it is important to prepare strategies for IP management in digital economy.

The first strategy deals with people. It is very important that people acquire IP skills and knowledge. The second strategy is related to business: to align IP with business goals and structure. The third possible strategy can be to develop an adequate IP strategy in order to build and integrated and digital IP portfolio. These are only few possible strategies to respond to digital economy challenges from both academia or industry perspective.

V. CONCLUSION

Development of digital economy is affecting all institutions within innovation systems: industries, universities and public institutions.

Digital transformation is definitely not a new topic, but it becomes more and more ubiquitous. The consequence is that the importance and dynamics of IP management issues is getting higher and the IPRs protection and management becomes more important.

There is no doubt that linear models of university technology transfer process are not efficient or relevant in the light of digital economy due to the complexity of the process and rapid technology development.

Universities that are conducting research and development in non-traditional scientific fields are looking for different technology transfer concept and process which will be more realistic and not generalized (one-fits-all approach) as in traditional linear technology transfer model.

The valuation of IP in digital economy development become more relevant. However, despite to the increased number of economic valuation techniques development of international standardized valuation techniques remain a challenge since the value of IP depends on the context.

Development of digital economy continued to spawn new processes and technologies with a big impact both on the management of IP assets and the enforcement of IP rights. The data-driven nature of the economy has also raised questions about rights and responsibilities over data.

The critical need to improve trade secrets protection resulted in the recent adoption of important new legislation in the EU and the US. Other areas of intellectual property also saw notable developments through case law and legislation,

The IP system has always shown flexibility in adapting to new technologies and will continue to do so in the future. The emergence of other new technologies in the future will also have implications for IP protection which may go beyond the issues being discussed today.

There is no doubt that universities' Technology Transfer Offices will need to adapt to the new concepts and methods of commercialization of their research results beyond the traditional technology transfer process due to the digital economy development. They will need to adapt and implement their existing technology transfer and IP protection and management policies as well as commercialization mechanisms for bringing their technologies to the market.

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E E

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PAPERS

Comparison of Graduate Specialist Study of Computing and Specialist Study of Information Security and Digital Forensics at the Zagreb University of Applied Sciences

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***Abstract* - The aim of this article is to demonstrate the purposefulness of the existence of two distinct but very related studies in the field of computing at the Zagreb University of Applied Sciences, given the similarities and differences, and the satisfaction of students with the study and the contents of the subjects and the manner of the knowledge transfer. The graduate specialist Study in Computing and specialist Study of Information Security and Digital Forensics are compared, at the level of the first two semesters. The comparison is done by using qualitative analysis and comparing the contents of the subjects and related outcomes, and the quantitative analysis of the student survey at the end and the beginning of professional subjects.**

Key Words– efficacy study, engineering study program design

I. INTRODUCTION

Zagreb University of Applied Science (in further text TVZ)[6] has recently introduced a new specialist study of Information Security and Digital Forensics (in further text ISDF), a seemingly close study of the graduate Study of Computing and Information Technology (in further text CIT). This article compares the content of both studies and points to their compatibility and interdependence by criteria introduced used in higher education in Croatia and was motivated by ideas found in the article "Developing An Instrument To Measure Engineering Design Self-Efficacy" [4].

When the studies were introduced, the goals of the study were different. Both studies cover similar areas, although in different ways. These different ways are the outcome of how similar issues were recognized and defined by profession in different time periods. The goal of this paper is to see how already existing study compares with recently introduced one and how students feel about both of studies. The comparison in this paper was done by comparing the study structure and learning outcomes for the theoretical part and by comparing students experience and achieved results for the practical part. The main components of this comparison are learning outcomes, subjects, and lectures in the listed subjects.

II. DESCRIPTION OF STUDY OF COMPUTING AND INFORMATION TECHNOLOGY

CIT is a graduated study introduced more than 10 years ago [2], based on the trends in education before the economic crisis of 2008 and its impact on computer science and IT professional education. There are 341 lectures and 323 learning outcomes in 33 subjects. It is 4 semesters study with 120 ECTS. When graduate students become Master of Information Technology. The purpose of the study is to prepare students for a basic level of computing in the information technology field. The study program is divided into several modules: Design and multimedia, E-business, E-government, E-health, Computer Systems, Computer Networks and Systems, Software Engineering, and this is the reason for the number of outcomes and subjects. As it is a graduate study it covers a wide area of technical subjects aimed to introduce students to various basic skills needed in computing, information technology, project management, programming, strategy, etc. The idea is to educate a reliable engineer with basic knowledge and ability to learn new skills and knowledge through further educations and career progress with the accent on understanding the full lifetime education process with the possibility to choose micro-specialization in the field.

TABLE I: CIT SUBJECTS

No	Subject
1.	Server Administration
2.	Tools and methods of artificial intelligence
3.	Bridge

4.	Digital economy
5.	Graduate thesis
6.	Discrete Mathematics
7.	Property Management
8.	Information System Usage and Management - EUCIP
9.	Mathematics
10.	The methodology of professional and research work
11.	Motivation and Teamwork
12.	Advanced theory of algorithms and systems
13.	Advanced UNIX solutions
14.	Advanced Web Designing Techniques (.NET)
15.	Advanced Web Designing Techniques (open source, PHP)
16.	Advanced programming in open systems
17.	Advanced programming in the Java programming language
18.	.NET environment
19.	NOSQL and advanced big data analytics
20.	Object-oriented program development
21.	Business ethics and law
22.	Applied statistics
23.	Programming Engineering and Information Systems
24.	Open Systems Programming
25.	Designing Innovation
26.	Mobile application development
27.	Development of embedded systems
28.	Scripting languages in computer systems
29.	Strategic Technological Entrepreneurship
30.	Computer Network Technologies
31.	Project management and management
32.	Quality control
33.	Network Service Management in MS OS

III. DESCRIPTION OF INFORMATION SECURITY AND DIGITAL FORENSICS STUDY

ISDF study was introduced in 2018/2019 while being in preparation for about 4 years [3]. It is 4 semesters study with 120 ECTS. When graduate students become Master in Information Security and Digital Forensics. The purpose of this study is to prepare students for different practical roles in cybersecurity, where the term is defined from Kaspersky Lab: "Cyber-security is the practice of defending computers, servers, mobile devices, electronic systems, networks, and data from malicious attacks. It's also known as information technology security or electronic information security. The term is applied in a variety of contexts, from business to mobile computing" [1].

The ISDF study program is roughly separated into two distinct areas: information security and digital forensics. A roughly equal amount is dedicated to both parts, with a goal to produce a reliable, self-confident expert in the field who can easily accept new knowledge and skills during career. Almost the same amount of time is dedicated to practical student work and to lecturing with the aim to provide as much as possible hands-on experience with current tools and practices in a near real-world environment. Lectures are designed to provide theoretical input for practical work and to expand the students' security awareness and consciousness.

Since this is a specialist study set of pre-required skills exist for students, unfortunately, some students lack these skills. To rectify this problem during the first semester, the additional lecturing is provided for programming practices in Python and in the introduction into networking, since this was the most critical skills missing for most of the enrolled students.

The study consists of 4 semesters, with the last one dedicated to graduation thesis work. The first semester is mostly for introduction, while second and third are oriented to main learning outcomes. The study has 23 different subjects, with 84 different learning outcomes. The total number of lectures covered in the study is 470. Most of the classes have 30 hours of lecturing and 30 hours of practical work or other hands-on activities for students.

In this study, practical work in a virtual digital forensic laboratory was introduced on the TVZ private cloud. This is assumed as a key feature because it provides students with the ability to work in an almost real environment with real-life tools [5].

TABLE II: ISDF SUBJECTS

No	Subject
1.	Digital forensics
2.	Digital media, security, and protection
3.	Graduate thesis
4.	Ethical hacking
5.	Mobile device forensics
6.	Computer forensics
7.	Memory Forensics
8.	Malware forensics
9.	Information security
10.	Integrated information security systems
11.	IT Forensics documents and securities
12.	Mathematical models of information security

13.	The methodology of professional and research work
14.	Organization and management of digital forensic analysis
15.	Applied cryptography
16.	Computer forensics
17.	Safety of computer networks
18.	Web application security
19.	Scripting and object languages for forensics
20.	Safe programming techniques
21.	Business continuity management
22.	Risk Management and Information Security Incidents
23.	The legal basis of digital forensics

IV. COMPARISON

Detailed comparison among learning outcomes and subject topics for both studies is too big to be represented in detail, but summary findings are presented and commented. Relevant study details for each study are already shown in the preceding chapters. Study statistics are taken from online reports of internal TVZ questionnaire system, with participating 40 students.

From above mentioned data, it is visible the graduate study has much more learning outcomes than specialists one, which makes sense since the graduate has to cover much wider knowledge than a specialist one.

As from listed above it is visible that studies have some similarities, but lectures, subjects, and learning outcomes are equal or close in the only handful of situations. This shows both studies are different and not overlapping, better to say studies are complementing each other, the specialist study is specializing subjects from graduate one into more specialized types of knowledge.

Because of study structure, both studies only have "Graduate thesis" as a common subject. More interesting, real commonalities are in different areas of expertise, for example for mobile devices there is mobile application programming comparable with mobile (devices) forensics. This subject looks very similar, but in fact, specialist one is depending on graduate one. Such a relationship can be found among subjects related to scripting languages and programming techniques, where actually a set of subjects from graduate study creates prerequisites for specialists' study. The same can be seen in mathematics and programming subjects too. In more technical areas ISDF Ethical hacking and Web application security subjects are requiring prior knowledge from graduate CIT programming, administrations and web related subjects. The full difference is visible when learning outcomes are compared.

TABLE III STUDY EVALUATION BASED ON THE STUDENT QUESTIONNAIRES

Survey	**Average Computing and Information Technology**	**Average of Information. Security and Digital Forensics. Study**	**Average TVZ**	**The difference between the two study programs**
Was the introduction to the subject matter adequate?	3,28	4,59	3,4	1,31
Was the introduction to the organization of teaching adequate?	3,3	4,47	3,4	1,17
Was the introduction to the required literature adequate?	3,27	4,53	3,3	1,26
Was the grading properly explained?	3,28	4,59	3,4	1,31
Measure your own ability to meet the requirements of this subject	3,29	4,5	3,3	1,21
Your degree of interest in this study field	3,24	4,82	3,3	1,58
The subject was well organized?	3,74	4,42	3,4	0,68
Was my previous knowledge sufficient to understand this subject?	3,7	4,12	3,3	0,42
Are teaching materials of adequate?	3,72	4,75	3,4	1,03
Are the learning objectives realized?	3,68	4,62	3,4	0,94
How many hours of independent learning was used weekly (1.0-2h, 2.2-4h, 3.4-6h, 5.6-8h, 5> 8h)	2,9	2,91	2,7	0,01
Was the lecture time appropriate?	3,72	4,58	3,4	0,86

Was teaching interesting and dynamic	3,68	4,83	3,4	1,15
Was the learning environment pleasant and stimulating?	3,77	4,92	3,4	1,15
Are contemporary trends and insights about the subject area are being covered in the lectures?	3,79	4,78	3,5	0,99
Will you use in your future work presented content?	3,53	4,67	3,3	1,14
Did get helpful feedback after colloquia and exercises?	3,61	4,62	3,4	1,01
Were the lecture preparations, tasks, exercises of adequate size and complexity?	3,67	4,62	3,4	0,95
Were the exercise procedures clear and understandable?	3,74	4,58	3,4	0,84
Grade your level of interest in this study?	3,56	4,75	3,3	1,19
The average difference between studies				**1,01**

In the Table III results of the student, surveys are compared, for each question the average value of student response is shown, in both studies an average of the all the specialists' study programs that TVZ offers. Value 5 means excellent, 1 means poor.

Student survey data are considered to see how student population reacts and feels about new and possibly related old program, what is important factor in concluding about future of both CIT and ISDF.

It is visible that both ISDF and CIT study programs are getting higher grades than average of all other TVZ specialists' study programs. The reasons we find is that the students enrolled in those two study programs have a better success rate than average TVZ students in previous bachelor programs.

The ISDF study gets an average of 1.01 points higher than CIT this difference in the results show much higher levels of student interest and expectation of higher usage of acquired knowledge in their future work. It is important to note that data used in this comparison was from the survey for a teacher who lectures on both ISDF and CIT, from what we conclude that teacher and lecturing style is not a point of difference. Maybe the most interesting result is that the new program brings higher motivation to students (Q: Grade your level of interest in this study, Q: Your degree of interest in this study field?) and to teachers what (Q Was teaching interesting and dynamic?) It is also important that students of ISDF find introductory lectures and presentation of the content more interesting that students of CCIT.

V. CONCLUSION

Systematically doing a comparison like one presented in this paper is important for understanding and documenting the need for the introduction of the new more specialized study programs, even if this new program feels close to exiting one. It has a moral impact on students and teachers, introducing healthy excitement on a "new" view while keeping values and providing a continuation of lecturing. The conclusion is existing CIT should coexists with ISDF because both are independent.

There are also some drawbacks, from the economic viewpoint new study program almost always split student population interested in the field, what increase the expenses of the university, but also it increases student interest rate and future student employability.

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Introducing Cornerstone Courses into Electrical and Computer Engineering Curriculum

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***Abstract* – Almost all engineering programs have some form of final, culminating design experience, which is typically taught as a senior year capstone design course. Due to ABET requirements these are team and project based. Many programs will also have projects interspersed among required and elective courses, but these tend to be overrepresented in freshman year. We have recently introduced a set of courses during sophomore year that mimic our approach to capstone courses and provide authentic engineering design experience. These so-called cornerstone courses provide scaffolding by introducing all of the components of teamwork and design process but in a less formal and formative way. We will provide details of our goals, student learning outcomes, tools used, logistics and initial experiences.**

Keywords – curriculum development; engineering education.

I. INTRODUCTION

Curriculum design of engineering programs is an ongoing process that has yielded many different approaches. The process itself is driven by many different factors, such as accreditation, available resources, government policies, and faculty beliefs. Currently, there are many calls for reforming, or even revolutionizing, engineering education, as well as increasing the number of engineering graduates [1]-[3]. On a practical level, however, there are many obstacles to implementation of any significant reforms.

One such obstacle is the current structure of many engineering programs. Even though there has been significant movement in reforming overall curriculum, it has mostly been focused on freshman and senior years. In the United States, latter was largely driven by ABET 2000 requirement to implement a final design experience, so-called capstone design, that all student should participate in [4]. In our electrical and computer engineering (ECE) programs we started a capstone program in late 1990-s and early 2000-s and have reported on its organization in [5]. While there are many different ways that capstone design course or courses can be implemented there is a general feeling among engineering faculty that we have figured out what goals and objectives are appropriate for capstone as well as how to set these courses up.

Another problem that has plagued engineering programs for a very long time is low retention rates in freshman years. Traditionally, freshman year in engineering programs was reserved for building up students' math and physics skills. This meant that it was usually the calculus sequence that determined retention because students would not take any engineering classes until their sophomore year. It was also observed that lack of clear application of the principles learned in math and physics led to low motivation among students and lower retention rates [6].

This problem was addressed in two primary ways:

1. Introducing engineering courses in freshman year, which typically did not have heavy math prerequisites and were intended to build student interest and motivation to study engineering.
2. Introducing different ways to teach introductory math and tying it more directly to engineering applications. One such program was started by Wright State University [6] and with support from NSF has spread to other US universities.

These are not mutually exclusive. We used ideas from the first approach when designing our freshman sequence, which starts with a gentle introduction to engineering and gradually ramps up requirements and expectations from students [7][8]. Another way to design a holistic approach to freshman introduction to engineering is "Living with the lab", which was initially developed at Louisiana Tech [9] and implemented in mechanical engineering at PSU [10].

Some programs offer so-called "cornerstone" courses, e.g., [11][12], but the majority of these seem to be freshman courses aiming to provide motivation for potential engineering students, while providing somewhat authentic design or problem solving experiences. These freshman students, however, will typically not have enough technical background to integrate various strands of electrical and computer engineering.

Much of the curriculum reform has so far focused on freshman and senior years. As noted in [2]

> *"… the senior year has seen notable change through capstone design experiences, which ask students to synthesize the technical knowledge, skills, and abilities they have gained with professional capacities, using reflective judgment to make decisions and communicate these effectively. However, this ideal of the senior year has not yet been fully realized, because many of the competencies required in capstone design, or required of professional engineers, are only partially introduced in the first*

year and not carried forward with significant emphasis through the sophomore and junior years."

To address this lack of emphasis on professional skills we decided to implement a pair of courses at sophomore level that would scaffold student development towards capstone projects. In sections below we will first discuss our overall curriculum, followed by description of cornerstone courses, with come observations and conclusions at the end.

II. OVERALL ECE CURRICULUM

In order to provide full context for our new courses, we need to first discuss overall curriculum in ECE programs at Portland State University. Our electrical and computer engineering programs are four-year programs with roughly 180 quarter-based credits required, which is usually translated as 120 semester-based credits. These are split roughly equally among lower-division coursework (freshman and sophomore courses) and upper-division coursework. A brief overview of main components: general education, math and science, and ECE specific, is given below.

A. General education

General education requirements take around 22% of total credits, as illustrated in Fig. 1. On freshman level, students take integrated sequences of courses called "Freshman Inquiry", followed by a set of courses from so-called "Sophomore Inquiry". These are meant to provide students with a solid foundation in four main areas: inquiry and critical thinking, communication, diversity, equity and social justice, and ethics and social responsibility [13]. Third component is "Junior cluster" in which students select courses from a list for a given cluster.

Electrical Engineering General Program

FRESHMAN			SOPHOMORE			JUNIOR			SENIOR		
FALL	WINTER	SPRING	FALL	WINTER	SPRING	FALL	WINTER	SPRING	FALL	WINTER	SPRING
General Education Requirements											
FRESHMAN INQUIRY									JUNIOR CLUSTER		
UNST	UNST	UNST	SOPHOMORE INQUIRY						Private	UNST	UNST
			UNST	UNST	UNST				Public	Upper	Upper
									Invest	Division	Division
1XX	1XX	1XX	2XX	2XX	2XX				EC 314U	Cluster	Cluster

Figure 1. Outline of general education requirements in electrical engineering (EE) program at Portland State University (PSU).

B. Math and Science

Math and science requirements occupy approximately 25% of the total credit hours, as illustrated in Fig. 2. In common with many other programs, first two years are used to teach students math and science fundamentals, with only one statistics course in junior year.

Electrical Engineering General Program

FRESHMAN			SOPHOMORE			JUNIOR			SENIOR		
FALL	WINTER	SPRING	FALL	WINTER	SPRING	FALL	WINTER	SPRING	FALL	WINTER	SPRING
Math & Science Requirements											
Calc I	Calc II	Calc III	Linear Algebra	Differ Equations	Calc IV			Prob/Stat for ECE			
MTH 251	MTH 252	MTH 253	MTH 261	MTH 256	MTH 254			STAT 351			
			Physics	Physics	Physics						
Chem											
			PH 221	PH 222	PH 223						
CH 221			PH 214	PH 215	PH 216						
CH 227											

Figure 2. Outline of math and science education requirements in EE program at PSU.

C. ECE specific education

Students are admitted into ECE programs at the beginning of the junior year but ECE courses start with freshman year, as shown in Fig. 3. Junior year has a very heavy load of ECE specific courses, which can present a shock for all students, but especially for transfer ones. Note that there are five freshman ECE courses but they only have college algebra for math prerequisites. Senior year is dominated by capstone sequence (ECE 411/412/413) and electives.

Electrical Engineering General Program

FRESHMAN			SOPHOMORE			JUNIOR			SENIOR		
FALL	WINTER	SPRING	FALL	WINTER	SPRING	FALL	WINTER	SPRING	FALL	WINTER	SPRING
Engineering/Computer Science Requirements											
Explor Electrical Engr	Engr Comput	Engr Program	Elec Circ I	Elec Circ II	Elec Circ III	Electron I	Electron II	Junior Elective	Jr/Sr Elective	Jr/Sr Elective	Senior Elective
ECE 101	ECE 102	ECE 103	ECE 221	ECE 222	ECE 223	ECE 321	ECE 322		ECE 3XX	ECE 3XX	
			221L	222L	223L	321L	322L	ECE 3XX	ECE 4XX	ECE 4XX	ECE 4XX
	Digital	Digital	ECE 211	Proj Dev		Signals	Signals	Signals	Ind Des	Sr Proj	Pr Dev II
	Circuits	Systems		ECE 212		Systems	Systems	Systems	ECE 411	Dev	ECE 413
		ECE 172				I	II	III		I	Prof Prac
	ECE 171	ECE 172L				ECE 315	ECE 316	ECE 317		ECE 412	ECE 424
						Micro Proc	Engr E-mag I	Engr E-mag II			
							ECE 331	ECE 332			
						ECE 371	ECE 331L	ECE 332L			
							Power Systems				
							EE 347				

Figure 3. Outline of electrical engineering specific requirements in EE program at PSU

D. Transfer students

Portland State University is an urban university with a network of four nearby community colleges (CC-s), which provide students with alternative venue for finishing the lower-division engineering courses, most of the science and math coursework, and most of the general education requirements. PSU also has a dual-enrollment arrangement with community colleges which enables students to take courses simultaneously at both institutions. This arrangement benefits students by reducing cost and providing more flexibility. The downside is that it requires close collaboration between different institutions. Transition from community college to university environment can be jarring so we have to make sure that students are well prepared before transferring to PSU.

Most of our transfer students will transfer at the point of admission into program, i.e., at the start of junior year. This has created a potential problem because CC-s do not currently offer equivalents of our cornerstone courses, which means that vast majority of our transfer students will have to take them but they will already be at junior level. Furthermore, this means that instead of having only sophomore students in the cornerstone courses we also have a large number of juniors. On the one hand, this is good because such students will bring higher level of skills to their projects. On the other hand, these students have to take a large amount of other ECE courses (see Fig. 3), which could overload their schedules. In the future, we plan to offer special summer session of the cornerstone courses which we hope will capture most transfer students before they transfer to PSU as juniors.

One final note: Figures 1-3 illustrate our ideal program outline but due to diversity of students (age, economic

background, academic preparation, etc.) they invariably construct their own paths. Our understanding of these pathways is limited and will require further study.

III. Sophomore Cornerstone Course

We recently introduced our own version of a cornerstone courses at the sophomore level. The first one is ECE 211 Introduction to Design Processes, followed by ECE 212 Introduction to Project Development. We had two additional goals in mind when designing them:

1. Teach students design and project development well before they encounter them in their Capstone projects.
2. Provide an environment for experiential learning where integration of various strands of electrical and computer engineering disciplines can happen.

In our curriculum, students enrolled in ECE 211/212 will be familiar with topics such as programming, problem solving, DC circuits, and digital logic design. They should also be taking a sophomore-level circuits classes concurrently. This background should enable them to undertake more challenging technical projects.

Learning outcomes for ECE 211+212 courses can be stated as "Students will be able to:"

A. Develop requirements and specifications based on identified need.

B. Find information for the design of a product that meets customer needs.

C. Perform a functional decomposition for a given design.

D. Communicate effectively: create design log, deliver progress reports (oral or written), document product design requirements, and write a final report.

E. Implement basic project management techniques, including organizing teams and making individual contributions to overall team effort.

F. Complete and demonstrate a project that satisfies a specific need.

To accomplish these goals, we decided on developing two courses with 1+2 credits, instead of one course. There are two main reasons for this: a) spaced practice is known to produce better learning outcomes and this is easier to accomplish over two quarters (20 weeks) than in one quarter, and b) by having a break between two courses, students are given an opportunity to refine their design proposal over the break and finalize it during the first week of the 2nd quarter (i.e. in ECE 212).

During ECE 211 students:

1. Further develop their non-technical, professional skills, which were originally introduced at the freshman level.
2. Implement one trial run of what we call a "practicum," wherein teams of students are asked to accomplish a very specific engineering task.
3. Prepare a proposal of a project that a team will work on during ECE 212.

ECE 212 is a project-based, 10-week long course during which students work on bringing their design idea to fruition, while following the best practices established in ECE 211. The timeline for the project includes:

1. Last 3 weeks of ECE 211: Idea development and project proposal.
2. First week of ECE 212: Project is finalized.
3. Weeks 2-9: Project implemented during four 2-week-long sprints.
4. Week 10: Project demos.
5. Week 11: Project documentation submitted.

Main components of our cornerstone courses are product design, teamwork, project management, integration, and each is discussed below.

A. Product Design

Most of the initial instruction and practice of design happens in ECE 211. Given that this is a 1 credit course we cannot go into great depth of the design process. Instead, we focus on:

1. Overall approach to design process,
2. identifying a need,
3. performing a high level of functional decomposition, and
4. defining product requirements.

We discuss different approaches such as human-centered design and design thinking. While the list could contain many more topics, we believe that the most important part is when students put these ideas and processes into practice. In order to stimulate their creativity, we let each team define their own product and project with only a few general requirements:

- Shall satisfy a defined need
- Shall have one or more sensors (inputs)
- Shall have one or more actuators or displays
- Shall use ESP32 microcontroler or similar
- Should use a PCB or protoboard for electronics
- Shall be well documented

If students are properly introduced to design process in ECE 211, followed by extended practice in ECE 212, then we believe that they will be much better prepared for their capstone projects.

B. Teamwork

One of the main goals of our cornerstone courses is to develop student skills in project management and teamwork (outcome E.). These are now explicitly listed as ABET requirement in Student Outcomes, criterion 5 *"an ability to function effectively on a team whose members together provide leadership, create a collaborative and*

inclusive environment, establish goals, plan tasks, and meet objectives" [page 42, 4]. It can be difficult to disentangle teamwork from project management because students learn and demonstrate them together as part of a larger project. None the less, we have developed assessment for each of them separately.

Student training in teamwork happens mostly experientially, i.e., students are assigned to teams and asked to perform tasks as a team. First practice is done in ECE 211 where they are asked to perform a well-defined project and produce a working prototype over a period of two weeks. This micro project is modeled on our experience with so-called practicum project in capstone course [5].

One further learning opportunity is through collectively constructing a team contract. Within this document students describe [14]

- team procedures,
- team expectations, and
- consequences for failing to follow procedures and fulfill expectations.

Students construct the first contract before their practicum and refine it at the beginning of ECE 212. At this point they had first-hand experience with implementing items from their initial team contract and can make meaningful changes. Providing opportunities for revision is well known technique for improving, e.g., technical writing. However, question still remains whether constructing and improving team contracts leads to improved behavior.

C. Project Management

There are many ways to approach project management (PM) but there are several constraints that we need to take into account:

1. We cannot expect sophomores to do full PM of any kind, so we should design it as a step towards a more complete implementation in, for example, senior capstone course.
2. Process should be iterative so that students get to implement improvements as their project and understanding evolve.
3. It should be relatively transparent and observable to team members and instructors.

Based on our experience we believe that Scrum satisfies these criteria and can be modified to engineering education environment [15][16]. Scrum is an iterative approach to PM which allows for periodic evaluation of goals and processes used. Scrum personnel consists of Product Owner, Scrum Master, and Development Team. Scrum events include: Daily Scrum meetings, Sprint Review, Sprint Retrospective and Sprint Planning. During Scrum team produces two main artifacts: Product Backlog and Sprint Backlog [17][18]. We have used it for freshman and senior courses and have now expanded it to cornerstone courses.

In their practicum project within ECE 211 students act as Scrum Masters and there is no need to have Product Owner because project is completely defined and team only has to execute it. In ECE 212 teams work on delivering prototypes for their own designs and have to take some of the responsibilities of Product Owner. In order to provide more guidance and structure, we also hire older undergraduate students to serve as Scrum Masters. Because they have more experience, these Scrum Masters are also a good resource for technical issues but their primary role is to keep teams on track, i.e., meeting deadlines, assigning tasks, keeping documentation etc. Scrum masters provide feedback both to teams and also to instructor so that he/she can take corrective action.

To keep track of their planning and internal processes, students use two tools: Trello for sprint and day-to-day planning, and Gantt chart for project overview. Gantt chart is usually associated with waterfall PM style. We have found that students need to plan their overall activities and they have adopted Gantt chart quickly. We also allow them to modify the chart as the project progresses. Students are introduced to Trello [19] in their freshman classes, but now they have to utilize Trello for all aspects of planning and implementing their sprints.

D. Integration

Students in ECE 211/212 have completed a significant number of ECE courses, including programming, problem solving, digital logic, and digital systems courses. They should also be concurrently taking basic electrical circuits courses. This enables them to put together many different strands of their education as they apply them into their project. The main tool through which this happens is an ESP32 based microcontroller, such as [20]. Compared to freshman courses, students will have to write more extensive programs and use some of the more advanced features, such as IoT capabilities. Because projects require interfacing to real world, teams have to develop hardware to accomplish their goals. This is not only electronics hardware but also 3D printing of parts or cutting of materials for enclosures. This requires acquiring new skills, e.g., learning drawing programs such as Fusion 360 [21] or Solidworks [22]. Note that students have a great deal of resources at their disposal through our student-run Electronics Prototyping Lab (EPL) makerspace [23]. We believe that this component is especially relevant today as life-long learning skills and interdisciplinary experience are highly valued.

IV. Early Observations and Assessments

Even though this is the first year of implementing our cornerstone courses, we can share some observations, propose improvements and discuss some assessment results.

- Our freshman problem solving course (ECE 102) and C programming course (ECE 103) need to provide more specific instruction on using microcontrollers. This will be done by adding lab sections to ECE 103 which will deal with basics of microcontroller programming. This will leave only some more advanced topics, such as

communication to cloud services, to be discussed in ECE 211.

- We are still searching for more formal methods of assessing project management. PM is not a new topic but we have not been able to identify practical tools that could be used for formative and summative assessment.
- Based on CATME peer-rating survey tool [24], most teams function well. Less than 10% of students receive score of 3 or lower (out of 5) for their contribution to the team. CATME provides a wealth of other information that we are currently analyzing.
- We currently rely on peer assessment using CATME tool and informal observations by instructor. We need another tool to assess teamwork and we are attempting to triangulate results by using feedback from Scrum Masters. This presents two problems: a) training Scrum Masters to provide reliable and actionable feedback, and b) providing them with a rubric for this purpose. Our current rubric [16] centers on the use of Trello and does not capture well inner workings of a team.
- Using more experienced undergraduate students as Scrum Masters has worked very well and further improvements are to come from more training in the future.
- Students are warming up to using PM tools (Trello and Gantt charts) but have not fully embraced them yet.
- Among design concepts, the most confusing to students seems to be product requirements. They often confuse them with tasks that need to be completed, specific parts that need to be purchased, or, more generally, with technical specifications. However, we do not expect that all of this will become clear at this level – only that this is a stepping stone in student development.
- Among Scrum concepts, the most difficult one relates to the purpose of Scrum Retrospective. It is meant to be process oriented, i.e., how well did the team work overall, how did the internal processes work, what needs to be fixed, etc. Instead, students tend to think of it as list of technical accomplishments or failures, which are normally part of Scrum Review.
- For some tasks, such as reports at the end of each two-week long sprint, it was necessary to develop templates for the form and format of the reports. This constrains student freedom in describing various events and processes, but it was the only realistic way to process fifteen reports in a timely fashion.
- After some initial trepidation, students have come up with an intriguing and wide ranging set of products and projects, such as: UV curing chamber for 3D printed structures, automated chick hatching system, forest fire detection, automated door lock, air-quality monitor, automated control for beer brewery, water level monitor, bike charger for devices, robotic pet cat, rotating storage, package delivery detection and safe deposit, bird repellent, motorcycle tachometer and speedometer, soil monitor, and fancy doorbell. Most of these are challenging, original or both, which addresses our initial worries that students would only select easy projects.
- We need to pay special attention to schedule because many of our students work, have families or carry a heavy course load. Using CATME to set up teams helps, as does using regularly scheduled class times for daily Scrum meetings.

V. Conclusions and Future Work

While we introduced many new ways to improve students' professional development in the freshman year, there was no follow up in sophomore and junior years. We believe that with two cornerstone courses described here we will fill in this gap and enhance student learning in the areas of design, teamwork, project management, and communication. We have successfully implemented Scrum approach to project management, which is now explicitly taught across three out of four years of curriculum.

Given that this is the first offering of the courses, we have much to learn but the early assessment and observations are encouraging. In order to more fully assess student learning we are either developing our own tools, such as rubrics for project management in Trello, or using existing tools, such as CATME for peer-evaluation of teamwork. In the future, we will need to pay special attention to assessment of design process and project management.

Overall, students have taken the courses seriously and have developed many original and challenging projects. We hope to continue this trend in the future.

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Education for technology transfer to small and medium entrepreneurship - Results of the T4 project implementation

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Abstract **- Today, it is a common practice to establish technology transfer centers that are technically capable of transferring technology that are funded by European or national sources. The key players in such centers are experts who connect innovators with potential users of their innovations. Since technology and knowledge transfer to small and medium-sized enterprises are considered a turning point in building an innovative and strong European economy, it is essential to ensure the preconditions for a permanent transfer of technology to such companies. Particularly important is the education of experts involved in such processes. This paper describes the results of the Erasmus KA2 Project T4 (Transnational Technology Transfer Training: Training Blueprints for Accelerated Growth), which subsequently formulated a set of competencies and the corresponding curriculum for Transnational Technology Transfer Manager (TTTM) in a small and medium-sized enterprises (SMEs).**

Keywords - technology transfer; TTTM; SME; technology transfer manager curriculum

I. INTRODUCTION

Large multinational companies are better utilized by globalization processes than small and medium-sized enterprises (SMEs) that make up much of the European economic space. Taking advantage of their size and strength, most multinational companies are developing critical sets of competitive intelligence tools based on technologies, commercial and marketing intelligence. Due to its small size and lack of skills in developing new technologies, SMEs are in a disadvantage in order to compete with large companies in the global economy. Future growth and sustainability of SMEs will largely be dependent on the use of new technologies and the acquisition and absorption of knowledge.

The European Commission supports such processes in order to maintain a strong and innovative European economy through a variety of strategies [1] and sources of funding [2]. A small contribution to such guidelines is the project Transnational Technology Transfer Training: Training Blueprints for Accelerated Growth (T4) [3] funded by the Erasmus+ program. This paper describes the activities from T4 project that are related to the achievement of the following specific objectives:

- Specific Objective 1: mind the gap between SMEs and transnational technology innovation processes (simplify technological and R&D language plus set up a competence identification mechanism to accelerate and better finalize training processes;
- Specific Objective 2: establish a permanent, transparent, recognition oriented, evolving & multi-actor training mechanism which will allow to respond to the needs of SMEs.

According to T4 project methodology, the key to successful technology transfer towards SMEs is to achieve the appropriate competencies and skills of experts named as Transnational Technology Transfer Managers (TTTMs) involved in such processes. The T4 project methodology has also taken into account the diversity of economies and cultures from which TTTMs come from so the institutions from the following countries participated in the project: Romania ("Dunarea de Jos" University of Galati - UNIDU), Italy (FVB - The Hive business incubator, Consorzio Intellimech), Slovenia (Pomurje Technology Park), Croatia (Polytechnic of Šibenik – VUS, Croatian Chamber of Economy – Varaždin County - HGK) and Austria (Carinthia University of Applied Science - CUAS). For the purpose of achieving the above objectives, the T4 project has delivered four important intellectual outputs, and two of it is described in this paper:

- Intellectual output 2 (IO2) - T4 Competence Profile - the exhaustive map of the competences of the TTTM;
- Intellectual output 3 (IO3) - T4 Training Program - the online training course for TTTMs.

II. T4 COMPETENCE PROFILE

In preparation for IO2, a study was carried out using the questionnaire in which it called different companies from countries involved in the project to give their opinion on the necessary TTTMs profile competence. The study included 95 companies and the structure per respondent country is shown in Figure 1.

Co-funded by the Erasmus+ Programme of the European Union

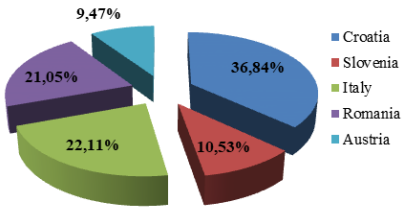

Figure 1. Distribution of participating companies by countries

The structure of the surveyed companies is shown in Figure 2 that indicates a considerable scope of SMEs, which was particularly important for the project. According to [4], the category of small and medium-sized enterprises (SMEs) consists of enterprises which employ more than 10 and fewer than 250 persons and have either an annual turnover not exceeding EUR 50 million or an annual balance sheet total not exceeding EUR 43 million.

The majority of the surveyed companies come from the domains of manufacturing, services and research and development sector as shown in Figure 3. The roles of responsible persons who completed the questionnaires are shown in Figure 4.

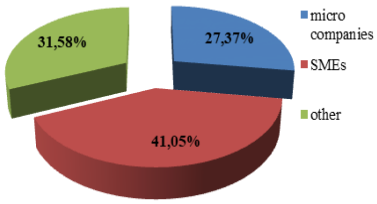

Figure 2. Distribution of participating companies by size

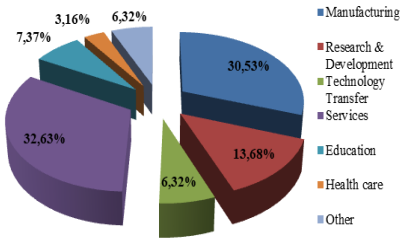

Figure 3. Distribution of participating companies by business domain

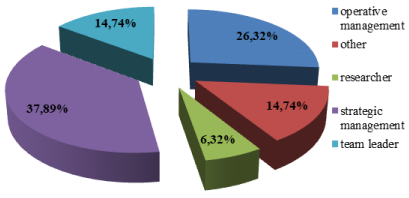

Figure 4. Distribution of participating companies by respondents

The competence profile is divided into five groups of TTTM expertise:

- Combination of technical topics and business related topics
- Patent-related topics
- Team player and networker
- Multi-project planning and management
- Project funding

In the submitted questionnaire the respondents were suggested different topics that the TTTM competence profile might have. The proposed topics are also derived from reviewed job profiles of academic organizations and enterprises as well as from publications of projects with an equivalent focus. Respondents could agree with the proposed competence (Rather agree, Fully agree), reject it (Disagree, Rather disagree) or stay neutral. Based on the responses from the questionnaire, TTTM competencies were selected by more than 50% of the respondents.

Selected combination of technical topics and business-related topics are shown in Table 1. According to the results, this group of competences is a combination of technical (TTTM must be an engineer with an academic level as master of sciences – M.S.) and business skills (empathetic and versatile in all phases of technology transfer). TTTM must also be trained in Mastering of Business (MBA) compliant topics. In addition to this group of competences, the required work experience of TTTM has been explored (shown in Table 2) and the expected experience in practical business is between 4 and 10 years.

Selected competences of patent-related and commercialization expertise are shown in Table 3. According to the results, TTTM must represent knowledge of specific legal issues with respected to intellectual property. Also TTTM must have strong skills in the field of search of existing databases associated with intellectual property (patents, trademark and industrial design) and keep track of the latest information in the innovation field (journals and publications, innovative companies). A TTTM expert must possess marketing and sales skills. Therefore, the TTTM identifies, protects and commercially exploits intellectual property (technology).

Selected competences for multi-project planning and management expertise are shown in Table 4. According to the results, TTTM shall be trained in communication skills in general and especially in negotiation, team building, conflict management and moderation of multi-disciplinary teams. Moreover, he must be proactive in networking with commercial partners. Also, he must know creative techniques and effectively communicate both verbally and writing in English language (C1 level skills).

Selected competences for multi-project planning and management expertise are shown in Table 5. According to the results, TTTM shall be trained in risk management, project management and project controlling with tools. Also, he must be skilled in business planning to successfully develop technology's business plan.

Selected competences for project funding expertise are shown in Table 6. According to the results, the TTTM must understand governmental and private funding programs. Also, he needs to know the entrepreneurship and especially the startup business.

TABLE I COMBINATION OF TECHNICAL TOPICS AND BUSINESS-RELATED TOPICS

Question/Answers	Disagree	Rather disagree	Neutral	Rather agree	Fully agree
TTTM requires as prerequisite M.S. background in technical studies.	1,06%	17,02%	28,72%	37,23%	15,96%
TTTM requires as requisite to be empathic.	0,00%	0,00%	32,98%	42,55%	24,47%
TTTM shall be trained in MBA-compliant topics.	6,52%	9,78%	33,70%	41,30%	8,70%
TTTM shall be trained in technology transfer life cycle	2,13%	2,13%	14,89%	42,55%	38,30%

TABLE II REQUIRED TTTM WORK EXPERIENCE

Question/Answers	0-3 years	4-6 years	7-9 years	10-12 years	at least 13 years
TTTM requires as prerequisite years of experience in his/her domain of expertise	5,26%	50,53%	18,95%	21,05%	4,21%

TABLE III PATENT-RELATED AND COMMERCIALIZATION EXPERTISE

Question/Answers	Disagree	Rather disagree	Neutral	Rather agree	Fully agree
TTTM shall be trained to search effectively in patent databases.	2,11%	8,42%	32,63%	35,79%	21,05%
TTTM shall be trained to search effectively in trademark and design databases.	4,21%	6,32%	27,37%	44,21%	17,89%
TTTM shall be trained to search effectively in innovative companies databases.	0,00%	0,00%	12,63%	54,74%	32,63%
TTTM shall be trained to search effectively in industrial researches databases	3,16%	0,00%	14,74%	46,32%	35,79%
TTTM shall be trained to search effectively in journals and publications of the innovation sector.	0,00%	3,16%	21,05%	51,58%	24,21%
TTTM shall be trained in the knowledge of specific legal issues of sectors of expertise	1,05%	8,42%	24,21%	44,21%	22,11%
TTTM shall be trained in models for licensing of commercial rights of technologies.	0,00%	5,26%	21,05%	41,05%	32,63%
TTTM shall be trained in assessment of markets and to understand markets for technologies to be transferred.	0,00%	2,11%	8,42%	40,00%	49,47%
TTTM shall be trained in marketing of technologies to be transferred.	0,00%	5,26%	17,89%	45,26%	31,58%
TTTM shall be trained in sales of technologies to be transferred and to develop a sales strategy	0,00%	6,32%	21,05%	47,37%	25,26%
TTTM shall be trained about and how to gather the main players of specific industrial sectors	0,00%	4,21%	25,26%	34,74%	35,79%

TABLE IV TEAM PLAYER AND NETWORKER EXPERTISE

Question/Answers	Disagree	Rather disagree	Neutral	Rather agree	Fully agree
TTTM shall be trained in moderation of multi-disciplinary teams.	0,00%	0,00%	7,37%	37,89%	54,74%
TTTM shall be trained in team-building and conflict management	0,00%	1,05%	12,63%	37,89%	48,42%
TTTM shall be trained in order to stimulate and orient researchers.	2,11%	2,11%	15,79%	46,32%	33,68%
TTTM shall be trained in order to network with commercial partners.	0,00%	0,00%	18,95%	41,05%	40,00%
TTTM shall be trained in communication skills in general.	0,00%	1,05%	7,37%	34,74%	56,84%
TTTM shall be trained in the application of creativity techniques.	0,00%	4,21%	20,00%	44,21%	31,58%
TTTM shall be trained in negotiation skills.	0,00%	2,11%	14,74%	38,95%	44,21%
TTTM shall be trained in English language skills C1 level	0,00%	0,00%	13,68%	34,74%	51,58%

TABLE V MULTI-PROJECT PLANNING AND MANAGEMENT EXPERTISE

Question/Answers	Disagree	Rather disagree	Neutral	Rather agree	Fully agree
TTTM shall be trained in the application of structured methodologies.	0,00%	2,11%	23,16%	55,79%	18,95%
TTTM shall be trained in project management.	0,00%	2,11%	12,63%	46,32%	38,95%
TTTM shall be trained in financial monitoring of technology transfer projects.	0,00%	2,11%	20,00%	37,89%	40,00%
TTTM shall be trained in developing a technology's business plan	0,00%	2,11%	14,74%	44,21%	38,95%
TTTM shall be trained in risk management.	0,00%	2,11%	20,00%	40,00%	37,89%

TABLE VI PROJECT FUNDING EXPERTISE

Question/Answers	Disagree	Rather disagree	Neutral	Rather agree	Fully agree
TTTM shall be trained in governmental fund-raising	1,05%	10,53%	25,26%	49,47%	13,68%
TTTM shall be trained in private fund-raising.	0,00%	7,37%	35,79%	31,58%	25,26%
TTTM shall be trained in best practices of start-up support	0,00%	0,00%	36,17%	32,98%	30,85%
TTTM shall be trained in entrepreneurship.	0,00%	7,45%	15,96%	47,87%	28,72%

III. T4 TRAINING PROGRAM

According to the collected competencies that are related to TTTM competence profile, the development of the appropriate TTTM training program is initiated. T4 project has accepted definition [3] of professional competencies as unitary and dynamic set of knowledge and skills expressed through specific descriptors of knowledge (knowledge, understanding and use of specific language, explanation and interpretation) and specific descriptors of abilities (application, transfer and problem solving, critical and constructive reflection, creativity and innovation). Moreover, transversal competences are defined [3] as a set of value and attitude acquisitions that go beyond a certain field / program of study and are expressed by the following descriptors: autonomy and responsibility, social interaction, personal and professional development.

From the previous analyzes carried out under the project, the following professional competencies are recommended [3]:

- C1 – Appropriate application of innovation management knowledge and technology transfer management;
- C2 – Operation with concepts from: Academic Research & Leadership; Financial Accounting; Economics; Financial Management; Controlling & Business Planning; Marketing & Sales; Strategic Management; HR Management & Organizational Management; Trend analyzes;
- Market analyzes; Market assessment; Customer characterization;
- C3 – Appropriate application of knowledge on: Intellectual property law, Patenting process;
- C4 – Appropriate use of: Research databases, Patents, Business English;
- C5 – Appropriate application of techniques for the development of technical creativity and leadership of high-performance teams;
- C6 – Carrying out activities of integrating nature: Elaborating the business plan, planning the strategy in the field of quality, Risk management.

Also, the following transversal competencies are recommended [3]:

- CT1 – Identify the objectives to be achieved, the resources available, the conditions for their completion, the working steps, the working times, the related implementation deadlines and related risks;
- CT2 – Identify roles and responsibilities in a multidisciplinary team and apply effective relationship and work techniques within the team;
- CT3 – Effective use of information and communication resources and assisted training.

Since the T4 project has a transnational component, it was necessary to ensure the recognition of the proposed training program in the area of European vocational education. A suitable rating framework for the acquired training program was selected as European Credit System for Vocational Education and Training (ECVET) [5] (ECTS credits were not appropriate because technology transfer projects are not only part of higher education institutions). It is estimated that the proposed training is worth of 60 ECVET credits which is equal to the learning outcomes that are reasonably expected to be obtained by the learner during the training. Since the planned training program consists of multiple units, the distribution of ECVET credits per unit is made according to the correlation with its contribution to the knowledge, skills and competences required by the proposed qualification.

According to the above guidelines, the course plan is made as shown in Table 7.

Following the structure set out in Table 7, the project partners did the final steps:

- Defining training units and their detailed structure;
- Brief description of the training units (content, presentation / implementation, specific materials, evaluation).

TABLE VII TTM TRAINING COURSE PLAN

No.	Name of the training unit	Lecture	Applications	No. of ECVET credits	Learning outcomes	Competence
1	INTRODUCTORY UNIT / Introduction to innovation management and technology transfer	75%	25%	3	To give a general overview of the course, its contents, and the general structure; To identify the main themes and the correct vocabulary of technology transfer and innovation management;	C1
2	BUSINESS INNOVATION AND THE ROLE OF TECHNOLOGY / Management of innovation and creativity	80%	20%	4	To operate with the new creativity tools and use them in order to support startup companies in innovating not only their initial idea or product but also the business model; To analyze and filter the right funding opportunities for the right type of venture, SME or startup company.	C1
3	THE ESSENTIAL ROLE OF BASIC COMPETENCES AND SKILLS / Developing skills and knowledge in interdisciplinary fields related to innovation and technology transfer	75%	25%	10	To operate with the new concepts, to use these concepts in order to write a business plan for the retechnologization of a specific sector.	C2
4	PROTECTED VS. OPEN TECHNOLOGY / The issue of technology transfer legislation	60%	40%	4	To understand and adopt current and relevant legal frameworks and the risks related to the protection of intellectual property brought by the development of technology; To identify a specific legal constraints and intellectual property management	C4, CT3
5	TRANSNATIONAL PROJECT MANAGEMENT / Management of innovation and technology transfer projects	60%	40%	6	To plan and implement projects, operate the project management tools and lead highly efficient teams.	C5
6	MANAGING TRANSNATIONAL ALLIANCES / Issues related to the organization of technology transfer	60%	40%	5	To understand and adopt current and relevant legal frameworks and the problems of the organization of technological transfer activities.	CT1
7	NEGOTIATION IN A TRANSNATIONAL CONTEXT / Negotiation and conflict mitigation techniques in technology transfer	60%	40%	5	To develop specific skills on communication and negotiation, leadership of high-performance teams, conflict management, psychology of groups and dynamics.	CT2
8	COMMERCIALIZATION & MARKETING COMMON TECHNOLOGY BASED PRODUCTS, SERVICES, PROCESSES / Techniques of market prospecting and sale of products and services specific to transnational transfer	60%	40%	5	To conduct a market research for potential technology transfer in a given field, and to assess further market development following completion of the technology transfer in case	C6

No.	Name of the training unit	Lecture	Applications	No. of ECVET credits	Learning outcomes	Competence
9	EVALUATION UNIT / knowledge testing - final evaluation on each module; final evaluation for the entire course.	0%	100%	6		
10	TECH TRANSFER LAB: TRANSNATIONAL TECHNOLOGY TRANSFER IN SMEs / application of learning - solving a prepared case study	0%	100%	12	To apply acquired knowledge through prepared case study.	C3
Total no. of ECVET credits				**60**		

Based on such preparation, initial teaching materials were developed and transferred to the e-learning platform [6] for the purpose of implementing the education of future TTTM experts. Teaching materials are tailored to the employees (managers, consultants, technical and administrative staff) from different target business organization that most often participate in technology transfer (SMEs, R&D centers/universities, clusters, regional development agencies, technology parks and centers of business development). The scope of these teaching materials has been prepared initially for approximately 60 hours of teaching with a purpose to increase and enhance the skills and competences of European SMEs in the domain of transnational technology transfer and to motivate interested public and private organizations in terms of increasing their ability to meet the SMEs need for skills. These teaching materials are also appropriate for one course at postgraduate level engineering degree program for 30 hours of lectures and 30 hours of exercises. However, there is a possibility of extending the scope of the teaching materials (e.g. full VET qualification or postgraduate qualification level of the engineering study program) with respect to learning outcomes, competences, curriculum distribution, theoretical and practical teaching ratio as in Table 7. The possibility of such extensions contributes to the sustainability of project results in the future.

Also, at the end of the project in December 2018, all teaching materials are integrated into the T4 project book [7].

IV. CONCLUSION

Managing innovation processes and transferring technology to SMEs is a key prerequisite for the sustainability of the European economy. The T4 project has explored and identified the key competencies of experts who can coordinate such processes and actively participate in them. It is obvious from the obtained results that such competencies cannot be obtained during formal engineering education, although it, with previous work experience, is a basic precondition for the TTTM expert. However, the established additional learning outcomes enable the development of appropriate vocational education modules that such competencies can acquire. Taking into account today's modern forms of education, the project also delivered appropriate teaching materials to the e-learning platform. In addition, a set of established competencies and related learning outcomes can help improve existing study programs in order to better prepare engineers to participate in technology transfer.

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Učenje „e-learning“ putem e-learninga – primjer iz prakse

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Sažetak **- Poučavanje i učenje događa se na svim mjestima gdje god je čovjek živio ili živi. Korištenje IKT-a u nastavi radi povećanja motiviranosti, objektivnijeg i djelotvornijeg poučavanja danas polako prelazi u standard. U ovom radu autori detaljno opisuju način izvođenja i ocjenjivanja studenata na predmetu „E-Learning“ koji se izvodi u petom semestru na smjeru Programsko inženjerstvo u Visokoj školi Virovitica. U nastavi su se koristili različiti alati i metode za poticanje aktivnog i suradničkog učenja studenata. Vrhunac studentova razumijevanja gradiva je kreiranje vlastitog e-kolegija u Moodle-u sa svim potrebnim teoretskim dijelovima i aktivnostima (anketa, test, zadaci, prezentacija,...).**

Ključne riječi – e-learning; nastava; ocjenjivanje; ishodi učenja; ERR

I. UVOD

Široka prihvaćenost Interneta kao i razvoj tehnologije bazirane na Internetu (Web 2.0, Web 3.0, Web 4.0) su značajno utjecale i utječu na današnje obrazovanje, ne samo na proces učenja nego i na samu ulogu nastavnika i studenta u procesu učenja što potvrđuje i velik broj znanstvenih radova koji se bavi konceptom primjene informacijsko-komunikacijske tehnologije (IKT) u sustavu visoke naobrazbe i promjenama tradicionalnog načina pristupa obrazovanju. Naime, formalni, informalni i neformalni obrazovni procesi danas se snažno oslanjaju na informacijsko-komunikacijskim tehnologijama. Ove tehnologije postaju prevladavajuće na svim razinama obrazovanja, a posebno u visokom obrazovanju. Brojna istraživanja provedena su u posljednjih dvadesetak godina s ciljem otkrivanja čimbenika koji utječu na prihvaćanje i korištenje različitih IKT rješenja, jednako od strane nastavnika i studenata. Neosporno je da danas te tehnologije donose brojne prednosti u raspoloživosti i iskoristivosti podataka, informacija i znanja, efektivnosti u njihovoj razmjeni i komunikaciji, ali još uvijek i sumnje u apsolutnu nadmoć nad klasičnim metodama učenja i poučavanja [1]. Međutim, činjenica je da današnja rasprostranjenost i dostupnost informacijsko-komunikacijske tehnologije stvara nove mogućnosti za razvoj i ulogu znanja u društvu, ne samo u ekonomskom (kroz širenje inovacija i produktivnosti koju donosi) nego i u ljudskom razvoju (u načinima kako danas pojedinac proizvodi, distribuira, pristupa i ponovo koristi informaciju, znanje i zabavu).

Tehnološke promjene značajno su utjecale ne samo na proces učenja nego i na samu ulogu nastavnika i učenika/studenta u procesu učenja. Tehnologije digitalnog učenja bazirane na Internetu su potakle razvoj novih nastavnih metoda kao i razvoj novog oblika nastavnog plana i programa čime su dovele i do transformacije cjelokupnog obrazovanja. Kako navodi Jamlan [2] u početku su procesi učenja bili ograničeni pisanim radnim materijalima koji su se učenicima slali kućama, nakon čega je uslijedilo korištenje radija i televizije u svrhu poučavanja, što je naposljetku utrlo put web baziranim tehnologijama i dovelo do digitalnog učenja koje prema američkom Savezu za izvrsnost obrazovanja (eng. *Alliance for Excellent Euducation*) predstavlja bilo koji oblik instrukcija uz učinkovito korištenje tehnologija. Dakle, digitalno učenje predstavlja bilo koji oblik instrukcija uz učinkovito korištenje tehnologija kako bi se poboljšalo učenikovo iskustvo učenja. Nadalje, ono obuhvaća široki spektar alata i vježbi, uključujući korištenje *online* i formativne procjene, povećanje koncentracije i kvalitete nastavnih sredstava i vremena, online sadržaje i tečajeve, primjenu tehnologije u učionicama i školi općenito, prilagodljive softvere za učenike s poteškoćama, platforme za učenje, sudjelovanje u profesionalnim zajednicama za učenje, pružajući na taj način pristup uputama i zahtjevnom sadržaju na visokom nivou kao i mnoge druge napretke u nastavi i učenju koje omogućuje tehnologija.

Unatoč postojanju različitih definicija *e-learning*-a ono što im je zajedničko može se svesti ovom jednom definicijom koja se navodi u Strategiji e-učenja Sveučilišta u Zagrebu [3] prema kojoj *e-learning* podrazumijeva proces učenja i poučavanja uz uporabu nekog oblika informacijske i komunikacijske tehnologije s ciljem unapređenja kvalitete toga procesa i kvalitete ishoda samog obrazovanja. Sukladno prethodno navedenom *e-learning* je digitalno učenje, a ovisno o intezitetu i načinu korištenja IKT razlikuje se nekoliko oblika. Primjerice, može se koristiti u klasičnom (tradicionlanom) obliku nastave tako da se računalo i internet koriste za vrijeme nastave ili u izradi domaćih zadaća. Zatim, u nekim slučajevima obrazovni programi se mogu djelomično izvoditi online, a djelomično na tradicionalni način i to se zove tzv. mješovito učenje (eng. *blended learning*, *mixed mode* ili *hybrid*). Mješovito učenje se odnosi na bilo koje vrijeme koje učenik/student provede učeći djelomično u instituciji, a djelomično online uz elemente vlastite kontrole vremena, mjesta, načina, i/ili brzine“. Također, obrazovni program odnosno nastava može se izvoditi u potpunosti na daljinu (eng. *Fully online*).

II. PREDMET „E-LEARNING“

A. Opis predmeta

„E-learning“ je izborni predmet u petom semestru na stručnom studiju Programsko inženjerstvo, te Telekomunikacije i informatika u Visokoj školi Virovitica. Tijekom semestra održava se 15 sati predavanja i 15 sati vježbi. Studenti mogu ostvariti 3 ECTS boda.

B. Način izvođenja

Predmet „*E-learning*“ izvodi se tijekom 15 tjedana. Prvih šest tjedana održava se po dva sata predavanja na kojima se obrađuje teoretski dio gradiva. Provedba predavanja temelji se na ERR okviru.

ERR okvir dio je projekta „Aktivno učenje i kritičko mišljenje u visokoškolskoj nastavi“. On omogućava stvaranje uvjeta za aktivno učenje na način da studentima omogućuje da nova saznanja uklope u postojeće znanje, da se aktivno uključe u nova iskustva učenja te da razmisle kako to novo znanje utječe na njihovo razumijevanje. Tri su faze poučavanja u ERR okviru:

1. Evokacija – faza u kojoj se studente uvodi u temu i traži da razmisle što već znaju o njoj te se također kod studenata pobuđuje znatiželja i zanimanje.
2. Razumijevanje značenja – faza u kojoj studenti dolaze u dodir s novim informacijama koje bi trebali naučiti i prate svoje razumijevanje
3. Refleksija – faza u kojoj se od studenata traži da razmisle o tome što su naučili u prethodnoj fazi [5].

Svaka od faza ima svoje posebnosti, a s obzirom na njih postoji 80 različitih metoda i tehnika koje se mogu koristiti kako bi cilj svake od njih bio ispunjen [4]. Na predavanju su se koristile tehnike poučavanja: insert i znam, želim znati, naučila sam, koje studentima omogućavaju da na temelju prethodnog znanja usvoje nove spoznaje.

U sustavu Loomen, na službenim stranicama predmeta, nalaze se sve teme koje se obrađuju na predavanju popraćene su nastavnim materijalom i vježbama koje su namijenjene studentima kako bi na što jednostavniji način savladali gradivo.

Sljedeća četiri tjedna sastoje se od laboratorijskih vježbi izrade e-predmeta u Moodle-u. Prvi tjedan se dogovaraju pravila i upoznaje se s radom u Moodle-u. Studenti svoj predmet izrađuju na virtualnom serveru gdje dobivaju ovlasti kreatora e-predmeta. Studenti odabiru temu svog projekta i odrađuju prvu vježbu. Projekt, e-predmet, odabire se na temelju ponuđenih tema: Instrukcijski dizajn, Arhitektura Moodle-a, Evaluacija studenata u Moodle-u, Interaktivnost u Moodle-u. Kako bi se olakšao rad studenata u grupama, po tri studenta, na laboratorijskim vježbama studenti popunjavaju tablice koje ih vode u osmišljavanju i realizaciji odabranog zadatka i rješavaju probleme, na koje su naišli tijekom rada kod kuće, sa predmetnim nastavnikom.

Tablice su koncipirane tako da studenti tijekom rada rasporede poslove koje moraju odraditi na svakog člana grupe. Na ovaj način želi se studentima stvoriti situacija u kojoj bi se mogli naći u poslovnom svijetu. Od raspoređivanja zadataka do poštivanja određenih vremenskih rokova i kvalitete odrađenog posla.

Nakon četiri tjedna stvaranja i kreiranja e-predmeta studenti međusobno upisuju e-predmete te prolaze kroz sve potrebne vježbe i aktivnosti koje su studenti drugih grupa predvidjeli. Predmetni nastavnici također upisuju svaki e-predmet. Tijekom ovog perioda želi se studente potaknuti na kritično razmišljanje o svom uratku i uratku kolega drugih grupa. Pri tome je važno napomenuti da se od kreatora e-predmeta očekuje da potaknu komunikaciju među polaznicima, prate rad i obavještavaju polaznike o napredovanju, te im pomognu ukoliko dođe do poteškoća tijekom odrade svega potrebnog za e-predmet.

Zadnja dva tjedna nastave predviđena su za prezentaciju nastalih e-predmeta, kritički osvrt na učinjeno i raspravu o poteškoćama na koje su studenti nailazili tijekom rada.

C. Način ocjenjivanja

Studenti rješavaju šest testova u sustavu Loomen na službenoj stranici kolegija. Na temelju tih testova mogu osvojiti 36 bodova, odnosno 6 bodova po testu. Testovi se rješavaju na početku sata počevši od drugog do sedmog sata. Aktivnost na satu i domaće zadaće boduju se sa 11 bodova. Aktivnosti i domaće zadaće uključuju:

1. ankete, kao npr. „Anketa za procjenu stilova učenja“ pomoću koje studenti mogu saznati preferencije u procesu učenja, te bolje istražiti razliku između preferencija i otkriti svoje preferencije.
2. zadatke koje studenti trebaju riješiti kod kuće ili istražiti određena područja koja se traže. Tako na primjer u zadaći „Platforme e-učenja“ potrebno je naći jednu platformu e-učenja i dati kratak opis ste. Zatim, potrebno je postaviti link za odabranu platformu kako bi je svi polaznici mogli pogledati i istražiti.

Na temelju popunjenih tablica koje studenti popunjavanju tijekom dogovaranja i raspoređivanja poslova na laboratorijskim vježbama dobiva se 6 bodova, a potrebno ih je predati nakon prezentacije.

Najvažniji dio obveza studenata je kreiranje e-predmet na temelju zadanih tema, odnosno projekt. Projekt se radi kod kuće i na laboratorijskim vježbama. Projektom studenti mogu osvojiti 42 boda i to na temelju:

1. prezentacije projekta na satu (7 bodova),
2. usmenom obrazlaganju i povezivanju prezentiranog e-predmeta s naučenom teorijom (7 bodova),
3. izgleda e-predmeta: veličina slova, boje, itd. (7 bodova),
4. sadržaja e-predmeta: slika, tekst, film, datoteka, obavijesti, anketa, itd. (7 bodova),
5. međusobnog ocjenjivanja grupa (7 bodova),
6. ocjenjivanja unutar grupe (7 bodova).

Predmetni nastavnici na temelju prezentacije ocjenjuju studente za svaku pojedinu stavku s ocjenama od 1 do 5. Pitanja su podijeljena u četiri grupe pitanja:

1. prezentacija i način prezentiranja,
2. usmeno obrazlaganje i povezanost s teorijom,
3. dizajn predmeta i

4. sadržaj predmeta.

Na temelju izračunatih postotaka svake grupe pitanja dodjeljuju se bodovi prema već opisnom rasponu bodova za projekte. Na isti način studenti ocjenjuju rad kolega iz suprotnih grupa (tablica 1.).

TABLICA I. PRIMJER PITANJA OCJENJIVANJA

Kategorije ocjenjivanja	**Pitanja za ocjenjivanje**
Prezentacija	Prezentacija ima određenu strukturu: uvod, razradu i zaključak Prezentacija je predstavljena u određenom vremenu Tekst je pregledan lako se prati Predstavljeni sadržaji su jasni i razumljivi Predstavljanje je tečno Govor je optimalno glasan
Usmeno obrazlaganje i povezanost s teorijom	Poznavanje teme o kojoj se govori Povezuje li se znanje stečeno iz teorije s prezentiranim sadržajem Argumentirano brani svoj stav Odgovaranje na postavljena pitanja
Izgled e-predmeta: veličina slova, boje, itd.	Veličina slova e-predmeta je optimalna Boje u tekstu su osmišljene tako da je lako čitati tekst i primijetiti bitne činjenice
Sadržaj e-predmeta: slika, tekst, film, datoteka, obavijesti, anketa, itd.	Navedeni su ciljevi predmeta razumljivi i izvodivi Ishodi predmeta se mogu lako ocijeniti Navedena je literatura i izvori koji su se koristili E-predmet sadrži uvodnu poruku i predstavlja članove tima Sadržaj e-predmeta je razumljiv Tekst je optimalne veličine Slika je primjerena za napisani tekst Film je zanimljiv i dodatno pojašnjava priloženi tekst Film proširuje temu E-kolegij sadrži obavijesti Anketa je razumljiva Testovi se temelje na sadržaju koji je predstavljen Pitanja u testu su različitih tipova Pitanja u testu su nedvosmislena Ukupni bodovi iz testova su vidljivi unutar 24h Dnevno prate rad studenata Odgovaraju na postavljena pitanja studenata unutar 24 h Obavješćuju studente o aktivnostima koje nisu odradili

Ocjenjivanje unutar grupa temelji se na ocjeni međusobne suradnje, poštovanja i prihvaćanja mišljenja unutar grupa (tablica 2.).

TABLICA II. OCJENJIVANJE UNUTAR GRUPA

Pitanja za ocjenjivanje
Ocijenite je li na vaš uspjeh utjecao rad Vašeg kolege? Ocijenite je li se kolega/ica pridržavao/la postavljenih vremenskih rokova? Ocijenite je li kolega/ica imala kreativnih prijedloga o sadržaju kolegija? Ocijenite je li kolega/ica poštovao/la stavove ostalih? Ocijenite je li kolega/ica dogovarao/la se o svemu što se radilo? Ocijenite je li kolega/ica pomagao/la ostalima unutar grupe? Ocijenite je li kolega/ica prihvaća/la sve članove grupe? Ocijenite je li kolega/ica prihvaća/la prijedloge ostalih članova? Ocijenite je li kolega/ica prihvaća/la rješavao postav-ljene zadatke?

Ocjena iz predmeta formirala se na način prikazan u tablici 3. Nakon predložene ocjene na temelju osvojenih bodova tijekom semestra student se mora izjasniti prihvaća li ocjenu ili će posebno odgovarati za veću ocjenu. Usmeni ispit iz predmeta klasično se ne izvodi jer studenti tijekom prezentacije svojih radova moraju argumentirano prezentirati svoj rad koristeći će teoretskim znanjem. Pri tom odgovaraju na postavljena pitanja iz teoretsko dijela i praktičnog.

TABLICA III. RASPON BODOVA PO OCJENAMA

Broj bodova	***Ocjena***
0,00 – 50,00	Nedovoljan (1)
50,01 – 58,00	Dovoljan (2)
58,01 – 75,00	Dobar (3)
75,01 – 92,00	Vrlo dobar (4)
92,01 – 100,00	Izvrstan (5)

D. Prednosti i nedostaci

Rad u grupi potaknuo je studente na razvijanje komunikacijskih vještina i donošenje zajedničkih odluka o načinu rada i vremenskim rokovima. Upravo su za ovaj način rada studenti imali najviše prigovora iako su sami odabrali kolege s kojima će raditi na projektu. „Ovisili“ su o radu drugih kolega u grupi i otvoreno rekli da bi im bolje odgovarao da je svatko mogao sam kreirati svoj e-predmet.

Samostalnim radom usvojili su korištenje novog alata i pritom pokazali kreativnost koja je potrebna za osmišljavanje e-predmeta. Kao kreatori e-predmeta imali su slobodu istraživanja svih potrebnih informacija o odabranoj temi i slobodu na koji način prezentirati istu.

Isto tako problem je nastao tijekom komunikacije s polaznicima e-predmeta. Studenti nisu uspjeli uspostaviti dobru komunikaciju s polaznicima i polaznici su većinu zadataka odrađivali sami bez adekvatne povratne informacije.

Razvijena samokritičnost i kritičnost najviše se očitovala tijekom prezentiranja uradaka i dodjeljivanja ocjena kolegama unutar grupe i ostalih grupa. Iako su studenti unutar grupa jedni druge ocijenili visokim ocjenama prilikom ocjenjivanja suprotnih grupa ocjene su bile manje. Kako bi se ovaj problem izbjegao u slijedećem ciklusu izvođenja predmeta načina ocjenjivanja unutar grupa će biti izmijenjen. Studenti će se međusobno ocjenjivati češće, odnosno nakon svake odrađene vježbe na temelju učinjenog. Ocjenjivanje će se temeljiti samo na tri ocijene 1 (nije zadovoljio), 3 (djelomično je zadovoljio), 5 (zadovoljio je) i to u dvije kategorije: je li student odradio dogovorno i je li poštivao dogovorene vremenske rokove.

U cilju utvrđivanja zadovoljstva polaznika krajem semestra proveden je anketni upitnik o zadovoljstvu polaznika. Studenti su popunjavali anketni upitnik čija su pitanja bila fokusirani na zadovoljstvo polaznika izvođenjem nastave, dostupnosti nastavnih materijala, pokrivenošću

primjerima iz prakse, organizacijom nastave i zadovoljstvom samim predmetnim nastavnikom.

III. ZAKLJUČAK

Koncepcija predmeta „*E-learning*“ osmišljena je na način da svaki student kontinuiranim radom tijekom semestra zadovolji sve ishode učenja i pri tome spozna važnost komunikacijskih vještina u grupnom radu, te prednosti i nedostatke e-učenja. Savladati jedan od alata *e-learninga* prioritet je u izvođenju predmeta što je i studentima bio najzanimljiviji dio. Kroz svoj rad studenti su morali primjenjivati teoretske osnove *e-learninga* kako bi uspješno kreirali e-predmet i argumentirano iznijeli stav o svom uratku i uratku kolega.

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A system for managing classes with a large number of participants

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Abstract - **This paper describes a system that enables complete managing and tracking of project-based classes with a large number of students and teachers. The system provides a complete platform solution from matching up students with mentors, tracking student activities and automatic presentation group creation.**

This paper also presents a novel approach for matching students and mentors. Matching is made using single- and two-sided algorithms with preference list. Once matched, students with different mentors are grouped by an advanced method so that each new group consists of a similar number of students with a high, average and low academic score.

Keywords - **Intelligent system, large course management; large groups of participants; student grouping**

I. INTRODUCTION

At University of Zagreb, Faculty of Electrical Engineering and Computing, one of the requirements for accrediting the course curricula according to the Bologna process [1] was the implementation of two obligatory courses for all the students: Seminar and Project. More than thousand students are enrolled on each of these courses every year and more than two hundred teachers' mentor them.

The grading on these courses is based on objective and subjective criteria. Objective criteria are used for tracking the students' performance by achieving milestones. Subjective criteria can be applied to grade a submitted paper on a given topic, as well as students' performance during the presentation. More than one evaluator should be used in order to make subjective grading more objective. During these courses both the mentor and the students have a role of an evaluator. This method is often used in massive open online courses (MOOC) courses [2].

Students are assigned to mentors for the Seminar course. All mentors can have up to five students. Students give a presentation in front of a group of up to 30 students at the end of the Seminar course. Their final grade consists of three separate scores: up to 40 points from the mentor; up to 20 points for activity and up to 40 points for attendance of presentations by other students. Only activity points are objectively given.

Project course is a mentor-based where students work in small groups of 6 to 8 students. A mentor grades the whole group at the end of the course. A student who is the group leader, distributes the given points to all other members based on their work performance and activity. Final grade is calculated based on this score.

A new system is built in order to manage all activities such as choosing mentors, mentor approval for students, assigning the student to the mentors, creating presentation groups, tracking the students' performance using the milestones, and grading the students. There are several reasons for not using already existing learning management system such as Moodle.

Seminar and Project courses are mentorship-based courses. Although learning management systems provide support for student mentoring, they are mainly focused on large groups of students and not as much on one-to-one teaching, which is required for such courses. The amount of additional work using standard plugins needed to create such course in learning management system like Moodle would be too large with thousands of students and two hundred mentors.

To automatically match the students with their mentor both courses require student's preference list which was not provided by previous learning management systems.

One of the requirements for the automatic group generation and assignment of students into groups was only partially solved by an existing learning management system.

This paper proposes the development of a computer system based on e-learning system ideas that would enable the course manager to track mentorship, grouping, and evaluation of a course with a large number of participants.

This paper suggests a novel approach in matching the students with available mentors. This system

provides an option for automatic creation of groups of students for presentation and teamwork, even when they have different mentors based on their previous academical achievement and scope of work.

II. System Implementation

A system was created to support complete management for the above-mentioned courses. This approach is not only for automatic student matching but also for creating student groups and monitoring students and mentor's engagement in the course engagement by using a limited amount of human resources.

Currently available teaching systems, including e-learning systems such as *Moodle,* do not have tools to provide this kind of service. They provide users with randomly generated or manually created groups that are not using any data about students and mentors which would pair them as proposed in this paper.

A. Communication among Students and Mentors

Learning process requires effective communication and exchange of materials. In e-learning based courses students are separated into virtual classes where teachers share materials and communicate with their students. This is an integral part of e-learning based courses.

The proposed system uses all of these practices for sharing materials and creating virtual classes. It allows mentors and students to share materials and exchange opinions within the group or with a wider audience. [3] The system is non-intrusive and is only used for official communication with no personal data transferred or stored.

Seminar and Project courses are both using similar methods for progress tracking. There are several milestones for both courses, used to track the amount of work done by the students. The milestones are also used to check how the mentors and students cooperate and to detect any existing anomalies.

All milestones are set in advance and based on other students' activities and studies. The milestones are based on the previous year data and they also include suggestions from mentors and students. A skipped milestone can result in deduction of a point for each missed day.

The proposed system automatically tracks document submissions and changes after a given date. At the end of the course the system automatically awards activity points based on the work performed at given milestones.

B. Matching Students with Mentors

There are several types of matching algorithms: random matching, matching by alphabetical order, matching by student-mentor culture, personal characteristics, gender, etc.

These types of matching algorithms are used when it a student can be assigned to any group or mentor. Therefore, they are widely used to assign a student to an activity group (for example classroom) where all groups have the same task. A student learns the same content no matter regardless of the group they attend. These types of matching algorithms are supported by various e-learning systems such as Moodle.

Simple matching algorithms are not as useful when there is a difference between groups – for example groups having different assignments. This kind of problem is typical for a mentor-based course.

Seminar and Project courses are mentor-based courses where matching a student with a mentor is one of the important features.

The proposed system solves the student-mentor matching problem. The match is made based on several factors such as student's preference list, previous student's academic achievements, and mentor's interest.

Gathering the students' and mentors' preference list can be a time-consuming process. It may take several days for thousands of students and two hundred mentors to create their own preference list. If this is done at the beginning of the semester, the students would have less time to work on their assignments.

A pre-course questionnaire is used to solve this problem. All students planning to attend the two courses need to fill in the questionnaire. This gives them up to two weeks to create their own preference list. When the course enrollment is completed, the new system automatically analyzes only the questionnaires from enrolled students– and those received from non-enrolled students are automatically discarded.

The Seminar course uses only the preference lists given by the students. Mentors cannot choose their students. The Project course uses preference lists from students and mentors. Based on the number of preferences and possible mentor and student combinations, several different matching algorithms were researched for these match-making problems.

The proposed matching algorithm can be applied to other allocation problems where matching algorithms with no preference list are currently used. The new algorithm can be used for both online and face-to-face courses.

This is a variation of a matching problem which was introduced and described by David Gale and Lloyd Shapley in 1962 in the article "College admissions and the stability of marriage" [4]. Today, this article by Gale and Shapley is considered a fundamental for allocation problems [5]–[8].

1) Matching Algorithm with Student Preference List

A preference list is a list where the selection is done in order. Out of two presented options and in case of two options A is more preferred option then B in case of both options being available. Option B is only used in case of option A is not available.

In the case of Seminar and Project courses, students select one or more mentors and rank them in order of preference. Each student can select as many mentors as necessary.

Matching with one-side preference list while the other side has limited number of spaces can lead to a problem with more than one solution. For example, students S1 and S2 rank mentor M1 at the first place. Mentor M1 can take only one student. One solution is that student S1 gets mentor M1 or student S2 gets the mentor M1.

To reduce the number of possibilities on the Seminar course, a student preference list is expanded with a ranking algorithm. For the Project course the number of possibilities is reduced by mentor's approval of students.

Both algorithms further reduce the possibilities by considering the student limit for each mentor. These limits can be set as a minimum or a maximum number of students per group.

The group limit settings allow the proposed algorithm to be used for various matchings. For example, limiting the number of students in the classroom by using their preference list.

2) Ranking Algorithm

A limited number of students can be assigned to a group and therefore not all of them can have their first selection. A new ranking algorithm solves this problem and award students with better grades. Students are ranked by grades and assigned to mentors in that order. For example, student at the top of the list will be prioritized over the second one. This can repeat until limit is reached after which the second selection is used. If there are no other selections on the list, a random one is applied. The algorithm continues until all students are assigned to a mentor or a group.

Ranking algorithm is used to solve allocation problem by combining in the Seminar course.

During a period of three years more than 3000 students were assigned to the Seminar course.

Figure 1 shows the results of using this algorithm for assigning students to mentors in academic year 2018/2019. As can be seen from Figure 1 – the majority of students – 38,8%, were assigned by their first selection, 20,3%, to their second or third selection. An average of 68,5% of the students received a mentor ranked up to their fifth selection on the preference list. 10,1% got a mentor ranked up below fifth selection. 21,4% of the students received a mentor they did not select.

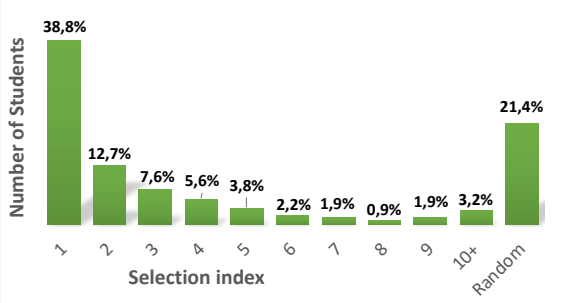

Figure 1 - Number of students paired with mentors, based on students' preference index in academic year 2018/2019

3) Mentors Approval of the Students

In Project course, the mentors can approve the students assigned to them. Each mentor can approve a limited number of students. In order to make the approval process easier for the mentors and avoid confusion, only students who picked them as their first selection are displayed.

If the mentor does not approve any student from the list, there are two possible reasons: technical problems or they did not wish to mentor any of the students. The proposed system can recognize the difference between these two situations and act appropriately. In case of a technical difficulty, it presumes that the mentor accepts all of the students. If the mentor did not approve any of the students then they are shown to another mentor.

C. Presentation Groups

At the end of the Seminar course, students hold a presentation in front of a group. Students with different mentors can form one presentation group and students with the same mentor are placed in the same group.

The final grade is determined by three modules. First of them are points received from other students attending the presentation. In order to be more objective students are required to rank the presentations in order of quality. The top students receive better grades than bottom ranking ones.

The problem that presents with this system is that each group must have students with different academic achievement since each group will receive good and bad grades. If only straight-A students were in a group then some of them would receive bad grades only because there are no students in their group that are worse than them and vice versa.

The groups having only students with high or low achievement are therefore unbalanced and creating such should be avoided.

An in-depth analysis was created to solved this problem. It compares various ways of merging small groups of students into a new large group. Figure 2 shows how a presentation group should be balanced. On the x-axis, students are ordered by academic achievement inside their group. Each group has up to 25 students. The y-axis presents students rank in comparison to all the students in the course. The course consists of up to 600 students. The group is considered balanced if the ratio between students with high, average and low academic achievement is the same as in the whole course.

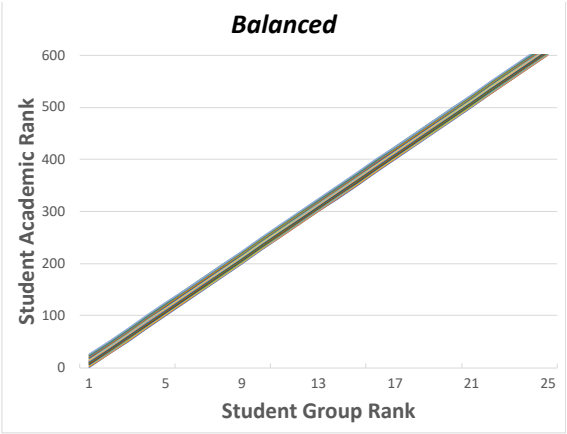

Figure 2 - Balanced presentation group

1) PRESENTATION groups - based on the mentors' expertise fields

Making groups based on mentors' expertise fields is a good approach when students are expected to listen to other student presentations in a familiar field. The issue with this model is that it creates unbalanced groups as shown in Figure 3.

Some mentors and subjects are more popular than others and since there are limited group spots, the mentor can pick the best students for him group. This can result in creating groups with only high or only low achieving students. The students with lower academic achievement are assigned to mentors with less popular subjects.

Another problem with this method is that some fields have a limited number of mentors so it is not always possible to group students who have similar field of expertise.

Figure 3 shows the result of this type of grouping where the student allocation is very far from the optimal one. As illustrated, the chart is very widely spread, showing unbalanced group – students within the group are not a good representation of all students on the course. As shown, one group is so unbalanced that its best-ranked student is in the middle of the student population rank – top one. There is also a group where all students are above average compared to the other groups – bottom one. Even the 21st ranked student in the group has an academic rank higher than most students ranked 7th in other groups. The same student has better overall rank than the best-ranked student in one of the groups – upper one.

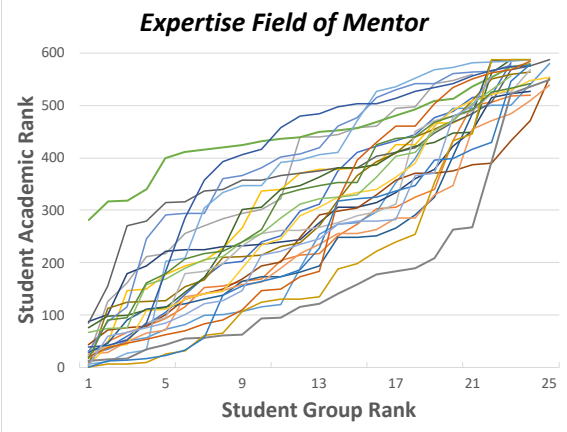

Figure 3 - Grouping of students based on expertise field of mentor

2) Presentation Groups – Based on Alphabetical Order

Groups based on alphabetical order are similar to the random ones, because they do not have any known preferences or characteristics.

Such groups are made by arranging mentors alphabetically and placing students into their groups.

Figure 4 shows a more balanced graph line as compared to the one from Figure 3 which represents groups based on mentors' expertise. This is a consequence of ignoring the popularity of a subject which was the main reason for non-balanced groups in the previous algorithm.

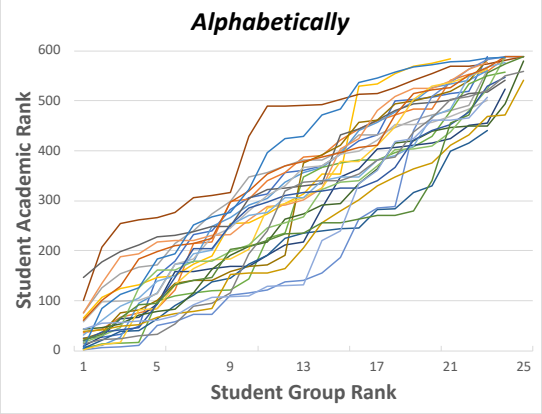

Figure 4 – Alphabetical grouping of students

3) Presentation Groups – Based on the Average Student Grades

Since balanced groups have the same amount of students with high, average and low academic achievements, one of the possible approaches is using student achievements as a grouping parameter.

In order to create presentation groups from already "grouped" students, the average group grade is calculated based on students' academic achievement.

This algorithm combines the group with the best average score and the group with the worst average score, and so on until a complete group is made.

This kind of grouping does not produce the required results as shown in Figure 5. This algorithm produces bigger extremes than the alphabetical grouping. It produced "S-shaped" lines that represent groups with not enough average grade students.

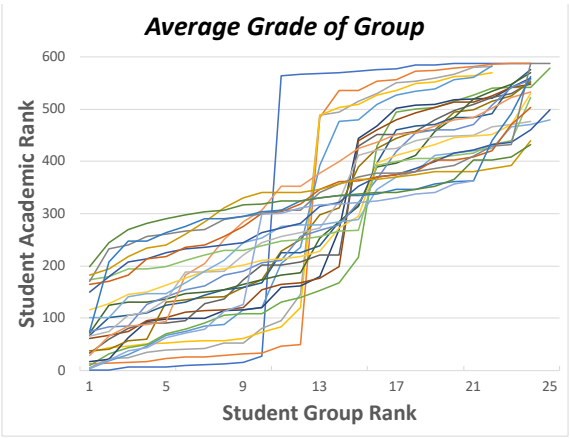

Figure 5 - Student grouping by group average grade

4) Presentation Groups – Based on the Most Successful Student

The system uses the new approach based on grouping by the highest-ranking students. Although it resembles the algorithm using students' average grades, this one has better results.

All students are arranged by rank. The total number of groups is calculated as N = (total number of students) / (group size).

The most successful student and all others in their mentor group are put in the first presentation group. The second ranked student and students from mentors' group are placed in the second presentation group and so on till the last N^{th} group. After the Nth group is formed, the algorithm adds more students to the first, second and other groups until all students are grouped. When the algorithm finishes all groups have a similar number of students.

The result of this approach is shown in Figure 6. The bottom left shows a distribution of above average students. The algorithm ensures that above-average students are evenly distributed between all groups, as well as those with below average grades. Since the algorithm prefers above-average students, a small dispersal is seen on the top right of Figure 6. The reason for that dispersal is due to a large group of 30 students consisting of several smaller groups of up to 4-5 students with different knowledge.

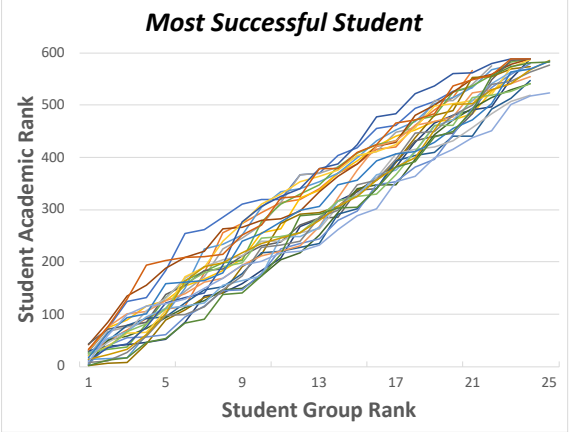

Figure 6 - Student grouping by the most successful ones

III. CONCLUSIONS

This paper presents a novel system for Seminar and Project course management with numerous students and mentors participating. The main idea of the system is taken from e-learning course ideas – enable course manager with tools for easy tracking of course achievements and a considerable number of participants. These ideas are expanded with custom made algorithms which support all processes and reduce administrative tasks.

Since both Seminar and Project courses are mentor-based, the integral parts of the new system are communication layer used for tracking course activity, an algorithm for matching students with mentors, and automatic group creation for presentations.

The communication layer is a part of the system that enables students and teachers to easily and securely communicate with each other. The system uses this data to track student's course activity with no additional efforts by the student or mentor.

The main difference between Seminar and Project course is that the Seminar course uses single sided matching algorithm augmented with previous student performance while Project course uses two sided-matching algorithms with a preference list from both students and mentors.

The best algorithm to create a presentation group, which depends on student grades, is based on the most successful student. The algorithm ensures balanced groups that have the same number of students with high, average and low academic achievement.

By combining all these methods, a computer system is created for both courses that reduces time for managing a classroom course with a lot of students. It can also be used for other similar courses.

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Gamification in Software Engineering Education

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***Abstract* – Gamification has proven to be an adequate approach in various educational environments, from kindergarten and elementary school to higher education classrooms. While it has been extremely effective with school students and standard subjects, such as STEM, when applied correctly, gamification and game-based learning can be applied with older students, even in the information technology and software engineering field. The paper outlines the results based on the experience of applying gamification of education to attract and stimulate student motivation and engagement in class. An approach for including games to teach software engineering methods and concepts is described. Different styles of software engineering games are examined and several of the most appropriate and relevant to the students' field of study are integrated in the Software engineering course. Descriptions of the games and the planned student progression through them are presented. A collaborative agile team-based approach is implemented and described. A suitable number of student groups have been selected, and the results from surveys held among those students are shown. Conclusions about the improvement of the process are discussed.**

Keywords - gamification, game based learning, education, software engineering, higher education

I. INTRODUCTION

Games are an innovative educational tool for actively engaging the learners and improving their motivation [1]. Games accelerate the acquisition of specialized knowledge of both elementary and intricate interconnections and actions in specialized fields. Educational games are used with most success in pre-school education, where most of the learning process is game-based. Games are also becoming a part of the curriculum of high school and university students in recent years [2, 3, 4]. In different studies, the game-based approach for adults is referred to as “gamification” [5] or “serious games” [6]. The term “serious games” is used to stress that these games are not meant to only entertain, but also achieve a certain educational result. The term “gamification” has entered the area of higher education as a description of the game-based approach used as a tool to increase student motivation and improve their engagement with the educational process [7].

As using games and simulations in the area of higher education is still in its early stages of development, experimental actions are necessary in order to achieve the desired improvement in all scientific fields. Gamification methods used in the course of Software engineering will be described in this report. Software engineering is a complex subject, the course is aiming to teach the students the different practices for creating software projects and solutions in both the practical and theoretical aspect. Software engineering is a wholesome systematic approach for analyzing, designing, creating, testing, documenting and supporting software projects by using different tools and methods for professional development and team management. The fast pace with which Software engineering has been evolving leads to the increasing necessity to teach students using the latest educational tools and keeping up with the newest trends in order to stay relevant to the business field. Fig. 1 presents a survey about the usability of the software project development practices in the industry [8]. The survey is conducted with developers in 2018. The results attest that the most widely used approaches are the agile methodologies: Agile, Scrum and Kanban. In the survey more than 58 981 participants have taken part.

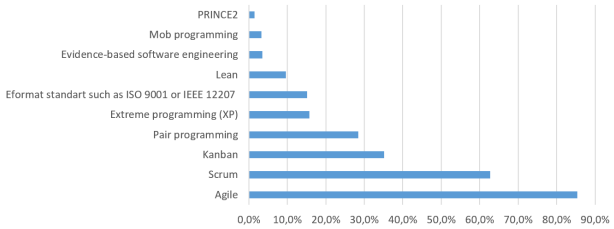

Figure 1. StackOverflow Developer Survey Results in 2018 about software methodologies

This paper will present a gamification method used in the learning process in the Software engineering course in the education of both Computer systems and technologies engineering students, and their peers from Telecommunications technologies bachelor degree courses in the University of Ruse. Some of newest and most relevant methodologies and technologies for designing different parts of a software project, as well as approaches for keeping track of and controlling the entire process - are being taught to the students. In the course workshops the learners go through the whole software process (Fig. 2) – from the problem to the end product, going through all the necessary stages - experiencing planning, how to deal with constraints on resources, teamwork communication and time management issues, all that has to be taken into account when designing and finishing a Software product.

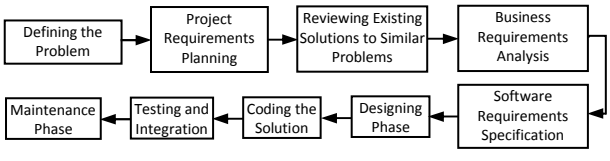

Figure 2. Software Engineering Process

The paper outlines the results based on the experience of applying gamification to the course. An approach for including games to teach software engineering methods and concepts is going to be described.

II. SOFTWARE ENGINEERING GAMES

A. *Collaborative Role Playing Game*

An experiment has been conducted with the participation of the students in the Software engineering course. It consists of using role playing as a game [9], where the students take on the roles of different positions taken by people in a normal software company. They have their own company and positions, each with its' different characteristics, which the students have to understand and apply.

Following the most modern trends in software engineering for using agile technologies [10], the students that are being taught in the course are given the task to create a software project. They are divided in groups of 5-6 people. Managing the project requires the creation of a special social construct – a project team, which has a temporary and strictly defined goal – to complete the project successfully. The teams have to create an imaginary company and define their budget for the project in the beginning of the semester, and the choices they have made are sealed with a virtual contract with a client.

Every member of the team has a main and secondary role. The roles in the software teams are as follows: Manager, Business Analyst, Programmer, Quality Assurance, Data Base Specialist, and Graphics Designer. The Manager is responsible for the overall control of the human resources and their tasks, with the goal being the successful delivery of the software product on time, based on the schedule, and its adherence to the clients' requirements. The Manager is necessary as all software projects need to comply with their budget and time constraints, which is an important aspect that has to be managed and understood.

The teams distribute their roles and responsibilities for the project by using a Gantt time chart. By using the Gantt chart the teams can visually present the time allocated for each task in the software project. The tasks are distributed horizontally – for each task there is one line, and each vertical line is a moment in time. Every task is a rectangle with a width proportional to the time it will take to complete it on the timetable. The plan details the tasks and activities that are needed for the completion of the work on the project; Mid-level expected results are defined; Control points are also defined – they are called milestones; A timetable with dates of beginning and completion for each task is designed; The time and resources necessary for the realization of the project are calculated; The resources – both human and material – are defined; The overall strategy for the quality management of the project is decided on; The personal responsibilities for each task is distributed to the members of the team, every person having tasks allocated on the chart. Fig. 3 presents a Gantt chart, created by a team of Erasmus exchange students, who were taught in the Software engineering course during their stay at the University of ruse in 2018.

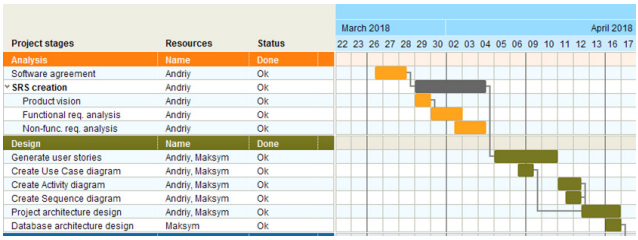

Figure 3. An example for Gantt Chart

The teams have to write all software requirements – including functional and non-functional ones – necessary for the successful project completion, with the guidance of Software Requirements Specification that they are given as an example. The Specification helps keep track of the main points that have to be completed for the project, introduces a shared vision of the completion of the project – for both the client and the company, as well as instructions on how to distribute each of the user roles as well as description of how each function of the software product should behave.

The teams are given the opportunity to play the role of Scrum or Kanban team. The agile methodologies are contemporary methods for creating, developing and supporting software products and services. Agile methodologies have the potential to meet the challenges in front of the modern software companies, functioning in an ever-changing and rapidly developing highly competitive scene [10]. In this business setting, the deciding factor between success and failure is managing time frames, quality assurance and pricing of the software products. These parts of the projects' lifetime are critical to the survival and evolution of a software company.

Scrum is an agile method for guiding the process of creating a software product [11], while giving the ability to react to different changes in the environment such as: product requirements, time for development, availability of resources and technologies; as all of these may be subject to change at the course of the project. Scrum allows higher levels of personal freedom to the teams and improves the flexibility of the whole process and its' ability to respond to change effectively. In scrum the teams have three main roles: product owner, team and scrum master. The team is self-governed and has a high level of independence and self-accountability. The Product owner is responsible for maximizing the profit gained for every investment. The owner achieves this by defining the product characteristics, thus creating a product catalogue, prioritizing each of the properties for the next sprint and constantly reevaluates and improves this catalogue. The Scrum master helps the product group with learning and applying the Scrum practices to the development process, and steers the team to success.

The teams which choose the Kanban agile methodology for process management [12], have the

opportunity to have a better view on the work process, as well as identification and vision on how tasks and process are handled on a Kanboard. Kanban's leading quality is transparency – the whole process is tracked, and each member of the team is given an equal amount of workload [13]. Kanban uses a visual control mechanism for tracking the work flow during the implementation of the different stages of realization. The Kanban methodology takes into account the number of started and unfinished tasks (WIP – work in progress tasks) and restricts starting more tasks until the previous ones have been completed, or until the next stage of development is nearing initiation. This approach allows the software developers to take tasks from a so-called "queue" with different sections - to do, backlog, planned, etc.; where all tasks are prioritized, categorized, described and the necessary restrictions have been placed.

Table I shows comparison between the Kanban and Scrum methodologies, which is given to the students to help them decide which methodology their teams would follow.

TABLE I. KANBAN VS SCRUM METHODOLOGIES

Scrum	Kanban
The time limited iterations are obligatory.	Time limitated iterations are optional.
The team promises to finish a work process in every iteration.	Work process finalization in every iteration is not obligatory.
Tempo is used as a metric for planning and improving the process.	Time for completion is used as a metric for planning and improving the process.
It is imperative that multifunctional teams are present.	Multifunctional teams are optional. Specialized teams are permitted.
Work needs to be separated in small parts in order to be finished within	There are no constraints on the size of tasks and their length.
It is necessary to use a chart for the remaining work (Burndown chart).	A work chart is not needed.
Indirectly limiting the incomplete tasks (for a sprint).	Directly limiting the incomplete tasks (during work flow).
Rating and prioritizing tasks is obligatory.	Rating and prioritizing tasks is not obligatory.
Three roles are mandatory - Product owner, Scrum master and team.	There are no mandatory roles.

After completing the specification, one of the first tasks for each team is to write user stories based on the specification. The list with user stories is a flexible method for managing the project requirements. User stories are short tasks, which define the specific goals for actors; which can be developed by the team in a short period of time - for example - in one sprint. For the creation and management of all user stories the students use the team management system – Jira.

Each team has access to Confluence and Jira (Fig. 4), deployed on a special cloud server for the university's needs. Confluence is used as a documentation version management tool, which helps keep track of the project's main priorities and requirements, while Jira is the team management tool for the work flow and tasks of the teams. Jira is used as a project management system; an especially useful component is the project board, which students use to augment learning Agile methodologies such as Scrum and Kanban, while also improving their task and time management skills. Both these applications are immensely useful in understanding the whole process of creating and managing a software project as a team and company.

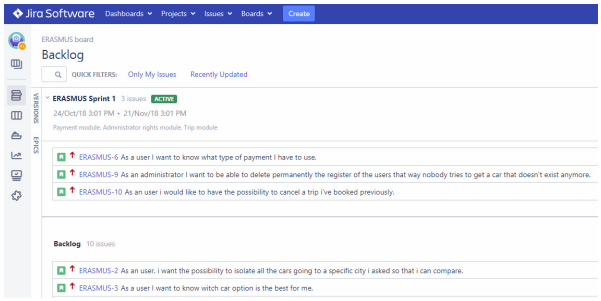

Figure 4. Jira Software used by students from the University of Ruse

B. Prioritization. Agile Estimating and Planning Poker Game

Software development teams can use different techniques for prioritizing the requirements of the project – organizing the tasks in level of importance is one of the most important responsibilities of the team. Even when projects start with stellar success, there comes a moment when a decision must be made on which requirements have to be completed, and which have to be postponed, in order for the product to be delivered according to the time schedule.

In the analysis of the requirements phase, every team decides the relevance and importance of each requirement by answering feasible questions. Time-space constraints have to be taken into account, resources, expenses and the possibilities for error must be well understood and calculated for. Another important major problem must always be planned for – clients frequently change their requirements even in an advanced stage of project development. Usually the clients have only an idea in the beginning, and the details are forged afterwards. This must be avoided, as it leads to incredible complications further down the development process. This is also known as the "metastasis of possibilities" – where the application features continuously grows to epic proportions.

One of the preferred methods which students use in the course is – MoSCoW [14]. This method is applicable to every software project, independent on the chosen control methodology. The "Moscow method" is a way to categorize requirements by importance, so as to decide which is actually important for the client, and which is not. The abbreviation MoSCoW means:

- Must have: requirements and functionalities, without which the main goal of the project would not be reached. They are the backbone of the system, the absolute minimum necessary for the project to have any meaning;

- Should have: features which are not critical to the products' core functionalities, but are incredibly important to the client;
- Could have: features which are useful to have in the application, but only if they do not require a large amount of work to be completed. They are the first ones that would be delayed when the project scope narrows due to incoming deadlines;
- Won't have: requirements which are absolutely out of the current scope of the project and do not enter the management plan. They are planned as future improvements or features to be added later in next versions of the product.

A mistake which students often make is to have all the project features and requirements marked as Must have, but this almost always results in a failed project.

Every task must be estimated before prioritization. The grading of the tasks is achieved by playing Poker Planning. Each of the teams starts the game and loads their user stories to be assessed. The grading is done through poker cards, where every card has a numeric value – weight. The team manager gives the team start game, and every member of the team has to personally estimate every user story, after which the game analyses all user grades and calculates the average result. Fig. 5 shows the online game (planitpoker.com), which is used by the students during class.

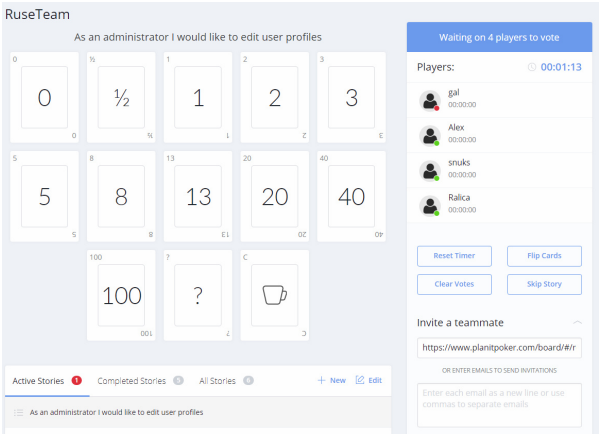

Figure 5. Poker Planning Game played by students during a lecture

Poker planning, also known as Scrum Poker [15], is a technique for rating efforts based on consensus. The members of the team judge user stories by playing with virtual numbered cards that other teammates cannot see. The results of the voting for each user story is revealed after everyone has finished choosing. Using such a game helps bypass the psychological effect anchoring bias, which occurs during voting by voice – as the risk of influencing each other's opinions beforehand is present. This effect can lead to incorrect grading and prioritizing tasks.

C. *Code Combat Game*

Various gamification techniques can also be applied during the code implementation phase. One example of a game geared towards teaching students to code is CodeCombat (Fig. 6). The system is, in its essence, a simple coding environment, disguised as a game. Its main objective is to teach students (mainly K-12) the basics of coding [16] in either one of two of the most popular programming languages – JavaScript and Python. Players get to control a variety of magical and/or hero characters through a multitude of levels, including mazes, obstacle avoidance and combat levels.

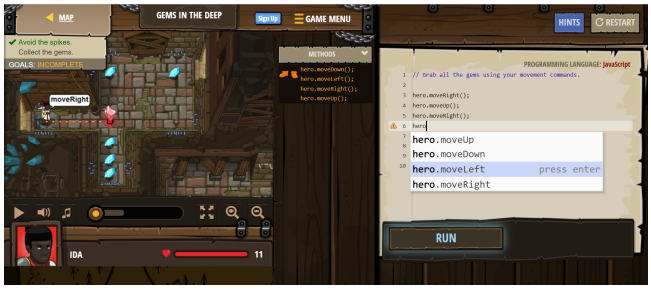

Figure 6. Code Combat Game played during a Software Engineering workshop

While this type of educational software might be intended for use with younger students, it can also be applied in higher education. It is especially interesting for computer engineering students who are less experienced with programming and coding.

The game has a dedicated classroom mode, which allows educators to track the whole class' overall progress, as well as generate reports and statistics on how the class or a particular student is doing (Fig. 7).

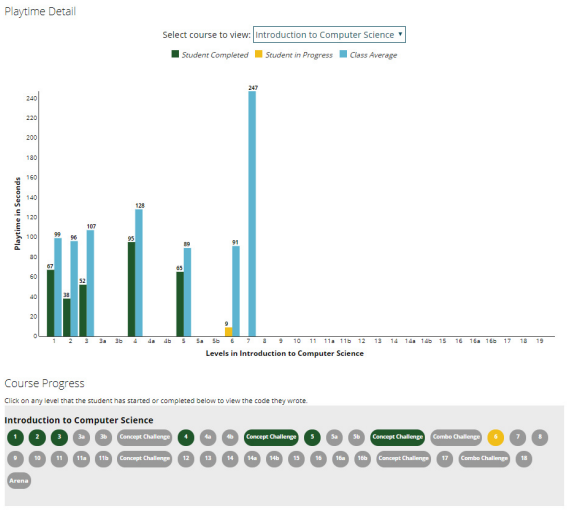

Figure 7. CodeCombat Playtime and Progress Stats

D. *Alphabet Brainstorming*

Alphabet Brainstorming [17] is a game which helps students generate connections between ideas and key words beginning with the letters from the alphabet. The game session was conducted with the students during the software engineering course, where they had to generate

as many words with key terms from the course lecture materials. Every student was given a sheet of paper with 30 letters from the Bulgarian alphabet. The goal was to determine at least one term with every letter of the alphabet. At the end of the game the generated terms for every letter were presented for discussion to all the students. Fig. 8 shows the overall student results from 2018. The results have been summarized and the most used key terms from the course have been picked out in the brainstorming game. An analysis on the student activity shows that 79% of the learners have succeeded in generating terms for more than 20 letters of the alphabet. The generated terms can be used as a reference to be included in the lecture material among more key words, which are usually put at the beginning of each lecture.

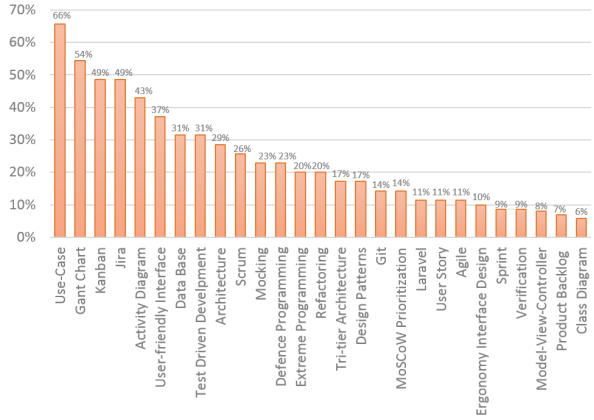

Figure 8. The terms used by students in the game Alphabet Brainstorming, from most to least

The educational goal achieved by using this type of game is improving knowledge acquisition skills in the learners, helping them synthesize connections between terminology and key words, and understanding them. The game is a great approach for reviewing the students' knowledge on the subject at the end of the semester.

E. *Kahoot Game*

The game Kahoot is an innovative method for actively engaging the students during class [18]. It can be used as a quiz game with a prize, for subject discussion or research on a topic from the lecture material. In the Software engineering course, Kahoot was used as a quiz game at the end of the semester during a lecture. The idea was to find out excellent students who had paid attention in class and quickly revise the course material. For the game there were 15 questions presented, which the students could view on their mobile devices using a generated code and logging in on the game's website. The game was received exceptionally well, as more than 90% of the attending students played the game and answered the questions in the allocated time frame. A competition formed about giving the most correct answer in the shortest time. After every question, the interactive board in the lecture room visualized the results in a player rank ladder with the students' points. At the end of the game there were three winners who received a golden, a silver and a bronze medal corresponding to their results.

On Fig. 9 the process for the creation of the quiz using kahoot.com website is shown.

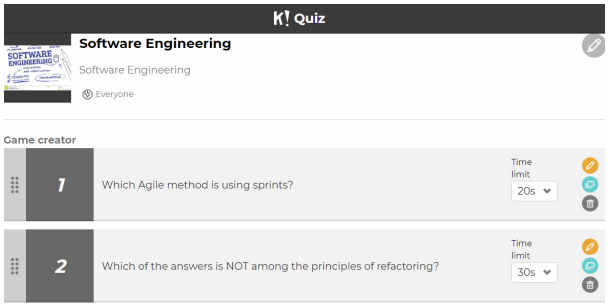

Figure 9. Kahoot Game Creator for Software Engineering

F. *The Millionaire Game*

The Millionaire game (Software Engineering Edition) was also used to review the course material at the end of the semester. Questions with different degree of difficulty were formed, and six difficulty levels were created. The students could also use jokers for help: having help from the audience (who were voting for the answer by lifting their hands); and call a friend. For the second joker, the students actually chose to call the assistant professor from the course, who was their workshop teacher. On Fig. 10 a question from the game is shown. It is about the Cumulative Flow Diagram, used in Kanban for tracking team progress and keeping information about tasks: Work in Progress (WIP), Cycle Time and Throughput.

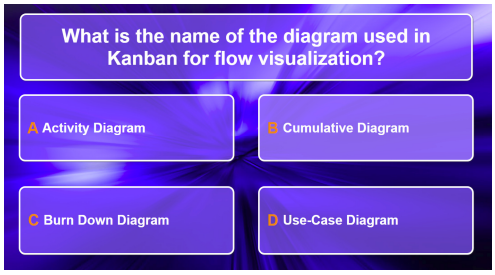

Figure 10. The Millionaire Game (Software Engineering Edition)

G. *Students Survey*

In 2018 a survey was held for full-time and part-time students' opinion on the software engineering course. The survey was done by 78 students who had finished the course. Fig.11 shows the results from the question where students had to evaluate the different games used in the course. The results on Fig. 11 show that the most interesting game for the students was the Brainstorming game, which had 65.5% of the participants voting for it. The role playing game was evaluated as interesting by 62.1% of the students, and in third place the survey ranks the Millionaire Game with 58,6%.

Results from the study show that all the students who have taken the survey approve the use of games in the learning process for the course. 79.3% of the respondents chose the highest option in the Likert Scale question "How would you rate the use of games in the Software engineering course?". The other 20.7% all selected the second best answer.

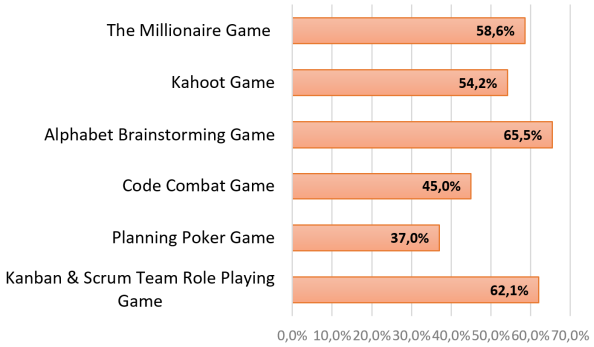

Figure 11. Survey Results - Software Engineering Games Evaluation

During the study, students have revealed that their interest and motivation to learn for the course has improved considerably after participating in the gaming activities. Notable are the answers to the question of whether the results achieved by the students themselves were above what they expected, and 44.8% of the learners attest that they have accomplished more in the course than they expected to achieve. The other 39.5% answered that they are satisfied (Fig. 12).

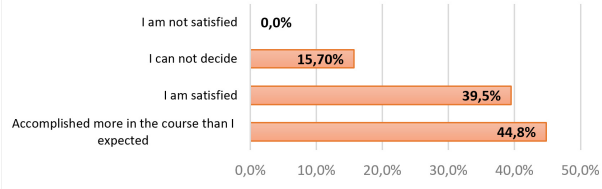

Figure 12. Survey Results

III. CONCLUSION

Software engineering is a mandatory subject included in the curriculum of computer engineers which aims to give them knowledge on complex matters which will be necessary for them for their future work in any software company. The course has only 60 hours of workload – 30 lecture hours and 30 workshop hours, which are not even close enough for the entire theoretical and practical material to be taught. The team that developed the study materials decided to use gamification as an innovative teaching approach for engaging student attention and heightening motivation for the learning process, with the goal of improving the students' ability to absorb and understand knowledge faster and more efficiently.

The educational games used in the course help demonstrate the use of software methodologies in a fun and efficient way. The results from the experiment show the positive approach students take to using gamification. The used gaming strategy in the learning process shows that this method is effective as it is being used for the third year. In the survey from 2018 a majority of the students showed that they approve of games as a viable strategy to improve learning, and prefer studying while playing.

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Enhancing Communication Competences through Mathematics in Engineering Curriculum

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Abstract **- This paper is focused on the development of soft skills within the process of learning mathematics in engineers' curriculum. The question: "What skills does the university mathematics develop?" has some straightforward answers: problem solving, analytical thinking, quantitative reasoning, ability to manipulate precise concepts and complex ideas, critical thinking, construct logical chains and detect false argumentation. During their studies in mathematics courses, future engineers acquire also other competences such as: communication skills, creative thinking, team working, ability to deal with other people, decision making, problem solving, personal character traits, etc. An important aspect of completing a degree is the development of communication competences and skills. Indeed, any future career and life in general (in family, community, society, public) requires the ability to communicate properly and mathematics courses provide tools for improvement of this ability. The authors conducted a survey among broad group of people involved in engineering education. The results from the questionnaires are analyzed and presented in this paper. Conclusions are drawn and additionally, some topics are proposed for discussion.**

Keywords – mathematics, engineering education, soft skills, communication competences

I. INTRODUCTION

This paper looks into the challenges that the stakeholders in engineering education face in modern world. The increasing complexity of technical systems, the production globalization and diversification, the fast-changing social environment, the need for protection of resources and nature are part of the causes for dissonance between the requirements of modern times and the conservative in its nature education. The position paper "Developing Graduate Engineering Skills", 2016, of the European Society for Engineering Education points out that:

"Engineering graduates will have to professionally cope with social changes, with new technologies as well as more and more complex problems that need to be solved - all within a global and commercial context. Hence, there is a need for a more complete description of the abilities that graduating engineers should have, and these must include methodological, personal and social competence areas as well as professional skills of conceiving, designing, implementing and operating engineering solutions." [1]

These new requirements motivate the International Society for Engineering Education (IGIP) to outline important directions in the development of engineering education: improvement the teaching methodology for technical subjects; development of practically oriented programs that meet the needs of students and employers; integration of humanitarian aspects in engineering education; understanding of the importance of the additional competences by students and lecturers (such as communication skills, teamwork, ethical and intercultural competencies).

Traditionally, mathematics courses are major building blocks in the engineering curriculum. It is indisputable how mathematics develops hard skills, but could it improve soft skills and how this could be done, has never been discussed in Bulgarian technical universities up to now (in the authors' knowledge).

Thus, the main tasks of this research are:

(1) to explore the attitudes about the necessary competences of different participants in the educational process in Burgas region;

(2) to identify the important competences and skills that mathematics can improve;

(3) to propose methodology for improving communication skills by learning mathematics.

II. COMPETENCES AND SOFT SKILLS

There are different ways to approach and classify the additional skills and competences needed in 21st century both in work environment and in personal life.

One point of view is the *competence* paradigm. *Competence* is the way a person uses all his personal resources (skills, attitudes, knowledge and experience) to solve properly a problem in a certain context. Competences can be classified in three groups: key competences, basic and functional competences. The EU key competences are literacy competence; multilingual competence; mathematical competence and competence in science, technology and engineering; digital competence; personal, social and learning to learn competence; citizenship competence; entrepreneurship competence; cultural awareness and expression competence [2]. According to the report "New Vision for Education Unlocking the Potential of Technology" of the World Economic Forum in 2015 [3], there are 16 skills grouped in 3 categories (foundational

literacies, competences and character qualities) that are going to be in the focus of educators the next decade. Claire Cain Miller claims in 2015 that "Math and Science are not Enough" and "The jobs that have grown most consistently in the last two decades have been those that require high math skills and high social skills" [4], [5].

Another approach is the *soft skills* paradigm. For the purposes of this study, soft skills are considered to be the following:

(1) communication skills;

(2) creative thinking;

(3) critical thinking;

(4) innovative thinking;

(5) work in a team/team working;

(6) ability to deal with other people;

(7) decision making;

(8) problem solving;

(9) personal character traits;

(10) common sense.

Communication is at the core of every skill from 2 to 9. For example, no matter how developed is the decision-making skill, if one cannot properly communicate the decision to others, they will have difficulties to follow it. Effective communication is also very important at work as few jobs are self-sufficient. Wrong communication leads to mistakes, failures and conflicts. Effective and honest communication builds teams and increases the loyalty of the employees. Vague and imprecise communication is harmful and could be even dangerous, e.g. improper instructions. [6], [7]

Generally, there are three types of communication: verbal, nonverbal and written [8], [9]. These types come out in several forms - intrapersonal, interpersonal, computer mediated, interviewing, small group communication; public speaking; mass communication [10].

In the next section, the change in attitudes about the necessary competences in Burgas region is presented.

III. CHANGES IN ATTITUDES ABOUT THE REQUIRED PROFESSIONAL SKILLS

A. *Employers' attitudes about required knowledge and skills in 2014*

A survey about the opinions of employers' on the knowledge and skills of the job applicants who graduated from Burgas Free University was conducted in different industry sectors, local government and state institutions in 2014 [11]. The research showed that the most important skills that employers expect are: personal and time management skills, motivation for development, mathematical literacy, data analysis skills. The analysis of the differences between the importance and evaluation of indicators showed significant discrepancies between knowledge and skills sought by employers and their real level in job candidates.

One of the aspects of the 2014 survey was to measure the attitudes towards the required *Knowledge and Skills*. The following indicators were included in the assessment of their significance: communication and interpersonal skills, cognitive skills, motivation and mastery, data and IT skills, time management, ethics, experience, personal qualities. The results showed that the most important indicator in *Communication and Interpersonal Skills* was "fluency in a foreign language" followed by verbal communication skills, teamwork skills, respect for others and written communication skills.

This research has raised a number of questions and has become a base for:

1) updating curricula and programs in Burgas Free University;

2) incorporating new teaching methods in some displaces.

B. *Goals and methodology of the 2019 survey*

In 2019, a survey, focused on the attitudes and needs of employers, as well as the attitudes of lecturers and learners in engineering, has been conducted. The survey aims at identifying the key competences and skills that mathematics can develop and improve. The authors believe that an important aspect of completing a scientific degree is the development of ability of efficient communication.

The research methodology is based on a survey method. Three questionnaires have been developed: the first one for the opinion of lecturers, involved in engineering education; the second one - for students and the third - for employers in different engineering companies.

The following strategy for selection of representatives from the main target groups is applied:

- sending invitations for participation in the survey to university mathematics lecturers in engineering faculties;
- conducting meetings with teachers in secondary vocational education in the field of technical sciences where the survey goals were explained and the questionnaires were filled out (one side effect from these meetings was the establishment of connections with school teachers);
- sending invitations to participate in the survey to students who are studying in undergraduate and graduate engineering programs in Burgas Free University and school students in secondary vocational schools with engineering programs;
- establishing contacts with employers and sending invitations for participation in the survey.

The survey was sent to 500 respondents; employers, university lecturers, mathematics teachers in secondary schools, university students and school students. The survey was completed by 437. Therefore, the responding rate is 87.5%. The number of employers that completed the survey is 127, the number of lecturers and teachers (in a proportion approximately 4:1) – 42 and the number of university and school students (in a proportion 3:1) – 268.

The first group of questions in the questionnaire is focused on identifying the opinions of the participants (students, lecturers and employers) on the importance of 15 skills for a successful future career: professionalism, teamwork and collaboration, oral communication, critical thinking, problem solving skills, writing skills, ethics, foreign language fluency, social responsibility, leadership, creativity/innovation, using IT, lifelong learning, self-development, workplace ethics. The questions are with a multiple choice and the respondents are asked to evaluate the significance of the above skills for a successful career within a five-point (1÷5) scale: 1 - insignificant; 2 - rather insignificant than significant; 3 - neither insignificant nor significant; 4 - significant; 5 - highly significant.

The second group of questions in the questionnaire aims at identifying the skills that can be formed, developed and improved in the mathematics educational process. The respondents in the survey are asked to express an opinion on the possibility of improving the following 9 skills: active listening, focused attention, logical reasoning, perception and processing of graphical and technical information, writing skills, presentation skills, precise and accurate expressing, debating. The questions are with a multiple choice and the respondents are asked to point out the degree to which they agree with the corresponding statement within a five-point (1÷5) scale: 1 – disagree, 2- rather disagree, 3 - neither agree, nor disagree, 4 - rather agree, 5- completely agree.

C. Resuts and conclusions from the 2019 survey

The answers to the questions from the first part of the survey (15 skills for successful future career) show that the most important for employers are the skills: professionalism, oral communication, lifelong learning, self-improvement and labor ethics. Lecturers, who teach mathematics to future engineers, add four more skills: critical thinking, problem solving, teamwork and collaboration, writing skills and social responsibility. More than 60% of the students' respondents focus their attention on developing skills for problem solving, oral communication and professionalism.

Overall, the most valued skill in the three groups of respondents is the strong motivation for self-improvement. Indeed, approximately 67% of the employers point self – improvement as highly significant, 80% of the lecturers and teachers share the same opinion and optimistically for us 71% of the students value self-improvement as very important. The second most important skill for the three groups of respondents is the high level of professionalism – 78% of the employers, 61% of the lecturers and 64% of the students find it highly significant. Oral communication, workplace ethics and life-long learning follow up.

As the current study is focused on attitudes about communication skills, there are 6 out of all 15 questions that are directly linked to it: oral communication, critical thinking, problem solving, teamwork and collaboration, writing skills, using IT. The numerical results for two of these issues in percentages are presented on Table 1 and visualized (along with the results from the other four questions) on Fig. 1.

TABLE I. RESULTS ABOUT SIGNIFICANCE OF TWO OUT OT 15 SKILLS IN PERCENTAGES

Rank	Oral communication		
	Students	***Lecturers***	***Employers***
1	0.00%	0.00%	0.00%
2	3.39%	3.45%	0.00%
3	16.95%	6.90%	11.24%
4	20.34%	31.03%	33.20%
5	59.32%	58.62%	55.56%

Rank	Critical thinking		
	Students	***Lecturers***	***Employers***
1	5.08%	0.00%	0.00%
2	5.08%	6.90%	21.20%
3	11.86%	13.79%	33.35%
4	35.59%	24.14%	34.43%
5	42.39%	55.17%	11.02%

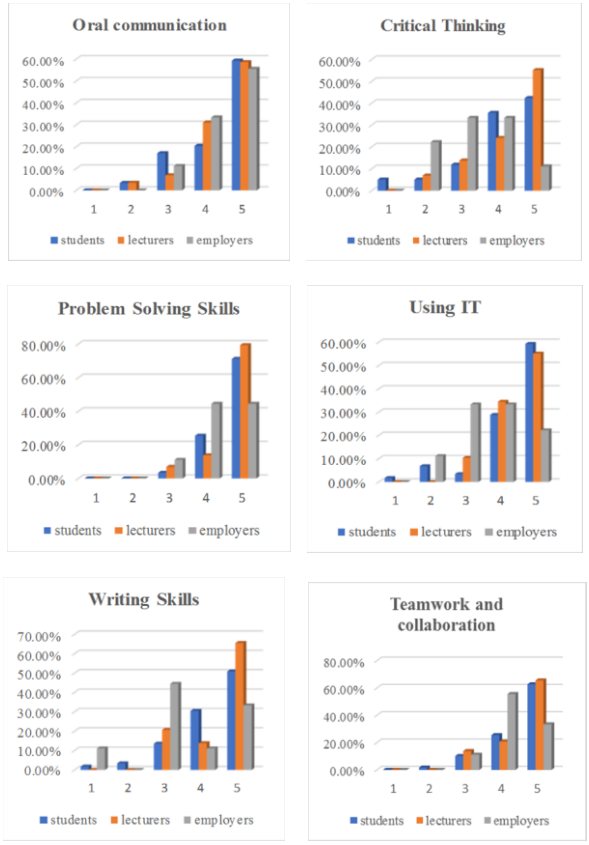

Figure 1. Rankings of 6 out of 15 skills according to their importance for a successful career
scale: from 1 = insignificant to 5 = highly significant

The analysis of the results leads to the following conclusions:

- the development of oral communication skills and problem-solving skills is very important for the three groups of the respondents;
- while the lecturers and students note that writing skills, critical thinking and IT skills are very important for the future realization, the employers express a neutral attitude on this issue;
- the ability to work in a team is not of primary importance for employers (which is an unexpected result), while the efforts of lecturers and students are focused on its development.

The poll results show differences in opinion among respondents (employers, lecturers and students) about the potential for developing the soft skills through mathematical training (Fig. 2).

While lecturers and students believe that learning mathematics supports the development of *written communication*, employers take a neutral position on this point. There is no clearly defined opinion among the employers on the development of precise and accurate expressing through mathematical training - around 34% of the employers respondents neither agree, nor disagree with the statement "Mathematics training can support the development of *precise and accurate expressing*", and almost the same percentage completely agree with it. In contrast, 66% of the lecturers completely agree with this statement and the same answer gets also the highest percentage from the students. The results about *active listening* are similar: the respondents have two answers: *neither agree nor disagree* and *rather agree* with almost the same percentage (about 45%). With over 53% both lecturers and students give the answer *completely agree* on this question. A significant percentage of disagreement - a total of 44.25%, is expressed by employers for the development of *presentation skills* through mathematical training.

Among employers, an important fact can be identified: their opinion is clearly stated - math education forms focused attention, perception and processing of graphical and technical information, ability to use facts and logical reasoning, to form opinion and skills for conducting an arguable dispute. More than 60% of lecturers express their belief that math education is focused not only on building mathematical skills but also on developing soft skills. They give the highest percentage to active listening and focused attention. The results show that students expect to develop their skills during their math studies, which will be necessary for successful implementation on the labor market, including skills such as active listening, written and presentation skills. Although the three groups prioritize different communication skills that can be improved mathematical courses, they show a positive attitude to the statement that mathematics courses provide tools for enhancing the competence of future engineers in various forms of communication. The employers and the students, as consumers of the educational product, outline and emphasize where the future efforts have to be directed.

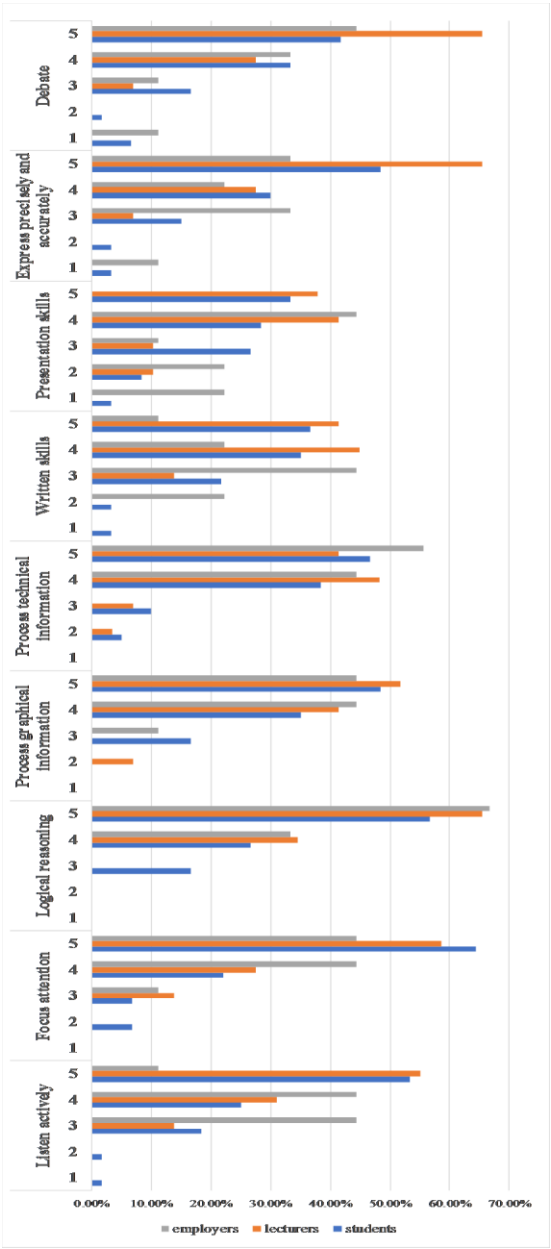

Figure 2. Degree of agreement with the following statements "While studying Mathematics I learn to …"
scale: from 1 = disagree to 5 = completely agree

After comparing the results in 2014 and 2019, several changes are noticed. While 5 years ago the employers rank as most important team working, then respect to others, written communication, verbal communication and foreign language fluency, in 2019 the same group of respondents rank the required skills as follows: logical reasoning, processing technical information, processing graphical information, debating, focused attention.

Both authors of this paper are experienced lecturers in mathematics. Over the years our efforts have been focused on various approaches and methodological tools for improvement of students' ability to think critically, communicate effectively and solve scientific problems. The last year, new approaches for improving the communication skills have been sought and some of them are introduced in the following section.

IV. APPROACHES FOR SOFT SKILLS IMPROVEMENT IN MATHEMATICS COURSES AT BURGAS FREE UNIVERSITY

In the Faculty of Computer Science and Engineering of Burgas Free University, there are 4 bachelor engineering programs: *Computer Systems and Technologies*, *Communications and Electronization for Renewable Energy Sources*, *System Engineering in Industry and Tourism* and *Electric Energy Distribution and Electrical Equipment* with 4 major mathematics courses: ***Linear Algebra and Analytical Geometry, Calculus 1, Calculus 2*** **and** ***Coding Theory.*** The basic model of teaching mathematics courses is focused on three main aspects: acquiring mathematical knowledge, learning the logical processes of mathematical reasoning and soft skills with undeniable accent on developing skills as critical thinking and problem solving. Encouraging students to talk, participate in debates, listen, read, write and reflect on math problems and problem solving develops their own thinking as well as their communication skills.

While *lecturing*, we insist on strict mathematical concepts, notions and theorems but additionally provoke discussions on different interesting topics: infinity, infinitely small variables, vector variables, etc. These discussions directly involve students in verbal communication face to face, argumentation, using precise definitions, teaches them to basic rules for listening, speaking and behaving in interpersonal communication.

In *seminars*, halve of the time the students are divided into small groups of 3-4 and work on specific tasks together. They are expected to debate within the group, find solutions and the present it on the white board in front of the seminar group. The skills that we are working on are: verbal communication in front of an audience, to be able to speak clearly and correctly, to listen actively and stay focused on to the content, to be able to formulate clear conclusions and find solutions. The presentations during seminars are an opportunity for students to demonstrate deeper understanding on a specific topic. Carefully prepared presentation and systematized feedback enables students to gain experience and enrich their communication skills. The presentations develop multiple skills: search for information, assess the relevance of this information, systematize and analyze information, behave properly and speak in public, choose the right language and have confidence. The coursework defense and working on projects during the semester contributes mainly to the improvement of the ability to discuss, reason and draw conclusions but also to other communication skills as: emotional sustainability, self-expression, self-esteem and dealing with insecurity and lack of self-confidence. Very often, the students work on team projects in disciplines such as Calculus and Coding theory and present their work through presentations. Solving mathematical problems in seminars, as well as task assignments, contributes not only to the formation of knowledge, skills and specific mathematical skills but also to the development of oral and written communication using clear and precise language of mathematics. Furthermore, students develop ability for a task content analysis, analyzing information, building logical reasoned and clear conclusions.

Our students have *additional assignments* - writing essays, mathematical problems for homework and self-training in software environments. The skills that we believe are developed with these activities are: written communication – to follow written instructions and basic rules and requirements for the layout of different types of documents, to write reports on specific topics, to properly use written language, to follow the stylistic and grammatical rules in writing, to clearly, accurately and unequivocally express their ideas in written form; to be able to formulate clear messages, to read carefully and to understand the content of the written information. In order to motivate students to study mathematical subjects, in the last five years they are given essays on the applications of a different mathematical topic in the engineering sciences. The students receive clear methodological instructions and technical requirements for the written work. As a result, the lecturers had the opportunity to find out that the first-year students experience difficulties to understand what is expected and how to present their work. Approximately 60% of them present work that does not meet the topic and/or does not meet the requirements, while this percentage for the students in the second or third year is 10-15%. This is a clear indication that students need support for improving their skills for expressing themselves well in writing.

During their education, the students of Burgas Free University may use *web-based courses* for assisted training. These courses are a prerequisite for stimulating communication and improving their communication style: briefness and accuracy; short and meaningful statements; specific and precise questions. Through the individual assignments in the web-based courses, they develop their ability to work with ICT as well as create tables, charts and presentations. What is more, participation in chat groups develops real-time discussion skills on specific issues, skills to work in small groups, builds confidence in online communication.

The *final exams* in mathematics are held in two parts - written and oral. The written part consists of problem solving and/or a test with open and/or closed multiple choice questions. Examination procedures are a form of learning and thus during the written part of the exam the students develop their skills for time management, writing short and specific answers, formulating clear and correct answers. Oral examinations help them acquire skills for active listening, for argued answers and the development of their speaking style.

In the mathematics course, first-year students are introduced to one *interactive method - Mind maps*, which are applied in knowledge systematizing and generalizing. Applied in mathematics courses, Mind map is a method that provides tools for constructive communication among the subjects in the learning process, assists the process of presenting concepts, theories and ideas, points out the logical connections and relationships. This method can be applied to: take notes, generate ideas, formulate and solve tasks and problems, create an action plan, co-operation, creative expression, team building, preparation of a presentation, report or speech, project management, event organization, etc. (Fig. 3)

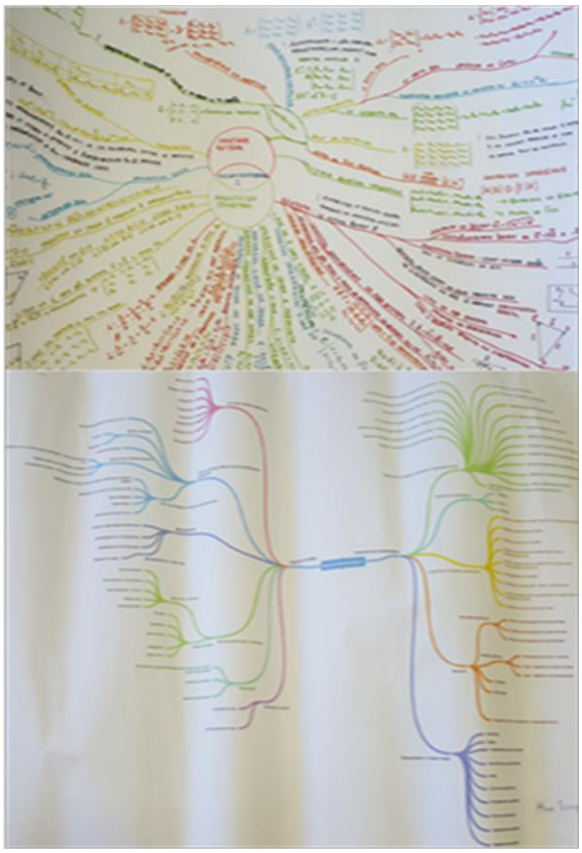

Fig. 3. Two Mind maps: hand-made and software-made

V. CONCLUSION

Burgas Free University periodically conducts surveys among employers to monitor changes in their attitudes and expectations. In this paper, the results from two such surveys -2014 and 2019 are compared. The results of the first survey, conducted among employers, represent their opinions on the needed knowledge and skills of job applicants. The results of the second one, conducted among employers, lecturers and students in engineering, identify the opinions about the key competences and skills that mathematics can develop and improve.

In response to modern requirements, in each of the disciplines, which are laid down in the curricula of engineering specialties at universities, it is necessary to use different methods and forms to support the development of soft skills. The authors, as experienced mathematics lecturers, have found successful approaches to support the development of some communication skills of their students, such as oral communication, written communication and communication through ICT in their courses.

In the context of increasing competition in the labor market and the background of constantly growing demands on engineers, the growing ultra-modern intelligent technology the professionals must adapt and continuously develop new knowledge and skills. New market conditions require flexibility and a rapid transition to new technologies and machines as well as very good communication and team skills. Therefore, the university lecturers have to rethink the objectives of their curriculum and to assist in the process of building the necessary soft skills in students. This motivates the authors of this research to explore the attitudes and opinions of students, teachers and employers on these issues. Being professors in mathematics, the question which soft skills and to what extent they can be built in the process of learning mathematical disciplines is of particular interest to us. The goal of the study is to start a discussion whether studying mathematics could support the development of communication skills: active listening, verbal communication, written communication, public speaking communication. Another point for discussion is: is there a place in mathematics classes for debates, discussions, group work, presentations, writing emails.

Future development of this study is systematizing experience and good practice of university lecturers, develop methods for assessing the communication and then implicitly include improvement of students' communication and other soft skills as objective in mathematics university course.

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Computer-based methods for assessing information security competencies

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***Abstract* - With the growing importance of information security and cybersecurity, there is a widely recognized need for more security experts and a higher level of security education among all members of society. Effective methods for assessing information security competencies are a necessary prerequisite for developing, evaluating and improving security education. The goal of this paper is to provide groundwork for developing assessment methods of information security competencies that are both effective and feasible for use in formal education. To accomplish this, a list of requirements is proposed, and existing assessment methods are surveyed through the lens of these requirements.**

Keywords - computer based assessment; security education; security competencies; security competitons; automatic assessment; automatic problem generation

I. INTRODUCTION

With the growing importance of information security and cybersecurity, there is a widely recognized need for more security experts [1]–[3] and a higher level of security education among all members of society [3]–[5]. For example, regarding experts, there is a need for more penetration testers, malware analysts and incident responders, while for the general population, there is a need for better understanding of how to communicate securely, how to protect oneself against identity theft, how to create strong passwords or how to protect oneself against *phishing*.

Effective methods for assessing competencies are necessary for developing, evaluating and improving education in general. The same holds true for information security education. And even outside of education, effective methods for assessing information security competencies are useful for evaluating job candidates, developing challenges in security competitions [6], [7], researching connections between information security competencies and other factors, e.g. correlating assessment results with technology that assessees use during assessment [8] and generating research datasets (e.g. network traffic of cyberattacks) by collecting data during assessment [5], [9], [10]. The goal of this paper is therefore to provide groundwork for developing assessment methods of information security competencies that are both *effective* and *feasible for use in formal education*. To accomplish this, a list of requirements is proposed in section II., existing assessment methods are surveyed through the lens of these requirements in section III. and a conclusion is given in section IV.

II. PROPOSED REQUIREMENTS

As noted in the introduction, the focus of this paper is providing groundwork for assessment methods that are both *effective* and *feasible for use in formal education*. Naturally, an assessment method must be effective, i.e. it must provide valid and relevant measurement results if it is to be used as foundation for developing and improving education. In addition to that, to be feasible for use in formal education, the assessment must enable a small number of teachers to assess a relatively large number of students without significant resource investment. Based on these goals, the following specific requirements were identified as being key.

A. Providing an authentic assessment environment

An effective assessment method must be valid. Validity refers to the degree to which evidence and theory support the interpretations of test scores for proposed uses of tests [11]. To validly assess information security competencies that are useful in the profession, measuring only declarative knowledge is inadequate. Instead, it is necessary to measure how an assessee *acts* in a real-world scenario, e.g. when a malware sample needs to be analyzed or when one's e-mail communication needs to be secured. Supporting this point, in [12], the authors say that in cybersecurity, "the only meaningful assessment in the profession is the success or failure of attacks".

To assess how an assessee acts, methods such as written or oral exams are inadequate, because with such methods, the assessee must *explain* what he would do in a certain situation instead of actually *doing* it. On the other hand, some computer-based assessment methods, such as various simulations and virtual environments, can place the assessee in an authentic environment where he can directly react to a simulated situation. Such computer-based methods can *directly* measure how an assessee performs a task that corresponds to a set of competencies, and therefore, they have the potential to be a highly valid form of assessment. This is in line with the concepts of ecological validity and representative design [13].

B. Gathering data and mapping them into precise assessment results

An effective assessment method must also be sufficiently precise, i.e. it should provide results at a needed level of granularity. In this context, this means that the assessment results should differentiate between levels of competency. For example, in the context of malware analysis, assessment results should specify how good an assessee was at analyzing a malware sample (how fast was the analysis finished, which indicators of compromise were gathered...), instead of just indicating whether he succeeded or failed at the analysis.

C. Scalable scoring

When considering how feasible a certain assessment method is for use in formal education, an important factor is scalability. In this context, this means that an assessment method should be able to handle a sufficiently large number of students year after year without requiring a proportionally large allocation of resources. For example, while oral examination might be effective as an assessment method, it requires a teacher to invest a significant amount of time per student. In a situation where a few teachers are holding a course for over a hundred students, such an approach may not be feasible. In this context, scalability can be divided into two requirements: scalable scoring and scalable construction of assessment problems.

The necessity of scalable scoring is evident – manually monitoring and scoring students' work is often tedious and requires significant amounts of time per each student. Therefore, an assessment method should provide a scalable way of measuring an assessee's actions and turning them into final assessment results.

D. Scalable construction of assessment problems

Using the same assessment problems for assessing multiple students, especially when these problems are reused year after year, is prone to cheating, since students can share the solutions amongst themselves [14]. The same holds true outside of formal education, e.g. in information security competitions [15]. In addition, if problems are not changing over the time and become publicly known, students could focus on learning to solve specific instances of problems, without understanding their broader context. Just as manually scoring students' work is not scalable, having the teachers manually construct variations of assessment problems is not a scalable approach either. An assessment method should provide a scalable way of constructing a unique assessment problem for each student, in such a way that all constructed problems are equivalent when used for assessment, while at the same time being sufficiently varied. The problems should be varied enough to make cheating by sharing information between students (either by outright sharing answers or by sharing procedures for solving a problem) impractical. This approach has an added benefit – a scalable way to construct problems with aforementioned characteristics can be used to provide practice problems, i.e. a series of problems that are varied, yet assess the same competencies [14], [15].

E. Providing a motivating assessment process

One factor that can negatively impact the validity of an assessment is an assessee's lack of motivation. For example, the organizers of Build-it, Break-it, Fix-it (BiBiFi), a secure development contest, found that a large percentage of teams opted not to participate in one phase of the contest, seemingly due to insufficient incentives [8]. From one perspective, it might be desirable to have assessment results affected by an assessee's motivation, i.e. an assessee that lacks motivation should be assessed as having a lower level of competencies. However, it is unknown how this lack of motivation during assessment translates to a lack of motivation in the field. That is why developing an assessment method that is motivating for an assessee and then, if needed, assessing motivation separately, seems like a superior approach.

III. SURVEY OF EXISTING ASSESSMENT METHODS

In the previous chapter, the following requirements are proposed:

a) the assessment method should place the assessee in an authentic environment where he can directly react to a simulated situation; assessment results can then be formed by measuring the assessee's actions inside this environment

b) the assessment results should be sufficiently precise, i.e. they should differentiate between levels of competence

c) the assessment method should make scalable scoring possible, i.e. it should provide a scalable way of measuring an assessee's actions and producing final assessment results

d) the assessment method should provide a scalable way of constructing variations of assessment problems; the constructed problems should be equivalent when used for assessment, while being sufficiently varied

e) the assessment process should be motivating to the assessee, with the goal of avoiding a situation where an assessee's lack of motivation negatively impacts the validity of assessment results

There are existing assessment methods of information security competencies that fulfill some of the aforementioned requirements. Some of these assessment methods appear in the context of formal education, but many appear outside of it, e.g. in the context of security competitions. This section will provide a survey of existing methods for assessing information security competencies through the lens of the proposed requirements.

A. Providing an authentic assessment environment

One established form of assessing competencies in the information security domain are Capture-the-Flag, or CTF, competitions [6], [16]–[23]. CTF competitions usually take the form of attack/defense-style CTFs or Jeopardy-style CTFs [20]–[22]. In attack/defense-style CTFs, a team of participants defend a host running vulnerable services while simultaneously attacking other

teams' hosts running the same services, while in Jeopardy-style CTFs, participants solve standalone challenges from a range of categories, such as reverse engineering, forensics and web security [20]. The challenges in CTF competitions are extremely diverse, yet they usually provide an authentic environment in which the participants try to achieve a certain goal. A web security challenge will often provide an authentic web site that participants directly interact with, trying to find and exploit vulnerabilities. On the other hand, a computer forensics challenge will usually provide one or more files that participants directly investigate, analyzing them and looking for clues.

While CTF competitions commonly take the form of aforementioned attack/defense-style CTFs or Jeopardy-style CTFs, there are CTFs that significantly differ from these formats. One good example is iCTF, an annual CTF competition that regularly introduces new competition formats [5], [10], [18], [24], for example a competition centered around building and operating a botnet [5] or even laundering money as part of cyber-criminal operations [10]. Another innovative competition format is the Social Engineering CTF (SECTF), annually held at DEF CON and DerbyCon conferences, in which participants gather confidential information about companies with techniques ranging from Open Source Intelligence (OSINT) to phone calls with a deceptive pretext (e.g. by presenting themselves as internal IT staff) [25].

The challenges in CTF competitions will sometimes be connected and provided within the context of a realistic story which helps construct an authentic assessment environment. For example, that was the case with PicoCTF 2013. [6], Hack the Vote CTF 2016. [26] and iCTF 2010. [5].

Outside of CTFs, there are other forms of information security competitions, such as the Cyber-Defense Exercise (CDX) [27] and the Collegiate Cyber Defense Competition (CCDC) [28]. While they are formally not labeled as CTFs, in this context, they do not significantly differ from the given description of CTF competitions.

Over the years, various frameworks for hosting CTF competitions have been published [29], often as free and open source projects, for example the CTFd [22], PicoCTF [15], iCTF [24] and SecGen [29] frameworks. While most of them were primarily designed for hosting competitions, such frameworks also provide an easy way to set up an authentic environment for assessing certain information security competencies.

Outside of security competitions, e.g. in military and research contexts, platforms that provide an authentic environment for performing cybersecurity training, assessment and research are often called cyber ranges [19], [30]–[33]. For example, KYPO is an academic cyber range in the Czech Republic providing complex cyber systems and networks in a virtualized, fully controlled and monitored environment [30]. Implementations of cyber ranges are diverse, but their main component is usually a simulated or emulated network of computers [32] and they sometimes include physical facilities for users to collaborate during training or research [30], [33].

Since cyber ranges provide an environment for cybersecurity training, it has been noted that they have some overlap with CTF competitions [32]. Both cyber ranges and CTF competition frameworks are useful as authentic assessment environments. However, compared to using a CTF framework, developing and deploying a cyber range will likely end up being more expensive, but also more general-purpose, i.e. the cyber range will be useful as an authentic assessment environment for a wider range of information security competencies.

B. Gathering data and mapping them into precise assessment results

To reason about the precision of assessment results, it is first necessary to describe how these assessment results are formed in practice. While assessment problems significantly vary between different information security disciplines, a commonly used approach for discerning whether an assessee successfully solved an assessment problem relies on so-called *flags*. For many different information security competencies it is possible to construct an assessment problem in such a way that, when the problem is solved, some piece of information is revealed to the assessee [20], [29]. This piece of information is generally called the *flag* [20], [29], [34] and is often a short piece of text (e.g. a random character string or a sentence). By providing this flag, an assessee can prove that he solved the assessment problem. This approach provides the basis for Capture-the-Flag competitions, hence the name "Capture-the-Flag".

To give an example, in a scenario that assesses offensive security competencies, the flag could be hidden on a computer an assessee is trying to attack [34] or in a message an assessee is trying to decrypt [34]. In this case, the flag can represent some confidential information an attacker is trying to reach. In a scenario that assesses defensive competencies that are based on data analysis, e.g. malware analysis or digital forensics, the flag could be hidden inside a packed malware sample [34] or inside a forensic disk image. In this case, the flag can represent indicators of compromise or evidence left by an attacker.

However, for some information security competencies, there is no sensible way to construct an assessment problem that reveals a flag when solved [35]. This is the case for many defensive competencies, e.g. for competencies that involve secure software development, system administration or even strategic decision making. In these cases, assessment results must take into consideration whether a system, a piece of software or an organization is meeting both functional and security requirements. Some offensive competencies are not suitable for a flag-based assessment approach either, for example competencies related to attacking the integrity or availability of systems. Examples of assessment approaches that are not flag-based include the Build-it, Break-it, Fix-it contest [8] and the Git-based CTF [36] for assessing secure software development, the CyberCIEGE game for assessing strategic decision making [37], the Resilient Server exercise (part of Class Capture-the-Flag exercises) for performing and defending against network denial-of-service attacks [35] and the approach described

in [38] for assessing competencies related to firewall configuration.

Regardless of whether they use flags, the aforementioned methods often provide a binary assessment result, i.e. they only indicate whether an assessee succeeded or failed at solving the problem. In other words, such approaches often do not provide granular information about the *level* of competence an assessee has shown.

To provide more precise results, it is advisable to break down a larger assessment problem into smaller subproblems [1].

Another way to gather more precise data is by logging the assessee's actions inside the assessment environment [1], [35], [37], [39]. For example, it can be useful to log the time taken for solving a problem [1], information about the commands an assessee used (*bash* history, timestamps, exit codes) [39] and/or the network traffic generated during assessment [35].

One more approach to gather more precise results from a single assessment problem is to provide optional *scaffolding* (e.g. hints) and measure how much an assessee relied on it for solving the problem. For example, the assessee can be given an option to receive hints for solving a problem, but with the downside of receiving penalty points for each hint used [1], [29]. As a result, an assessee who had to use hints to solve a problem will receive less points overall than an assessee who did not use any hints.

C. Scalable scoring

Within the surveyed assessment methods, scalable approaches to measuring an assessee's actions and providing final assessment results are common. The most common solution was automating this process. However, in cases where completely automating the process was not feasible, it was still possible to scale the assessment by having assessees assess each other's work.

Using flag-based assessment problems makes automatic scoring easy [35] – it is sufficient to have a system where assessees can submit flags which are then automatically verified and scored. This is what virtually all Jeopardy-style CTF competitions do, and this functionality is the most fundamental requirement in frameworks for developing such CTFs.

When it is not possible to use flags, automatically measuring whether an assessee successfully solved an assessment problem can still sometimes be done. One example is described in [38], where a port scan determines whether a student successfully configured a firewall to block certain malicious traffic, while still allowing necessary services to function. In this example, the assessee was given a defensive task (configure a firewall), and the port scan served both as an automated attacker, assessing security (i.e. checking whether certain malicious traffic was blocked) and as an automated user, assessing functionality (i.e. checking whether necessary services were still available).

For many defensive tasks, assessing functionality can be automated, like in the former example. However, automatically assessing security in a meaningful way often presents an insurmountable challenge. In other words, there is often no practical way to automatically simulate a sufficiently intelligent attacker. A good example of this is secure development, where automated testing can assess whether a program conforms to a specification, but automatically determining whether the program contains vulnerabilities is still a major challenge. In such situations, to enable scalable assessment, a group of assessees can be tasked with assessing the security of each other's defenses. For example, in Build-it, Break-it, Fix-it, a scalable secure development contest, the submitted programs were automatically tested to determine whether they meet the specification, however to assess their security, the teams were tasked with finding vulnerabilities in each other's submitted programs [8].

This concept is further illustrated by attack/defense CTFs, where functionality is automatically assessed by a *scorebot* (a simulated user periodically using a service), but security is assessed by having teams attack each other's systems, while defending their own [10], [24], [40]. This way, the teams serve the purpose of both intelligent attackers and intelligent defenders.

In the context of providing hints and measuring whether an assessee uses them, it is worth noting that this process can also be automated [1], [29].

Logging an assessee's actions can often be automated without major problems, however depending on the nature of logged data, using it to provide precise assessment results in an automated manner can be a challenge. For example, for exercises in the KYPO cyber range, measuring the time an assessee took to solve a problem and using this information when producing assessment results could both be automated [1]. However, in the *Total Recon* exercise provided within the EDURange framework, detailed information about the commands assesses used was automatically logged (*bash* histories, timestamps, exit codes), but interpreting this information was not simple to do manually, let alone automatically [39].

D. Scalable construction of assessment problems

Through the survey of existing assessment methods, two approaches for scalable construction of varied information security assessment problems have come up: automatically generating problems and having a group of assessees generate problems for each other.

A good overview of automatic generation of information security assessment problems is provided in [29] and [15]. In general, approaches to automatic generation of information security assessment problems range from generating flag-based assessment problems which only differ in the final flag, to generating problems which significantly differ throughout the whole process of assessment [15], [29].

Given that assessment problems can significantly vary between different information security disciplines, specific approaches to automatic problem generation also vary.

For example, to generate varied reverse engineering problems, MetaCTF makes generated programs unique by morphing their data structures and modifying their code [16]. On the other hand, to generate varied penetration testing problems, SecGen generates networks of VMs with randomized services and vulnerabilities [29].

The other approach for scalable construction of varied assessment problems has a group of assessees construct problems for each other. For example, in Build-it, Break-it, Fix-it, teams of competitors first build software according to a specification, and then look for vulnerabilities and develop exploits for other teams' software [8]. A similar example is the Git-based CTF, in which students in a class also develop and attack each other's software, however in this case, the students must also purposely inject a number of vulnerabilities into the software they develop [36]. Since assessees generate problems for each other, a downside to this approach is that the final assessment does not give an absolute result, only a relative ranking of assessees.

E. Providing a motivating assessment process

Throughout the survey of existing work, a common topic was student motivation during educational information security activities. However, in the surveyed work, motivation during assessment of information security competencies was not explored as a separate topic. Therefore, general efforts to raise student motivation during educational information security activities will be surveyed, given that assessment was generally an inseparable part of such activities.

A commonly encountered solution for enhancing motivation during educational activities was *gamification*. Gamification can be defined as "the use of game design elements in non-game contexts" [41].

Good examples of using gamification to motivate students during educational activities, including assessment, are the Internet Security (InetSec) and Advanced Internet Security (InetSec2) courses at Vienna University [3]. As part of these courses, students solve a number of practical lab exercises or *challenges*. Each challenge is embedded in a small storyline, while each student is given a unique *leet hacker pseudonym* such as *Warez Ninja* or *R00t Master*. By solving challenges, and by doing so quickly, students advance their position on the course scoreboard, thereby competing with other students. There is an additional scoreboard covering multiple courses where students advance among ranks such as *Stackmaster*, *expl0it Warlock* and *Master Guru*. This approach was evaluated with two surveys, and results indicated that the gamelike course experience and the competition among students is an effective way to motivate students to put more effort and hard work into their security education.

Similar approaches that use gamification to raise motivation amongst students were used in the cyber security course described in [42], in the "Incident Response and Investigation" module described in [43], in the "Divergent"-themed curriculum described in [2] and in the CPE123 course offered at Cal Poly, San Luis Obispo described in [44].

Another related approach which could motivate assessees is the use of educational games or "serious games". While using such games clearly has a large overlap with gamification, the term gamification does not encompass fully fledged games [41].

A good example of an educational game is CyberCIEGE, a video-game in which the player assumes the role of a decision maker for an IT-dependent organization [37]. The objective of the game is to keep the organization productive while providing necessary security measures to protect its valuable information assets [37]. A similar example is SecurityEmpire, a multiplayer computer game in which players build a green energy company while engaging in sound information assurance practices and avoiding security missteps [4].

IV. CONLUSION

The survey of existing assessment methods has shown that, regardless of the specific set of information security competencies, there is a sensible way to implement the proposed requirements. In fact, even though information security competencies are highly varied, the approaches for fulfilling the proposed requirements are often very similar.

The combination of proposed requirements and the surveyed approaches to implementing them should provide useful groundwork for developing future methods for assessing information security competencies that are both effective and feasible for use in formal education.

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3D Virtual Learning and Measuring Environment for Mechanical Engineering Education

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***Abstract* – Virtual learning and measuring laboratories have significant impact on the engineering education. Current trends and initiatives that engage digital generations engineering students in interesting educational experiences are discussed. The paper aims to provide some advantages of 3D virtual learning and measuring environments for mechanical engineering education. An interactive 3D virtual learning environment for measuring of constructive and geometrical Gear Hob parameters for engineering students is presented. Software engineering design process activity and class diagrams are described in details. 3D virtual measuring simulations of Gear Hob tools are tested with bachelor students in the Faculty of Mechanical and Manufacturing Engineering of University of Ruse. An experimental study with mechanical engineering students was performed to compare the learning performance and experience of students in the 3D virtual simulation environment vs that in the real laboratory classroom. The experimental results are analyzed and presented.**

Keywords - engineering education, virtual learning environment, virtual laboratory, virtual measuring, mechanical engineering, 3D measuring simulation

I. INTRODUCTION

There have been numerous warnings over the recent years that universities today face a shortage of mechanical engineering students. In the 1970s and 1980s becoming a mechanical engineer was tremendously attractive, but today's students are not motivated to study mechanical engineering specialties because they prefer to pursue modern degrees, such as computer science, economics and etc. Mechanical engineering education (MEE) needs contemporary learning technologies and up-to-date curriculum reform to increase application rates for engineering degrees. Today's mechanical engineering students, born in the computer age, are digital online learners who expect modern digital technologies in the mechanical engineering laboratories. The current rapid rise of 3D technologies is transforming our education. A modernization of our education is needed in mechanical engineering degrees with innovative approaches to attract new students and motivate them to study fundamental mechanical engineering sciences [1, 2].

Laboratory experiments are an important component of the training in engineering degrees [3] and at the same time, we have to address the problem that mechanical laboratories usually contain expensive, heavy and extremely dangerous equipment, so teaching the students in advance how to use such equipment in advance is of crucial importance. The other problem is that the number of laboratories is limited and they are usually available for students only during regular classes. An alternative to physical laboratories are the 3D virtual laboratories which are available 24 hours a day in the virtual space. Virtual laboratories can provide 3D virtual simulation of real laboratory equipment and students are able to perform workshops at any time using virtual simulation of 3D models of real laboratory equipment [4, 5].

The paper presents a 3D virtual learning environment for the Cutting Tools course at the University of Ruse. The course is essential for mechanical engineers, because they learn to use specific measurement tools to determine constructive and geometrical parameters of different cutting tools. An experimental study with mechanical engineering students was performed to determine the effectiveness of virtual learning environment in providing better instructions regarding basic mechanical engineering concepts.

The virtual simulation of the measurement can not give the students the same idea they would get when using the measuring instruments in physical laboratories. However, virtual measurement technologies provide the opportunity to unify the way the instruments work and to significantly increase the possibilities for mathematical processing, analysis, storage and documentation of the results. Students are provided with safe and time-independent access to expensive and rare instruments, tooling and technological equipment, such as a toolmaker's measuring microscope, a coordinate measurement system, among others. Virtual 3D learning and measuring environments allow students to learn in advance what the equipment looks like and how it works. This is very important for the effectiveness and safety of students who work in the real laboratory. For engineering courses, where practical exercises are related to laboratory work and the use of a variety of technological equipment as well as measuring tools, it is important to develop such virtual learning environments with 3D virtual simulations.

3D virtual learning environments (3D VLE) are used in many universities to enhance teaching and learning effectiveness [6, 7, 8, 9, 10]. Students in the 3D VLE acquired a better understanding and developed new skills

faster than their peers in the real lab condition. Some advantages of the 3D virtual learning and measuring environments for mechanical engineering education can be summarized as follows:

- Measuring 3D mechanical engineering models in 3D VLE allows to define parameters that are hard to measure in real conditions. Both very small and very large objects can be measured easily in a 3D environment. For example, in a real laboratory, a microscope is needed to measure tools with very small size;
- Safety of the measurement process in 3D environment - no danger of injury with sharp edged tools, heavy laboratory equipment and high speed sharpening machines;
- Measurements with expensive 3D lab equipment- some new advanced equipment can not be purchased due to its high cost in the real lab, but it is important for the students to learn up-to-date tools and technologies, to be better prepared and familiar with the engineering trends applied in engineering companies;
- 24 hours access - no access limits, which are usually necessary in real laboratories due to the lack of time and insufficient number of available laboratories.

A. *Augmented Reality in MEE*

Augmented reality is also an example for current trend technology as virtual learning who have the potential to attract digital students' engagement in class [11, 12]. A book with augmented reality 3D models has been created for students in the Cutting tools course [13]. The 3D models of cutting tools appear over 2D photos in the book and students can manipulate and rotate them for more detailed information. The book has been used since 2015 with students finding it attractive and useful.

II. SOFTWARE DESIGN

An original interactive 3D VLE for measuring of constructive and geometrical Gear Hob parameters is designed and developed. The developed software provides its users with the following capabilities:

- For students: Augmentation theoretical lecture notes using visual learning materials (a gallery containing images of different types of Gear Hobs, video materials with how Gear Hobs work in real conditions and 3D models of measuring tools in a 3D environment with detailed simulation of their work); Test control before proceeding with the measuring process; Virtual measurements with 3D virtual tools are performed according to a predetermined methodology for conducting the exercise; An electronic final report with student's results is compiled.
- For lecturers: They are given access to an administrator environment, where they can add, edit or delete test questions.

The following technologies have been used to design and develop the software: C#; Windows Forms .Net Framework; Microsoft Visual Studio; Adobe Flash Professional with ActionScript.

B. *Software Class diagram*

A software class diagram is presented on Fig. 1.

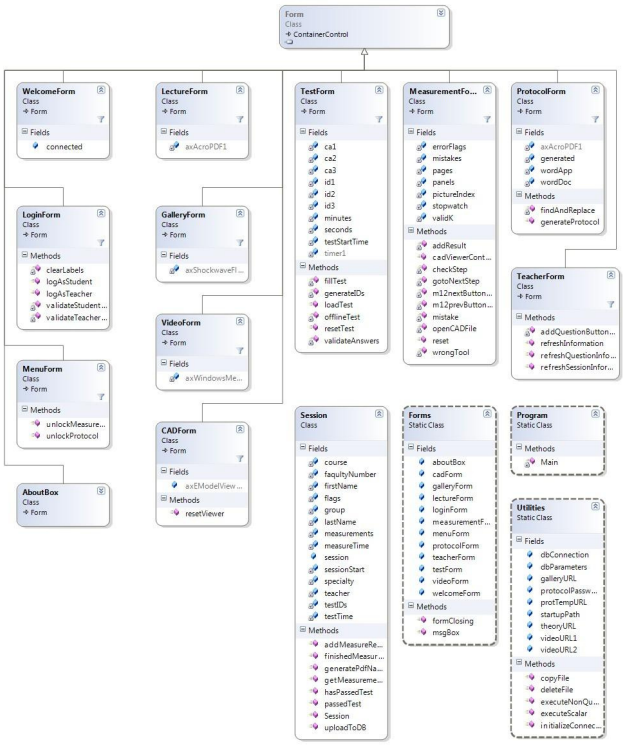

Figure 1. Class Diagram of 3D VLE for measuring of constructive and geometrical Gear Hob parameters

C. *Software Classes*

- Program.cs – Class for the main program that starts the application. The class creates a new instance of WelcomeForm.cs and displays the main menu.
- Session.cs – The class keeps the student's current session containing their personal information that he/she filled in the registration process, their test results, and measurements. It contains methods for generating a name for the final report by student names and a method for constructing a string which is used to store the session in the database.
- Forms.cs – This static class contains all the windows that are used in the application. Its methods and fields (attributes) are static as well. It contains a method that asks the user if they wants to exit the learning environment.
- Utilities.cs – Static class containing strings with the path to the program resources. The class contains methods designed to work with the database, as well as copy and delete a files.

- AboutBox.cs – The class contains information about the software's version and developer.
- CadForm.cs – The class contains the AxEModelViewControl component, which visualizes the 3D Gear Hub models. When the window opens, it is positioned at a program-specific location and loads a specific file. Later, this component is used in the virtual measurements. This method saves operational memory.
- GalleryForm.cs – The class is responsible for the Flash images gallery. The student can view a Flash and ActionScript gallery of the images. The gallery is in the AxShockwaveFlash instance and loads photos using a .xml file that is located in the program's resources.
- LectureForm.cs – The class contains an instance of AxAcroPDF that loads a theoretical lecture material on Gear Hobs.
- LoginForm.cs – The class is responsible for users' login process. Corresponding information fields are displayed for each type of user – student or a lecturer. In both cases, each field checks whether correct information is entered. The teachers' data is checked in the database, while the students' is validated by regular expressions. If there is no Internet connection or the connection to the database is unsuccessful, access as a teacher is impossible.
- MeasurementForm.cs – The class is responsible for the measurement process. The virtual measurements are made by the student, but only if they have passed the test control. There are three types of different measuring tools, which are used to measure the constructive and geometrical parameters of the Gear Hob. At certain stages, the student has to select the right measuring tool for the specific measurements. The measurement stages are 21 and they are represented in the class as TabPage objects that have the appropriate components for the stage. All stages are added to the TabControl and following stages are unlocked only if the student gave the correct answer in the previous one. In this class there are several arrays that make the checks easier and faster. One is an array of integers that stores the amount of mistakes a student has made for each measurement. Checking is done by a method that compares the contents of a corresponding input value with the correct value, and if it is wrong, a certain index is incremented in the error array. Correct values are added to the student session. If the value has been mistaken for more than three times, the correct value is displayed as a hint and the error is written in the student session. Three-dimensional models are loaded at the AxEModelViewControl instance in CadForm.cs. At the end of the measurements, the student session is complete and if there is an active connection to the database, it is stored there. Finally, the Final Report section is unlocked.
- MenuForm.cs – The class is responsible for the main menu that contains seven buttons leading to different sections of the VLE, initially two of them - "Virtual Measurements" and "Final Report Generation" are locked. When the student tries to select either of them, the corresponding window is displayed and the menu window is hidden. Initializing this window creates instances of the rest of Forms.cs.
- ProtocolForm.cs – The class contains an instance of AxAcroPDF that loads the generated final report. The report is generated and locked with a password to prevent the student from copying it and filling out fabricated data. The report file is generated in the app using a method that crawls and replaces pre-written tags with student session values. The report file is saved as a PDF document.
- TeacherForm.cs – The class is responsible for teachers' activities in the app. If the user is a teacher and has successfully logged in, the program will direct them to the teacher environment. The class consists of a TabControl with two TabPages, one for managing the questions and answers of the test control and the other for the session review. Each of them has one DataGridView that loads the information that is fetched from the database.
- TestForm.cs – The class is responsible for the test control. If the link to the database is non-existent, pre-defined questions and answers are used. Otherwise, the software connects to the database and retrieves the identification numbers of the questions and randomly chooses three of them. However, if there are less than three questions in the database, the previously defined test is used again. Once the program has selected three identifiers, it retrieves and loads the questions and corresponding answers from the database. A timer that counts down 3 minutes is also started. Students can continue if there are at least two correct answers. The program stops the timer and loads the student's time and identifiers in the student session. Finally, the "Virtual Measurements" section is unlocked.
- VideoForm.cs – The class contains an instance of the AxWindowsMediaPlayer component that plays videos.
- WelcomeForm.cs – The class is responsible for the initialization process. During initialization the class attempts to connect to the database. If it is unsuccessful, local queries will be used. There are two options for logging in as a student and as

a lecturer -, and, depending on the user type, the class sends the information to the LoginForm.cs.

D. *Software Resources*

- "3D CAD" – contains twelve 3D files (created and compiled with SolidWorks) that are loaded in the AxEModelViewControl during the student session.
- "Measurement Gallery" – gallery files used for the measurement process.
- "Flash Gallery" – files for the Flash photo gallery. The main file here is "gallery.swf", which loads the photos.
- "Video" – contains the video clip that is played in the video gallery.
- „Final Report"– the document, built with students' results of the entire virtual learning and measuring process.
- „Lecture Notes – theoretical lecture notes that are visualized by the students.

E. *Software User Interface*

Mechanical engineering students who are meant to use the software will have different computer skills and different abilities to work independently. Each learning software system has to be developed with an intuitive and user-friendly interface. The interface should facilitate students' work, focusing only on the functions, they need. The proposed learning software has been divided into separate sections, so students can be placed in a learning sequence. The main interface menu is presented on Fig. 2



Figure 2. User interface of VLE for learning and measuring Gear Hobs

F. *Test Control Section*

In order to be able to start the measurement section and generate a final report with results, the student is required to pass a test control. The test contains three questions, each with three possible choices. Only one of the answers is fully correct. In order to pass the test, the student must answer at least two questions correctly and if he/she does not pass the test, the software advises them to read the theoretical materials again. The test has a duration of three minutes for a purely statistical purpose, and the time result is included in the final report. The test section is presented on Fig. 3

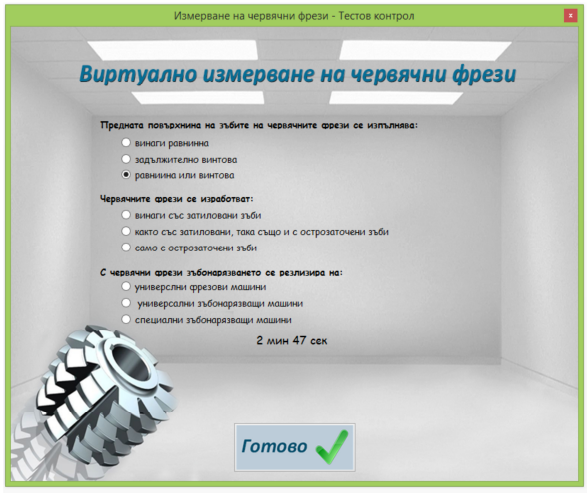

Figure 3. Test Section of VLE for learning and measuring Gear Hobs

G. *Virtual Measuring Section*

Once the student has successfully passed the test, the virtual measurements section is unlocked. It contains 21 stages with different measurements and calculations. Each subsequent stage is unlocked only if the previous one has been completed with the correct measurement result.

Gear cutting hobs are used to cut gear teeth (spur or helical) on cylindrical gear wheels. The cutting process is continuous and characterized by high output, and precision of the gear teeth [14, 15].

In the Cutting Tools course, mechanical engineering students learn how to measure the constructive and geometrical parameters of Gear Hobs. Three types of measuring instruments are used to determine the main Gear Hob parameters: caliper, combined measuring tool and gear caliper.

The second stage - using the caliper to measure the diameter of the base bore hole - is shown on Fig. 4.

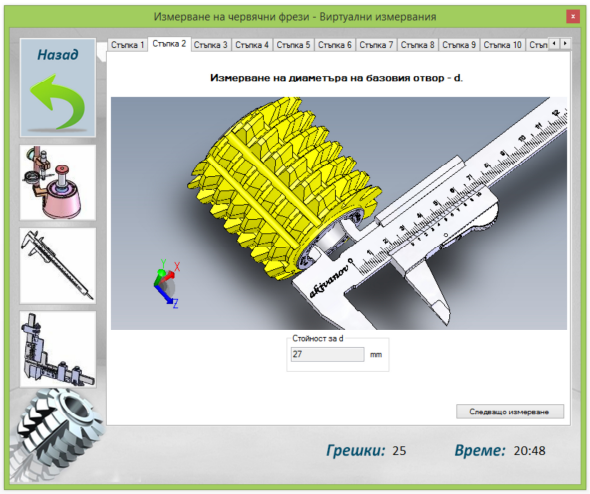

Figure 4. Second stage - Measuring the diameter of the base bore hole

The twelfth stage, the usage of a combined measuring tool to measure the relief angle, is shown on Fig. 5.

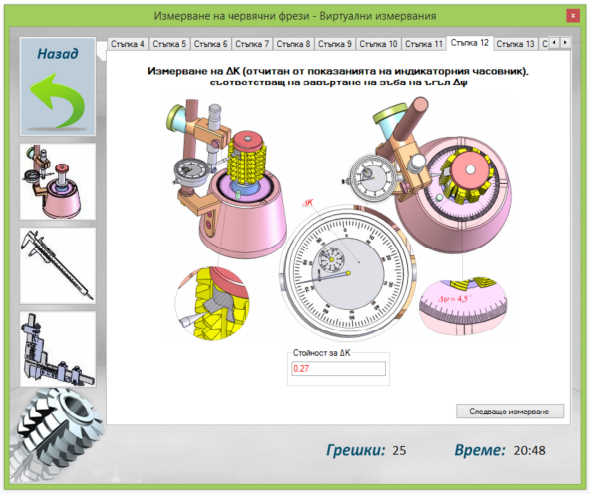

Figure 5. Twelfth stage – Coordinate measuring of the relief angle

For each measurement stage, the students have to decide if they need a measuring instrument and need to select the correct one. In some stages, calculations are required, using formulas predefined in the theoretical material. The process is explained using an activity diagram on Fig.6.

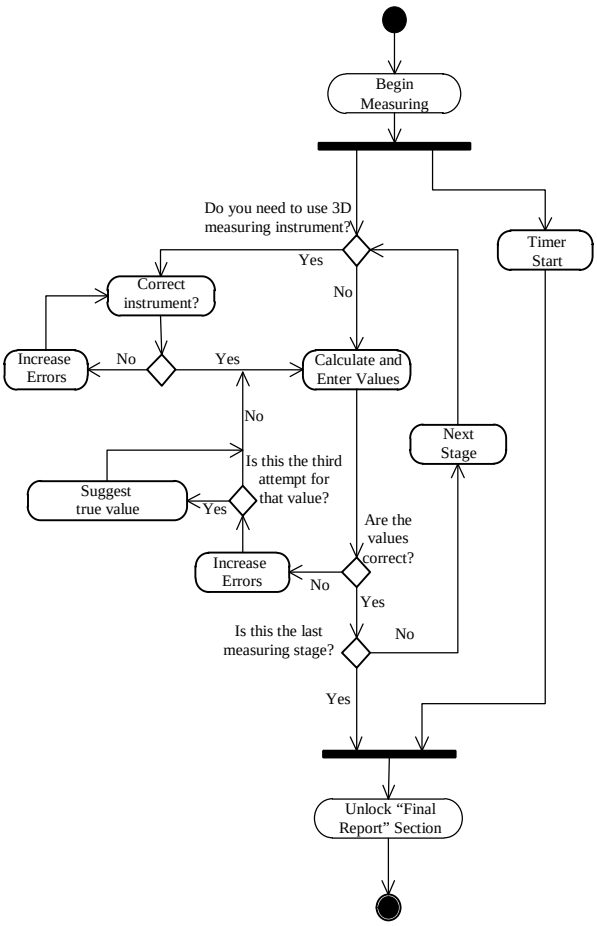

Figure 6. Activity diagram of Measuring Process

III. STUDENTS SURVEY

A survey approach is used to assess the effectiveness of the 3D VLE for Gear Hobs on the students' understanding and degree of acquired knowledge. The idea is to survey the students' opinion by seven predefined questions using five dimension Likert scale (strongly agree - 5, agree - 4, neutral – 3, disagree - 2, strongly disagree - 1):

- Question 1: Were the lecture notes and all visual materials (gallery photos, 3D models, and videos) valuable to better learn and understand of the topic?
- Question 2: Did the 3D simulation of measuring tools help you understand and learn with better details how they actually work?
- Question 3: Did the training you received in the VLE prepare you to measure Gear Hobs in real conditions?
- Question 4: Is the virtual measuring process logically well-structured and did it lead you to pass easily through all the measurement stages?
- Question 5: Did the virtual learning environment provide you with useful, on-time feedback messages on how to proceed?
- Question 6: Did you find the learning and measuring process in the 3D VLE fun and more exciting than the traditional one in the real lab?
- Question 7: How you are going to rate your overall level of satisfaction with the 3D virtual learning environment - from (not satisfied) 1 to 5 (very satisfied)?

The survey results show that 100 % of the students either strongly agreed or agreed that the 3D VLE helped them to better understand the topic for Gear Hobs. The Fig. 7 shows a summary of the results from the surveys in the last three years with full-time and part-time bachelor students enrolled in a Cutting Tools course at University of Ruse.

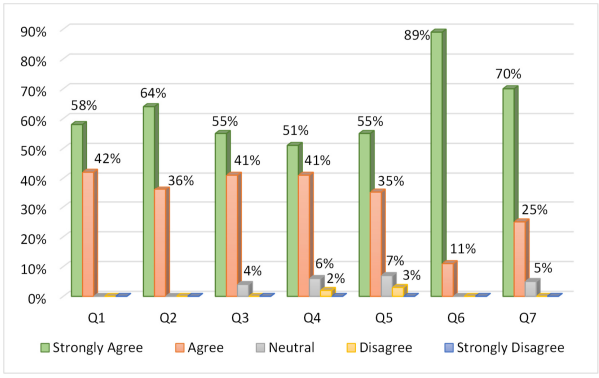

Figure 7. Students' opinion survey results

The survey results demonstrated that the 3D VLE had a positive influence in the students' learning and understanding. The overall results of the analysis of

student performance in the past years show that the students in the experimental group (54 students for 3 years), who used the 3D VLE as a learning augmentation tool, performed better and faster, had higher test results and finished all the 21 measurements of Gear Hobs with less errors in the final report, while the students in the control group (65 students for 3 years), who didn't use the VLE and follow-on the process only in real lab, performed slower and have more measurements' and calculations' errors in their final report results.

IV. SOFTWARE PERFORMANCE TEST

After the initial performance testing, it was found that the program uses over 700MB of RAM, which is unacceptable for this type of software. A problem has since been identified with the e-Drawings component, which occupied about 80MB of RAM for every single open 3D file in the VLE, and deprived the rest of the operating system of resources. The problem was resolved by using only one instance of this component, and depending on where the student is at the time of the virtual measuring process, it moves and loads the appropriate file. To some extent, this creates a certain amount of delay when using the software, but takes up to 4 times less RAM.

On low tier computer configuration, there was a delay when switching between different measuring sections. The problem was remedied using the "Multiple document interface" technique.

Some problems related to database connection were also resolved. If the software does not establish a connection to the database at the initial startup, it will try again to connect at different stages and also at the end of the student session.

V. CONCLUSIONS

The paper introduces an interactive 3D virtual learning environment for measuring constructive and geometrical parameters of Gear Hobs, which is intended to assist the education of mechanical engineering students in the Cutting Tools course.

The presented software enables students to have free, safe and remote access to the learning resources on the topic. Students have ability to learn how to use different type of 3D measuring tools in advance in the virtual space and then to perform the same measurements in the real lab using real instruments.

At this stage, according to student survey answers, it can be concluded that the 3D VLE for Gear Hobs measuring would satisfy the needs of the students. Students find the virtual environment useful, fun and attractive. They show better results in their final reports.

The following advantages of using virtual measurement environments have been identified:

- 3D VLE significantly increase the possibilities for mathematical processing and analysis, storage and documentation of all student's measuring results.
- They also enable performing remote measurements with the possibility of distributed performance, preserving the passed measurements and continuing with the next stages in a time convenient for the students.
- The virtual learning environment is more effective compared with the traditional lab environment in helping students to understand long measuring process with more than 20 stages, too long even for the real lab conditions.

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Laboratory Module for Training in the Subject "Specialized Communication Networks in the Vehicles"

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Abstract – **This paper presents a laboratory module developed for training in the subject "Specialized Communication Networks in the Vehicles" as part of the Master's degree course "Automotive Electronics". The developed laboratory modules allow the students to get acquainted with the bus structure, the principles of operation, the format and electrical levels of the signals and the structure of the transmitted messages in the specialized communication networks in the vehicles.**

Keywords – Controller Area Network; Local Interconnect Network; Laboratory module

I. INTRODUCTION

The main driving forces for the development of vehicle network technology have been the advances made in the electronics industry in general and government regulations imposed, in order to make the automobiles environmentally friendly.

With stringent emission standards for automobiles, it became impossible to attain the required degree of control without the help of on-board computing devices. On-board electronic devices have also contributed substantially to vehicle performance, occupant comfort, ease of manufacture and cost effectiveness.

At one time, a car radio was likely the only electronic device in an automobile, but now almost every component of the vehicle has some electronic features. Typical electronic modules on today's vehicles include the Engine Control Unit (ECU), the Transmission Control Unit (TCU), the Anti-lock Braking System (ABS) and Body Control Modules (BCM).

An electronic control module typically gets its input from sensors (speed, temperature, pressure, etc.) that it uses in its computations. Various actuators are used to enforce the actions determined by the module (turn the cooling fan on/off, change gear, etc.). The modules need to exchange data among themselves during the normal operation of the vehicle. For example, the engine needs to tell the transmission what the engine speed is, and the transmission needs to tell other modules when a gear shift occurs. The need to exchange data quickly and reliably led to the development of the vehicle network, as the medium of data exchange.

The automotive industry quickly realized the complexity of wiring each module to every other module. Such a wiring design would not only be complex, it would have to be altered depending on which modules were included in the specific vehicle. For example, a car without the anti-lock braking system (ABS) module would have to be wired differently than one that included ABS.

The industry's answer to this problem was to create a central network in the vehicle. Modules could be 'plugged' into the network and would be able to communicate with any other module that was installed on the network. This design was easier to manufacture, easier to maintain and provided the flexibility to add and remove options without affecting the entire vehicle's wiring architecture. Each module, which represents a node on the vehicle network, controls specific components related to its function and communicates with the other modules as necessary, using a standard protocol, over the vehicle network [1].

The aim of this paper is to present a laboratory module developed in the department of "Electronics" at the University of Ruse "Angel Kanchev". Using the module, the students learn the bus structure, the principles of operation, the format and electrical levels of the signals and the structure of the transmitted messages in the specialized communication networks in the vehicles.

II. BASIC NETWORKS IN THE VEHICLES

In the designed laboratory module, only two networks in the vehicle for communication between the electronic modules are incorporated. The first is LIN (Local Interconnect Network) and the second is CAN (Controller Area Network).

A. LIN/SAE J2602

LIN is a universal asynchronous receiver-transmitter (UART)-based, single-master, multiple-slave networking architecture originally developed for automotive sensor and actuator networking applications. LIN provides a cost-effective networking option for connecting motors, switches, sensors and lamps in the vehicle. The LIN master node extends the communication benefits of in-vehicle networking all the way to the individual sensors and actuators by connecting LIN with higher-level networks, such as the controller area network (CAN) [2].

B. CAN/ISO 11898-1

CAN is an asynchronous serial network that connects devices, sensors and actuators in a system or sub-system for control applications. This multi-master communication protocol, first developed by Robert Bosch GmbH in 1986, was designed for automotive applications needing data rates of up to 1 Mbps and high levels of data integrity. Beyond automotive applications, the CAN protocol is being used as a generic embedded communication system for microcontrollers as well as a standardized communication network for industrial control systems. The Bosch CAN specification does not dictate physical layer specifications for implementing CAN networks. These physical layers specify certain characteristics of the CAN network, such as electrical voltage levels, signaling schemes, wiring impedance, maximum baud rates and more. Over the course of the last decade, two major physical layer designs have come forward to become the basic physical layer specifications used in most CAN applications. They both communicate using a differential voltage on a pair of wires and are commonly referred to as high-speed (ISO 11898-2, SAE J2284) and low-speed CAN (ISO 11898-3). High-speed CAN networks allow transfer rates up to 1 Mbps. Low-speed/fault-tolerant CAN networks can communicate with devices at rates of up to 125 Kbps. In addition, low-speed CAN offers the ability for CAN data traffic to continue in the event of a wiring fault [2].

III. REALIZATION IN THE LABORATORY MODULE

A. Block diagram of the laboratory module

Key factors for designing the module are the requirements for the realization of communication over CAN and LIN networks in the automobile. The block diagram of the designed laboratory module is given in Fig. 1 and incorporates:

- Arduino Due;
- CAN interface module;
- LIN interface module;
- Bluetooth;
- WiFi;
- EEPROM;
- Real Time Clock and Calendar;
- Analog inputs, Digital outputs and Digital inputs/outputs;

B. Arduino Due

Arduino Due is an open hardware platform for fast prototyping of electronic devices and is very popular amongst the people from the hardware community. In our laboratory module, it will hold the firmware, which demonstrates the work of the two automotive networks – CAN and LIN [3].

C. CAN interface module

In order to implement the CAN communication in the laboratory module, a specialized interface circuit MCP2515 is used with available corresponding library for Arduino Due [4]. The circuit connects to SPI interface of the Arduino module. The firmware initializes the interface circuit and utilizes it to communicate with other modules over CAN interface. The integral circuit MCP2515 is responsible for the logical layer of the communication.

D. LIN interface module

As mentioned above, the LIN network is UART-based communication, thus no special hardware is needed except the implementation for the physical layer.

E. Bluetooth

A simple inexpensive Bluetooth module is used in order to implement wireless communication between the laboratory module and a computer or a smartphone. This wireless connection is used to transfer various debug data to a visual interface or as connection to a specially designed computer or smartphone program to control the laboratory module. The Bluetooth module has a Serial Peripheral Port (SPP) profile which makes the software implementation in host device a lot easier.

F. WiFi

The WiFi module connects the laboratory module to a wireless network. It is connected to the Arduino Due via I2C interface and holds an HTTP server where a web site holds the graphical user interface for the simulation of various automotive controls. The student interacts with the web site. The web WiFi module receives the data and then sends it to the Arduino Due "Lab Module CAN1". The data is mapped to a corresponding commands and then sends it to the "Lab Module CAN2" via the CAN interface. When the data is received in the "Lab Module CAN2", the module executes the corresponding action – switch on the left/right signal lights, the headlights, turn on the wiper blades, etc.

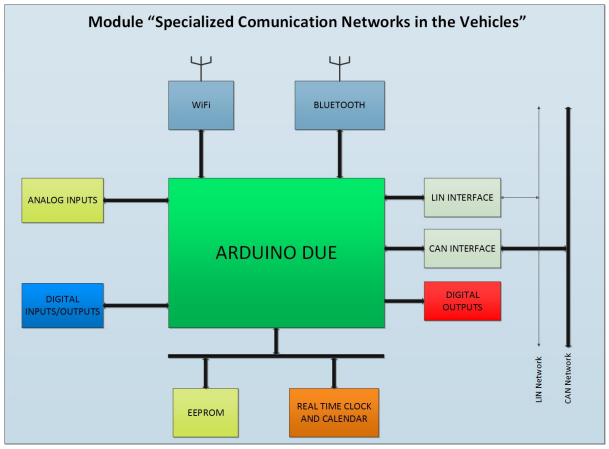

Figure 1. Block diagram of the Laboratory module

G. EEPROM

The EEPROM in the laboratory module holds various data related to the configuration of the module itself. It holds the CAN network ID for the module, speed of the communication, etc.

H. Analog inputs, Digital outputs and Digital inputs/outputs

The Laboratory module also accommodates several inputs. There are three analog inputs connected directly to the analog inputs of the Arduino module. There are resistors 150 Ω which can be connected with a jumper to GND, making the board suitable for measurements in applications using 4-20 mA current loop. The analog reference voltage for the ADC comes from 3 V high precision voltage reference IC REF5030 [5]. Thus, it sets the maximum measured voltage on the analog pins to + 3 V.

Four dedicated digital outputs, each with its own opto-couple IC with ability to drive 12 V loads are available. These outputs can drive relays or other actuators.

In addition to the analog inputs and the digital outputs, there are 8 bidirectional digital I/O pins. All of them can be configured internally to generate interrupts in the software. This way a simple keyboard with 4 buttons is designed. When a button is pressed, the corresponding interrupt service routine handles the function. A simple program to send four different button states is compiled and put in operation. The algorithm of the program is shown on Fig. 2.

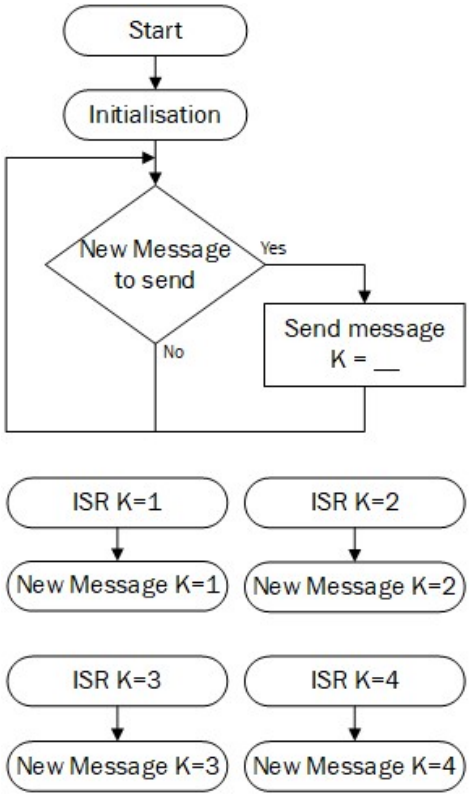

Figure 2. Algorithm of the simple program

The buttons are numbered 1-4 and pressing each one sets a flag for new message to be sent over the network. The message includes the number of the button. When the message is received by the addressed module, it is handled and the appropriate actions are taken – turning on/off actuators and other devices in the vehicle. Same algorithm is applied for the communication over CAN and LIN networks.

A typical connection of two devices with two keyboards is shown in Fig. 3. When pressing one button on the left device, the corresponding LED on the right device is turned on.

Both modules are connected to CAN-network, representing a long line of twisted pair of wires with connected resistors with 120 Ω at both ends. This value corresponds to the characteristic resistance of the long line.

Both inputs of a digital storage oscilloscope are connected to the lines CAN-HIGH and CAN-LOW.

Fig. 4 shows a screenshot of the graphic signal from the oscilloscope. Signal levels are recorded, as well as the shape of the signals over the time, and the structure of a transmitted message.

During the practical exercises, the students can realize the most common failure problems in the communication networks with the corresponding jumpers using the developed laboratory modules. Thus, some of them can be simulated – disconnecting one of terminating resistors, short circuit between lines, connection of the communication lines to +12 V or GND.

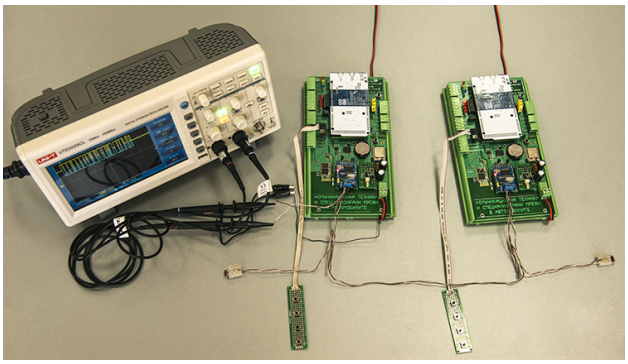

Figure 3. Connection between two modules with attached oscilloscope

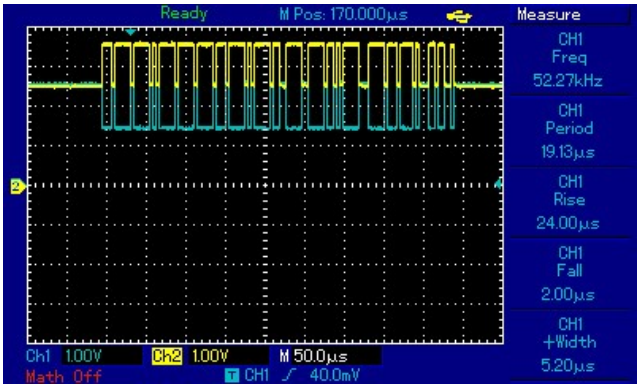

Figure 4. Screenshot from the oscilloscope

In this way, students are given the opportunity to study the impact of these problems on the communication parameters, to detect problems and to diagnose the network failures.

IV. Conclusion

The developed laboratory modules allow the students to get acquainted with the bus structure, the principles of operation, the format and electrical levels of the signals and the structure of the transmitted messages in the specialized communication networks in the vehicles.

For further improvement of the training, it is planned to develop six laboratory modules, three of which will work as CAN modules, two as LIN and one module as a CAN–LIN bidirectional converter. In this way, an even more complete study of the automotive communication networks would be achieved.

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Modeling of Cryptosystems Based on Linear Feedback Shift Registers Using Spreadsheets

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Abstract – **The paper describes spreadsheets-based applications implementing and graphically illustrating the processes of encryption and decryption of 3-symbol words in English using cryptosystems based on linear feedback shift registers (LFSRs). Numerous examples obtained by the applications are presented in the paper. Details about the functions used for the implementation are given. Some problems that arise when encrypting and decrypting texts are illustrated by examples. The applications are used in the educational process in the course "Telecommunication Security", compulsory for Bachelor in the specialty "Internet and Mobile Communications" at the University of Ruse "Angel Kanchev".**

Keywords – cryptosystems; linear feedback shift registers; encryption and decryption; spreadsheets; MS Excel

I. INTRODUCTION

The Ouroboros (or uroborus), an ancient symbol depicting a serpent or a dragon eating its own tail, and thereby forming a circle, have been used in many ancient cultures (originating in ancient Egyptian iconography, adopted as a symbol in Gnosticism and Hermeticism and most notably in alchemy), to depict eternity or renewal. The equivalent of the Ouroboros in the world of electronics is the Linear Feedback Shift Register [1].

The Linear Feedback Shift Registers (LFSRs), where the output from a standard shift register is manipulated and fed back into its input for causing the function to endlessly cycle through a sequence of patterns, are simple to construct and useful for a wide range of applications, but are often neglected by designers. One of the more common forms of LFSR is formed from a simple shift register with feedback from two or more points (taps), in the register chain. The data input to the LFSR is generated by XOR-ing or XNOR-ing the tap bits; the remaining bits function as a standard shift register. The sequence of values generated by LFSRs is determined by its feedback function and tap selection [1, 2, 3].

LFSRs are used in encryption and decryption applications and cyclic redundancy check applications. The sequence of values generated by LFSRs can be used in the encryption and decryption of data. A stream of data bits can be encrypted by XOR-ing them with the output from the LFSR. The stream of encrypted data bits in the receiver can be decrypted by XOR-ing them with the output of an identical LFSR. This is obviously a very trivial form of encryption, not very secure, but "cheap-and-cheerful" and may be useful in certain applications.

The paper describes MS EXCEL-based applications implementing and graphically illustrating the processes of encryption and decryption of 3-symbol words in English texts using LFSRs. Numerous examples obtained by the applications are presented in the paper. Details about the functions used for the implementation are given. Some problems that arise when encrypting and decrypting texts are illustrated by examples. The applications are used in the educational process in the course "Telecommunication Security", included as compulsory in the curriculum of the specialty "Internet and Mobile Communications" for Bachelors at the University of Ruse but it can be applied in other courses covering topics of cryptography and information protection, such as Cryptography and Data Security (Computer Systems and Technologies, Bachelors), Security in the Telecommunication Networks (Internet and Multimedia Communications, Masters), Coding and Security in Telecommunication Networks (Telecommunication Networks, Masters), etc. The applications allow easily assimilation of the material studied by the students as the steps at each stage of encryption and decryption are given in details and automatically generating tasks for individual assignments to students by the lecturers. They also assist the teacher in the process of checking students' solutions.

II. METHODOLOGY

A. Active learning in the educational process

In active learning, all students take a participation in the learning process. Students are engaged in activities such as talking, writing, problem solving, or reflecting. Active learning refers to a broad range of teaching strategies, involving some amount of students working together during the classes, individual work and/or reflection [4].

In order to facilitate independent, critical, and creative thinking and to increase student investment, motivation, and performance, active learning methods are applied. An individual assignment is given to each student. The assignment includes: 1) determining the states of an LFSR for a given initial state; 2) encrypting a given plaintext

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(3-symbol English text containing Latin letters, decimal digits, punctuation signs, arithmetic and logical operators and so on) using LFSRs; 3) decrypting a given cipher-text using LFSRs. During the practical exercises, the students must solve the tasks of pre-prepared form published in the e-learning platform of the University of Ruse "Angel Kanchev" [5] and submit to the teacher at the end of the classes. The opportunity for extra work is given to the students: 1) decrypting a given cipher-text when the initial state of the LFSR is not known; 2) implementing LFSR with *D* flip-flops and XOR gates and simulating its operation in Logisim or Multisim; 3) implementation and testing a device for encryption and decryption on a laboratory board based on Spartan-6 devices.

B. Individual assignment

During the practical exercises, each student should manually fill in the table, shown in Fig. 1. This table helps the student to encrypt/decrypt a 3-symbol message. The cryptosystem in this case is comprised of an 8-bit LFSR with a linear XOR-type feedback, when the initial state (seed) of the register is given.

In Fig. 1, block 1, the structure of the cryptosystem based on an 8-bit LFSR is visualized for making easier for the students to fill in the table. The cryptosystem is built from eight *D* flip-flops with moving the information to the right, and the bit at the input of the register is generated when adding modulo 2 (XOR-ing) the outputs of given flip-flops. In Fig. 1, block 2 and block 4, the student fills in the message for encryption and the 8 bits given as the initial state (feed) of the register according to the assignment. Next, the symbols of the message are written in the color (blue / yellow / green) cells of block 3 in Fig. 1, and each symbol is represented in the 7-bit ASCII code [6], written respectively in the column PT (plain-text) in block 8 again in the blue / yellow / green cells (7 bits per symbol). Students have the ASCII codes of the symbols in advance [6]. The 8-bit EBCDIC code for symbol representation could be used also.

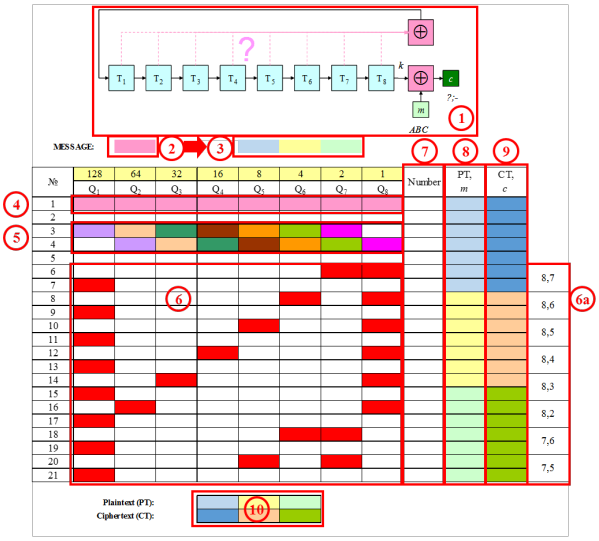


Figure 1. Encryption of a 3-symbol message – filling in a table (active learning methods in the training process)

Next, the table is filled in by the student manually. Each subsequent state of the register is determined based on the following relationships:

$Q_{n+1}^{t+1} = Q_n^t$, for $n = 1 \div 7$, where n is the number of the flip-flop in the chain, and t is the clock (a discrete moment of time).

The color explanations illustrated in Fig. 1, block 5 (for determining the bits from 2 to 8) and block 6 and block 6a (for determining the first bit of the register state for different possible options for taps selection) is used to facilitate filling in the table by students.

In the Number column, Fig. 1, Block 7, the decimal equivalent of the current state of the register is determined by the sum $\sum_{i=1}^{8} w_i Q_i^t$, where $w_i = 2^{8-i}$ are the weights of the respective digits, $Q_i^t = 1$ or $Q_i^t = 0$ in the current state.

To determine the ciphertext (CT) and to fill in block 9, Fig. 1, adding modulo 2 (XOR-ing) the cells of block 8 and their respective cells from column 8 for bit Q_8^t is used based on the formula: $CT^t = PT^t \oplus Q_8^t$ for $t = 1 \div 21$ (for ASCII code) or $t = 1 \div 24$ (for EBCDIC code).

Then, the student finally writes down the message for encryption (plaintext, PT, *m*) and the encrypted text (ciphertext, CT, *c*), transforming the encrypted text from ASCII code into characters (again using the table in [6]) in block 10, Fig. 1.

C. Spreadsheets and choosing a spreadsheet program for implementing the application

A spreadsheet is a file made of rows and columns that help arrange data easily, sort data, and calculate numerical data using mathematical formulas and the data in cells. Today, Microsoft Excel is the most popular and widely used spreadsheet program, but there are also many alternatives: Google Sheets (online and free), iWork Numbers (Apple Office Suite), LibreOffice Calc (free), Lotus 1-2-3 (discontinued), Lotus Symphony (Spread-sheets), Microsoft Excel, OpenOffice Calc (free), VisiCalc (discontinued). Although spreadsheets are typically used when working with numbers, the uses of spreadsheets are almost endless. Some other popular uses of spreadsheets are: finance, forms, school and grades, lists, sports [7, 8].

In order to facilitate the generation of a plurality of suitable individual assignments for students, an application is created which allows to encrypt (or decrypt) a 3-symbol message, and it performs all the steps described in Fig. 1.

For the implementation, Microsoft Excel is chosen as a spreadsheet program because of its advantages: 1) its tools make the work easier; 2) mathematical formulas and formulas for working with strings make things easier; 3) analyzing and storing data; 4) security; 5) online access; 6) it keeps data combined at one location [7, 8 ,9].

MS Excel allows to represent the studied processes visually in tables and it facilitates the perception of the material. Using spreadsheet programs is very suitable for implementing such solutions in the field of cryptography [10, 11, 12, 13].

III. RESULTS

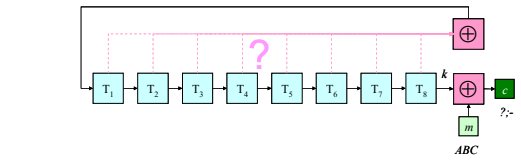
A. *Modeling the encryption process in cryptosystems based on LFSRs using spreadsheets*

Using the principles in Fig. 1, spreadsheets-based application implementing and graphically presenting the encryption of English texts using LFSRs is developed and described in the paper.

21 options of taps selection are implemented: 1) 8,7 (Q_8, Q_7); 2) 8,6 (Q_8, Q_6); 3) 8,5 (Q_8, Q_5); 4) 8,4 (Q_8, Q_4); 5) 8,3 (Q_8, Q_3); 6) 8,2 (Q_8, Q_2); 7) 7,6 (Q_7, Q_6); 8) 7,5 (Q_7, Q_5); 9) 7,4 (Q_7, Q_4); 10) 7,3 (Q_7, Q_3); 11) 7,2 (Q_7, Q_2); 12) 6,5 (Q_6, Q_5); 13) 6,4 (Q_6, Q_4); 14) 6,3 (Q_6, Q_3); 15) 6,2 (Q_6, Q_2); 16) 5,4 (Q_5, Q_4); 17) 5,3 (Q_5, Q_3); 18) 5,2 (Q_5, Q_2); 19) 4,3 (Q_4, Q_3); 20) 4,2 (Q_4, Q_2); 21) 3,2 (Q_3, Q_2). The number of options can be increased by encompassing more than two flip-flops included in the feedback of the register by using multiple logic gates of the type two-input XOR, or using a multi-input XOR logic gate.

The process of encryption of a 3-symbol word (for example, EOF) in English is illustrated in Fig. 2.

Regrettably, sometimes, in the ciphertext there are 7-bit combinations that do not display printable characters, but correspond to control characters or simply are not used. For example, the message RSA (Rivest-Shamir-Adleman, one of the first public-key cryptosystems, widely used for secure data transmission) is encrypted, with a cryptosystem based on an 8-bit LFSR – option 19 (taps: Q_3, Q_4), initial state (seed): 01111101.



MESSAGE: EOF — E O F

Option 5

8,3

№	128	64	32	16	8	4	2	1	Number	PT	CT
	1	2	3	4	5	6	7	8			
1	0	1	0	1	1	0	1	1	91	1	0
2	1	0	1	0	1	1	0	1	173	0	1
3	0	1	0	1	0	1	1	0	86	0	0
4	0	0	1	0	1	0	1	1	43	0	1
5	0	0	0	1	0	1	0	1	21	1	0
6	1	0	0	0	1	0	1	0	138	0	0
7	0	1	0	0	0	1	0	1	69	1	0
8	1	0	1	0	0	0	1	0	162	1	1
9	1	1	0	1	0	0	0	1	209	0	1
10	1	1	1	0	1	0	0	0	232	0	0
11	1	1	1	1	0	1	0	0	244	1	1
12	1	1	1	1	1	0	1	0	250	1	1
13	1	1	1	1	1	1	0	1	253	1	0
14	0	1	1	1	1	1	1	0	126	1	1
15	1	0	1	1	1	1	1	1	191	1	0
16	0	1	0	1	1	1	1	1	95	0	1
17	1	0	1	0	1	1	1	1	175	0	1
18	0	1	0	1	0	1	1	1	87	0	1
19	1	0	1	0	1	0	1	1	171	1	0
20	0	1	0	1	0	1	0	1	85	1	0
21	1	0	1	0	1	0	1	0	170	0	0

Plaintext (PT):	E	O	F
Ciphertext (CT):	(	m	8

Figure 2. Encryption of a 3-symbol message using a cryptosystem based on an 8-bit LFSR in MS Excel – option 5 (taps: Q_3, Q_8); plaintext: **EOF** (end of file), initial state (seed): 01011011; ciphertext: **(m8**

In this case, the ciphertext consists of non-printable characters (control characters or not used combinations in the character set of ASCII codes). The results from the encryption are shown in Fig. 3. Here, the first 7 bits (0001101) of the ciphertext represent the control character CR (Carriage Return), even not displayed in MS Excel, the second 7 bits (1011010) of the ciphertext represent the printable symbol Z (uppercase), and the last 7 bits (0010110) represent the control character SYN (Synchronous Idle). These three symbols are marked with red rectangles in Fig. 4.

The usage of the built-in functions in MS Excel for developing the application for encryption is illustrated in Fig. 5.

MESSAGE: RSA — R S A

Option 19

4,3

№	128	64	32	16	8	4	2	1	Number	PT	CT
	1	2	3	4	5	6	7	8			
1	0	1	1	1	1	1	0	1	125	1	0
2	0	0	1	1	1	1	1	0	62	0	0
3	0	0	0	1	1	1	1	1	31	1	0
4	1	0	0	0	1	1	1	1	143	0	1
5	0	1	0	0	0	1	1	1	71	0	1
6	0	0	1	0	0	0	1	1	35	1	0
7	1	0	0	1	0	0	0	1	145	0	1
8	1	1	0	0	1	0	0	0	200	1	1
9	0	1	1	0	0	1	0	0	100	0	0
10	1	0	1	1	0	0	1	0	178	1	1
11	0	1	0	1	1	0	0	1	89	0	1
12	1	0	1	0	1	1	0	0	172	0	0
13	1	1	0	1	0	1	1	0	214	1	1
14	1	1	1	0	1	0	1	1	235	1	0
15	1	1	1	1	0	1	0	1	245	1	0
16	0	1	1	1	1	0	1	0	122	0	0
17	0	0	1	1	1	1	0	1	61	0	1
18	0	0	0	1	1	1	1	0	30	0	0
19	1	0	0	0	1	1	1	1	143	0	1
20	0	1	0	0	0	1	1	1	71	0	1
21	0	0	1	0	0	0	1	1	35	1	0

Plaintext (PT):	R	S	A
Ciphertext (CT):		Z	

Figure 3. Encryption of a 3-symbol message using a cryptosystem based on an 8-bit LFSR in MS Excel – option 19 (taps: Q_3, Q_4); plaintext: **RSA**; initial state (seed): 01111101; ciphertext consists of non-printable characters (control characters or not used combinations in the character set of ASCII codes)

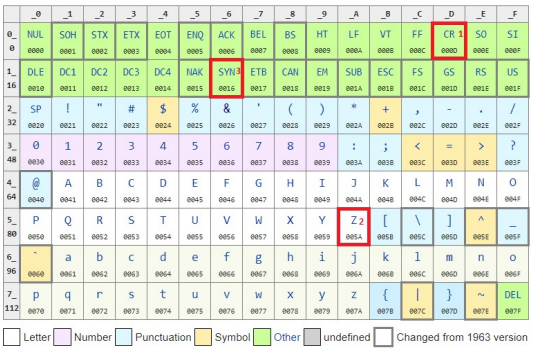


Figure 4. ASCII code – character set [6]

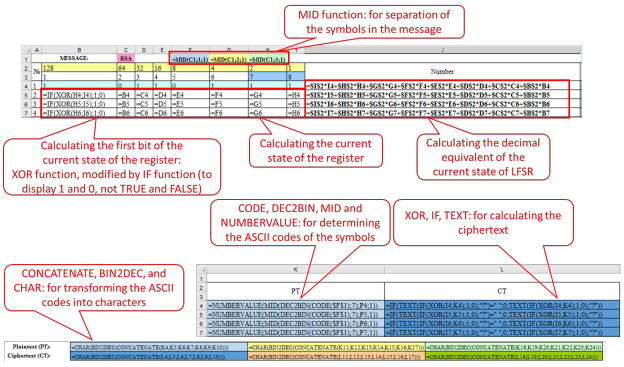


Figure 5. Functions used in the application for encryption

B. *Modeling the decryption process in cryptosystems based on LFSRs using spreadsheets*

Based on the application for encryption, spreadsheets-based application for decryption of English texts using LFSRs is developed also. The functions used are the same. Only the terms: Plaintext, PT, Ciphertext, CT are changed respectively with the terms: Ciphertext, CT, Plaintext, PT.

The application implementing and graphically presenting the process of decryption of English texts using a cryptosystem based on an 8-bit LFSR is shown in Fig. 6. The ciphertext is **(m8**, obtained in the encryption process (Fig. 2, option 5, taps Q_3 & Q_8). After decryption, the decrypted text is EOF, the same as the plaintext in Fig. 2.

However, if the initial state (seed) of LFSR is not the same as the one in the encryption process, i.e. changed, then the decryption will be done incorrectly and the decrypted text will not match to the plaintext transmitted on the channel in the digital communication system, i.e. it will not be correct. An example is shown in Fig. 7, in this case only the initial state of the register is changed from 01011011 to 01**1**11011.

MESSAGE: (m8 (m 8

Option 5

8,3

№	128	64	32	16	8	4	2	1	Number	CT	PT
	1	2	3	4	5	6	7	8			
1	0	1	0	1	1	0	1	1	91	0	1
2	1	0	1	0	1	1	0	1	173	1	0
3	0	1	0	1	0	1	1	0	86	0	0
4	0	0	1	0	1	0	1	1	43	1	0
5	0	0	0	1	0	1	0	1	21	0	1
6	1	0	0	0	1	0	1	0	138	0	0
7	0	1	0	0	0	1	0	1	69	0	1
8	1	0	1	0	0	0	1	0	162	1	1
9	1	1	0	1	0	0	0	1	209	1	0
10	1	1	1	0	1	0	0	0	232	0	0
11	1	1	1	1	0	1	0	0	244	1	1
12	1	1	1	1	1	0	1	0	250	1	1
13	1	1	1	1	1	1	0	1	253	0	1
14	0	1	1	1	1	1	1	0	126	1	1
15	1	0	1	1	1	1	1	1	191	0	1
16	0	1	0	1	1	1	1	1	95	1	0
17	1	0	1	0	1	1	1	1	175	1	0
18	0	1	0	1	0	1	1	1	87	1	0
19	1	0	1	0	1	0	1	1	171	0	1
20	0	1	0	1	0	1	0	1	85	0	1
21	1	0	1	0	1	0	1	0	170	0	0

Ciphertext (CT): (m 8

Decrypted text, Plaintext (PT): E O F

Figure 6. Decryption of a 3-symbol message using a cryptosystem based on an 8-bit LFSR in MS Excel – option 5 (taps: Q_3, Q_8); encrypted message: (m8; initial state (seed): 01011011; decrypted text: EOF – CORRECT decryption

MESSAGE: (m8 (m 8

Option 5

8.3

№	128	64	32	16	8	4	2	1	Number	CT	PT
	1	2	3	4	5	6	7	8			
1	0	1	1	1	1	0	1	1	123	0	1
2	0	0	1	1	1	1	0	1	61	1	0
3	0	0	0	1	1	1	1	0	30	0	0
4	0	0	0	0	1	1	1	1	15	1	0
5	1	0	0	0	0	1	1	1	135	0	1
6	1	1	0	0	0	0	1	1	195	0	1
7	1	1	1	0	0	0	0	1	225	0	1
8	0	1	1	1	0	0	0	0	112	1	1
9	1	0	1	1	1	0	0	0	184	1	1
10	1	1	0	1	1	1	0	0	220	0	0
11	0	1	1	0	1	1	1	0	110	1	1
12	1	0	1	1	0	1	1	1	183	1	0
13	0	1	0	1	1	0	1	1	91	0	1
14	1	0	1	0	1	1	0	1	173	1	0
15	0	1	0	1	0	1	1	0	86	0	0
16	0	0	1	0	1	0	1	1	43	1	0
17	0	0	0	1	0	1	0	1	21	1	0
18	1	0	0	0	1	0	1	0	138	1	1
19	0	1	0	0	0	1	0	1	69	0	1
20	1	0	1	0	0	0	1	0	162	0	0
21	1	1	0	1	0	0	0	1	209	0	1

Ciphertext (CT): (m 8

Decrypted text, Plaintext (PT): G j

Figure 7. Decryption of a 3-symbol message using a cryptosystem based on an 8-bit LFSR in MS Excel – option 5 (taps: Q_3, Q_8); encrypted message: (m8; initial state (seed): 01**1**11011; decrypted text: Gj – INCORRECT decryption

In the case of Fig. 7, in the reverse transformation, i.e. when decrypting, the message cannot be written because of the non-printable characters. Here, the first 7 bits (1000111) of the ciphertext represent the printable symbol G (upper), the second 7 bits (1101010) of the ciphertext represent the printable symbol j (lower) and the last 7 bits (0001101) represent the control character CR (Carriage Return), even not displayed in MS Excel. This symbol is marked with a red rectangle in Fig. 4, 1. In this case, the bits of the ciphertext (encrypted text) in the column CT should be written bit by bit, without using the conversion into ASCII codes.

The spreadsheets-based applications for encryption and decryption are used in the educational process in the course "Telecommunication Security", included as compulsory in the curriculum of the specialty "Internet and Mobile Communications" for Bachelors at the University of Ruse "Angel Kanchev".

The results from the encryption process of 3-symbol messages using a cryptosystem based on 8-bit LFSRs, obtained by the applications presented in the paper, are shown in Table I, for all the options (1…21), for a given initial state (seed) in two cases: case I: using plaintext RSA; case II: using different 3-symbol messages for plaintexts.

Using the applications described in the paper, an initial state of the register is sought, allowing for the ciphertext containing only printable characters (Table I). Students have to decipher the encrypted texts (ciphertexts) and, as a result, they receive 3-symbol messages, abbreviations used in the field of computer and communication technologies.

TABLE I. ENCRYPTION OF 3-SYMBOL MESSAGES USING A CRYPTOSYSTEM BASED ON 8-BIT LFSRS – FOR ALL THE OPTIONS, FOR A GIVEN INITIAL STATE (SEED); CASE I: PLAINTEXT – RSA; CASE II: PLAINTEXT – DIFFERENT ABBREVIATIONS USED IN THE FIELD OF COMMUNICATIONS

Option	Initial state (seed)								Case I		Case II	
									PT	CT	PT	CT
1 (8,7)	1	1	1	0	1	0	1	0	RSA	y-@	ABI	j<H
2 (8,6)	1	1	0	1	0	0	1	1	RSA	7*O	BCD	':J
3 (8,5)	0	0	1	0	1	0	1	1	RSA	8N8	CAD	)\=
4 (8,4)	1	1	1	1	1	0	0	0	RSA	]+~	DPI	K(v
5 (8,3)	0	1	0	1	1	0	1	1	RSA	?q?	EOF	(m8
6 (8,2)	1	0	0	0	0	0	1	1	RSA	29/	FAT	&+:
7 (7,6)	0	1	0	1	0	0	1	0	RSA	w|1	GSM	b|=
8 (7,5)	0	0	0	1	1	1	1	1	RSA	._|	HAL	4Mq
9 (7,4)	1	0	1	0	1	1	1	1	RSA	(?M	ICT	3/X
10 (7,3)	1	0	0	0	1	1	1	1	RSA	*%U	JCE	25Q
11 (7,2)	1	0	1	0	1	0	1	1	RSA	8$R	KRL	!%_
12 (6,5)	0	0	1	1	0	1	1	1	RSA	$f~	LSB	:f}
13 (6,4)	0	1	0	1	1	1	1	1	RSA	/@|	MAC	0R~
14 (6,3)	1	1	1	0	0	0	1	1	RSA	1+?	NIC	-1=
15 (6,2)	0	0	1	1	0	1	1	1	RSA	$v7	OSI	9v?
16 (5,4)	0	1	1	0	0	1	1	1	RSA	!F9	PCM	#V5
17 (5,3)	1	1	0	0	1	0	1	1	RSA	;+/	QDR	8<<
18 (5,2)	1	0	0	1	1	1	1	1	RSA	.:D	RGB	..G
19 (4,3)	0	0	1	1	1	0	1	1	RSA	<@n	SDH	=Wg
20 (4,2)	0	0	1	0	1	1	1	1	RSA	(Gi	TCP	.Wx
21 (3,2)	1	0	1	0	1	1	1	1	RSA	(!3	USB	/!0

The applications, developed and presented in the paper, help the teacher in the process of generating individual assignments for students by aiming not to allow non-printable (control or even unused combinations for ASCII codes) in the encrypted text to be obtained, making it impossible to formulate the reverse task, namely decryption of the encrypted text to be performed using the cipher-text. This is the main usage of the applications at the moment. Applications are also used to visualize encryption and decryption processes in cryptosystems based on linear feedback shift registers when explaining the theoretical layout of the task.

Additionally, the applications facilitate the lecturer in checking the students' work, thus saving the time of the lecturer, which he/she can use to perform other duties. In groups with a higher number of students, applications are used by students to check their work or the work of their colleagues. Here, however, one must rely on the correctness of student behavior.

At the moment, applications are not designed to allow a certain number of points to be assigned to each operation, because (as mentioned in the paper) the students solve their assignment manually in order to better understanding the material. Often the usage of developed software tools does not lead to insight into the material being studied, and students often do not understand the principles of the processes under consideration.

In the academic year 2017-2018, an experiment was conducted with 52 students. After teaching the theory about encryption and decryption using cryptosystems based on LFSRs and making some exercises by the students, some time to do a self-assessment with the students was done.

At the end of the experiment, the students were asked about their opinion about the lesson and to think about how they felt they were doing on the studied material. Each student was given three cards: a green, a yellow and a red card. Each card represented how students feel about the material studied in the classes, Fig. 8.

During the experiment, the students had to encrypt a plain-text based on the methodology presented in the paper. Their work was rated by 100 points. Only 8 of them did not do it (below 50 points, the "red" group), 18 of the showed satisfactory results (from 51 to 90 points, the "yellow" group) and a half of the students (26 students) showed excellent results (from 91 to 100 points, the "green" group).



Figure 8. Dividing the students into three groups: green, yellow, red

The students in the green group were the excellent students. They thought that the problem was easy and they got it and they could do it by theirselves. The students in the yellow group had the satisfactory results and they said that they needed a little more help to do the task. The students in the red group said that the task was very hard and they still needed a lot of help.

This way it might be seen which students understood the new lesson, which students struggled a bit and which students had a hard time understanding everything [14]. The lecturer had an overview of the students who learnt the new lesson and the students who did not. This made it easy to differentiate. The lecturer made three groups and divided the students according to the cards, respectively the results.

The cards divided students into groups according to their learning level. Using the self-assessment idea "networking for help", Fig. 9, [14], 1) students with a green card had to pair up with students with a red or a yellow card; 2) students with a yellow card had to pair up with students with another yellow or green card; 3) students with a red card had to pair up with a student with a green card. This way students helped each other understand the lesson.

Then the green group could start practicing more advanced topics and dig deeper into the lesson material: for example: 1) using the MS Excel-based application for encryption presented in the paper, the students generate individual assignments for encryption where the cipher-texts do not contain non-printable (control or unused combinations for ASCII codes) in the encrypted text; 2) using the MS Excel-based application for decryption presented in the paper, the students decrypt a given cipher-text when the initial state of the LFSR is not known, i.e. breaking the cipher (a hard problem for solving, even when using the decryption application, due to the large number ($2^8 = 256$) of possible initial states of the LFSR; 3) implementing the cryptosystem based on an 8-bit LFSR with D flip-flops and XOR gates and simulating its operation in Logisim (or other software product, such as MicroCAP, Multisim, etc.); 4) FPGA implementation and testing the cryptosystem based on an 8-bit LFSR on a laboratory board using Spartan-6 devices developed at the University of Ruse.

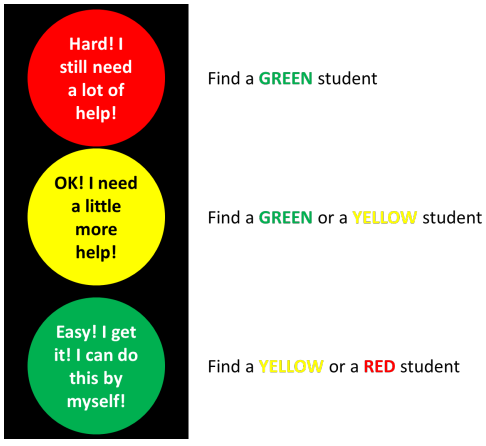


Figure 9. Presenting the self-assessment idea "networking for help"

The yellow group started practicing some medium exercises and got some extra explanation, for example doing some more exercises with the examples presented in Table I.

The red group started from almost scratch. Here the lecturer had to explain the lesson material again so they could learn the basics. They began with easier exercises, for example only one symbol, but not 3-symbol messages, using the applications developed to see all the steps and to understand the processes of encryption and decryption.

Student self-assessment implicates students in evaluating their own work and learning progress. Self-assessment is a valuable learning tool as well as part of an assessment process. Using self-assessment, students can: 1) identify their own skill gaps, where their knowledge is weak; 2) see where to focus their attention in learning; 3) set realistic goals; 4) revise their work; 5) track their own progress; 6) if online, decide when to move to the next level of the course. This process helps students stay involved and motivated and encourages self-reflection and responsibility for their learning [15].

IV. CONCLUSION

The paper presents MS EXCEL-based applications implementing and graphically illustrating the processes of encryption and decryption of English texts (3-symbol words) using LFSRs. Numerous examples obtained by the applications are given in the paper. Some features and problems that arise when encrypting and decrypting texts are illustrated and explained by examples. The applications allow easily assimilation of the material studied by the students as the steps at each stage of encryption and decryption are tracked in details. Additionally, the applications allow the assistant to automatically generate tasks for individual assignments for students, and assist the process of checking students' solutions.

For more effective learning, active learning methods are applied. During the practical exercises, an individual assignment is given to each student. The student must: 1) determine the states of an LFSR for a given initial state (seed); 2) encrypt a given plaintext (3-symbol English text containing Latin letters, decimal digits, punctuation signs, arithmetic and logical operators and so on) using LFSR; 3) decrypt a given cipher-text using LFSR. After solving their individual problems using a pre-prepared form, they submit it to the lecturer at the end of the classes.

The material is used in the educational process in the course "Telecommunication Security", compulsory in the curriculum of the specialty "Internet and Mobile Communications" for Bachelors at the University of Ruse but it can be applied in other courses involving issues of cryptographic information protection, such as Cryptography and Data Security, Security in the Telecommunication Networks, Coding and Security in Telecommunication Networks, etc., and even in courses, such as "Digital Electronics" and "Pulse and Digital devices" where students can learn about an interesting application of the digital devices studied in the courses.

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Assessment of Mental Fatigue During Examination Period with P300 Oddball Paradigm

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***Abstract* - Mental fatigue refers to the effects that people experience during and following prolonged periods of cognitive activity that requires work efficiency. Undergraduate students are faced with increased cognitive demands during the examination period that can lead to a higher level of perceived mental fatigue. The P300 component of the event-related potentials is considered an indicator of cognitive information processing, attention allocation and immediate memory. Variation in the P300 component has been linked to a fluctuation in natural and environmentally induced states. In order to evaluate the effects of sleepiness and the mental fatigue we used visual discrimination task to evoke the P300 potential. Reaction time (RT) to deviant stimuli and number of errors were also recorded. Several features of P300 evoked related potential, such as maximum and minimum amplitude, and latency were extracted to evaluate subject's performance in two sessions: during rested period and tired period. Subjects were placed into two sessions based on the battery of tests aimed to assess their arousal state. Rested state was recorded when subjects did not have any increased mental assignments. Tired state was recorded during their increased mental work overload during exam period. Results show a significantly smaller mean amplitude ($p < 0.05$) and slower RTs in a tired state.**

Keywords – mental fatigue, P300, examination period, EEG, event related potentials

I. INTRODUCTION

Mental fatigue refers to the effects that people experience during and following prolonged periods of cognitive activity that requires work efficiency.

During exam preparation, students' mental fatigue, sleepiness and stress are increased due to cognitive demanding tasks [1], [2]. Complex cognitive processes such as solving exam assignments require complex information processing functions, such as continuous planning and monitoring for action. To sustain performance on an exam, students are required to have access and regulate their cognitive resources for a given task [3]. Performing the task for a prolonged period causes a decline of information processing functions and lower availability of resources important for the performance and reasoning [4]. Therefore, mental fatigue has impact on the ability to process information.

Different aspects of information processing can be analyzed by measuring brain activity with electroencephalogram (EEG). EEG is the most widely used method for the assessment of neuropsychological activity because it is quite affordable and non-invasive [5].

Event-related brain potential (ERP) provides precise measurement of the information processing time that occurs between stimulus onset and response, due to its good temporal resolution [6]. The ERP component P300 is defined as the most positive peak in a window between 200 and 500 milliseconds [7].

The P300 component is considered an indicator of cognitive information processing, allocation and maintaining of attentional resources [8], stimulus classification speed [9], and the processing time required before response generation [10]. Kahneman [11] proposed diagram (Fig. 1) that describes relationship between attentional resource allocation and P300 outcomes. For example, when task conditions are undemanding, overall arousal level is smaller and the amount of attention available for task performance is larger. Thus, P300 amplitude is relatively large and peak latency is relatively short. Otherwise, when task conditions are demanding, overall arousal level is larger as greater amounts of attentional resources are needed. In this case, P300 amplitude is smaller and peak latency is longer [12], [13].

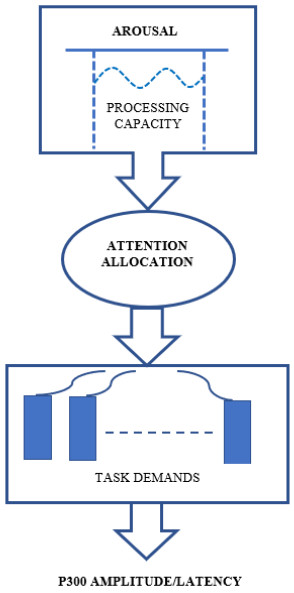

Figure 1. Relationship between attentional resource allocation and P300 outcomes (adopted from [11], [14])

Variation in the P300 component has been linked to a fluctuation in environmentally induced states such as mental fatigue. However, variation in the P300 component has also been linked to natural induced states such as circadian rhythms and sleepiness. For example, Higuchi et al. [15] found that the variations in the P300 latency and the amplitude are related with measures of sleepiness and attention level such that the P300 latency was longest at 08:00 AM, it reduced at 11:00 AM and after a slight increase at 14:00 PM, it declined again at 17:00 PM and 20:00 PM.

Therefore, in order to evaluate the effect of mental fatigue and sleepiness in undergraduate students during rested and during exam period we used visual discrimination task to evoke the P300 potential.

II. METHODS

A. Participants

This study was conducted at the University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, Zagreb, Croatia. The participants were recruited on a volunteer basis via emails and advertisements at the University Campus, the University of Zagreb and the University of Zagreb, Faculty of Electrical Engineering and Computing.

Fourteen healthy subjects participated in the study. All of them were students included in undergraduate program at the time of recording and have reported to have taken written exam before the tired session recording. Written exams were part of the midterm exams, with middle to high stakes. Participants came to the session recording immediately after the exam. There were 8 female and 6 male participants, with mean age of 21. None of them participated in P300 study before and did not reported any psychiatric, neurological or other disorders. All the participants with corrected vision wear glasses during the experiment. Participants were thoroughly familiarized with the laboratory setting, experimental procedure and tasks prior to taking part in the study. The study was carried out in accordance with the guidelines of the Declaration of Helsinki and approved by the ethics committee of the University of Zagreb, Faculty of Electrical Engineering and Computing. Participants provided written informed consent prior to taking part in the study and were informed of their rights under the Freedom of Information Act.

Three participants were excluded from further analysis due to increased number of artefacts during recording. Therefore, analysis presented in this paper is grand average of remaining eleven participants (6 female and 5 male).

B. Data Acquistion

The electroencephalogram (EEG) was recorded with 16 channel VAmp EEG amplifier (Brain Products, Munich, Germany) with passive sintered Ag/AgCl electrodes. The electrodes used were: O1, O2, P3, P4, Pz, C3, C4, Cz, T3, T4, F7, F8, F3, and F4 with additional HEOG and VEOG electrooculogram (EOG) electrodes. Linked mastoid electrodes were used as a reference with 5kΩ resistance between them. BrainVision Recorder software was used for impendence check and on-line monitoring. The EEG and EOG signals were recorded with 500 Hz sampling rate and bandpass filter of 0.01-70 Hz.Visual stimuli were presented on a notebook with 15.6-inch LCD screen. EPrime software was used to generate stimulus and triggers. Triggers were sent via parallel port to the VAmp amplifier and stored for offline analysis. Participants responded to deviant stimuli on the marked keyboard button. Responses were recorded and saved in the EPrime software for offline analysis.

C. Experimental Paradigm

To evoke the P300 potentials, oddball paradigm with visual stimulus was used. Green circle was presented as standard stimuli, while red circle as deviant stimuli. In Table I main stimulus properties of experimental P300 paradigm is given, as it is suggested in [16]. EEG recording procedure consisted of several parts:

1. EEG cap montage
2. Participants were asked to blink repeatedly (the recorded blinks were later used for blink artefact removal)
3. P300 oddball paradigm
4. EEG cap removal and washing

TABLE 1. P300 EXPERIMENTAL PARADIGM STIMULUS PROPERTIES

Stimulus Properties	Comment
Duration	50 ms
Interstimulus interval	1100 – 1500 ms
Dimensions of change	Color
Probabilites	.15 (standard) - .85 (deviant)

During the first session, participants were familiarized with the laboratory setting, experimental procedure, and the tasks, thus minimizing the potential effects of situation-induced arousal. General background questionnaires including demographic information and medical history as well as Student morningness-eveningness (Composite Scale of Morningness, CSM) [17] and handedness information [18] were also administered. Subjectively rated sleepiness (Karolinska sleepiness scale, KSS) and fatigue (Fatigue Assessment Scale, FAS) were measured before each of the P300 measurements.

The experimental paradigm session was repeated two times: during rested period and tired period. In each session participant was presented with total of 45 deviant and 255 standard stimuli. With interstimulus interval of 1100 – 1500 ms the whole P300 oddball paradigm lasted approximately 6 – 8 minutes. The whole EEG recording procedure with questionnaires lasted approximately 45 minutes.

D. Offline Data Analysis

EEG analysis

The offline analysis of gathered EEG data was done in BrainVision Analyzer 2. Preprocessing of EEG data consisted of several steps:

- Digital bandpass filtering with cut-off frequency 0.1 - 30 Hz
- Removing of ocular artefacts using ICA
- Semi-automatic removal of signal artefacts
- Segmentation based on deviant (S1) and standard (S2) stimuli
- Epoch averaging
- Baseline correction

For statistical comparison of P300 evoked potential the mean amplitude measure is used with time latency window of 280 – 420 ms. The number of trials averaged for each participant altered for each participant due to different number of artefacts. Mean amplitude measure is chosen for this application as it is not influenced by different number of trials across participants or by latency jitter in single trial EEG waveforms [5]. Minimum number of averaged trials was 30.

Reaction Time analysis

RT (Reaction Time) responses on keyboard were recorded with the EPrime software. Following inputs were recorded for each stimulus: participants ID, response, correct response, and the time of response relative to the previous stimuli. For each participant histogram of correct responses was calculated with 50 ms difference between bins. From histograms, a probability distribution is estimated. Also, statistical measurements are calculated from given data: mean, mode, median, skewness and kurtosis. Results from the analysis are shown in section Results.

TABLE 2. NUMBER OF TRIALS AVERAGED FOR EACH PARTICIPANT

Partici-pant ID	CSM score	FAS (Rested state)	FAS (Tired state)	KSS (Rested state)	KSS (Tired state)
I0001	24	18	16	7	4
I0002	Didn't fill out the form	66	31	8	4
I0003	25	23	22	8	3
I0005	19	26	23	7	2
I0006	24	23	24	8	3
I0007	35	20	19	6	3
I0008	33	25	24	7	2
I00010	28	32	30	7	1
I00011	29	30	34	6	4
I00012	26	27	24	8	2
I00015	28	25	25	8	2

III. RESULTS

Due to lack of space, all figures in Results section are result of grand average across all participants.

A. Bihevioral Data

For each participant Composite Scale of Morningness (CSM) score, Fatigue Assessment Scale (FAS) score and Karolinska sleepiness scale (KSS) score are given in Table 2. The sum of the responses on CSM yields a total score in range between 10 and 55. Results on CSM in our sample ranged between 19 and 35 where higher score reflects greater morningness. The sum of the responses on FAS yields a total score in range between 10 and 50. Results in the range between 22 and 34 indicate fatigue and results in the range between 35 and 50 indicate absolute fatigue. A Wilcoxon signed-rank test showed that FAS score did not change statistically significant in tired and rested state ($Z = -1.644$, $p = 0.1$). Indeed, median FAS score was 25 in tired and 24 rested state. On the other hand, a Wilcoxon signed-rank test showed that KSS score was statistically different in tired and rested state ($Z = -2.956$, $p = 0.003$). Indeed, median KSS score was 7 in tired and 3 in rested state where higher score indicates higher level of sleepiness.

Mean accuracy of responses to deviant stimuli are near 100% for all participants in both mental fatigue states (rested and tired), and therefore are not shown in detail here. Means and median of RTs are shown in Table 3 for each participant in both rested and tired state.

Average difference of RTs means in tired state and rested state is 29 ms. The slowing of RTs in tired state is due to larger probability of relatively long RTs rather than a rightward shift of entire RT distribution [19]. This is shown in Fig 2, where the orange line is RT probability distribution in tired state, and the blue is for the rested state. Largest probability for both tired and rested states is around 350 ms, however probability of tired state RTs have a heavier right tail. To numerically compare this effect, statistic measures skewness and kurtosis are calculated for grand averages of all participants (Table 4).

TABLE 3. MEDIAN AND MEAN OF RTS (MS) FOR EACH PARTICIPANT

Participant ID	Mean (Rested state)	Mean (Tired state)	Median (Rested state)	Mean (Tired state)
I0001	316	441	314	433
I0002	327	336	323	318
I0003	341	397	344	392
I0005	320	362	309	364
I0006	357	382	354	385
I0007	356	367	355	358
I0008	399	410	386	401
I00010	365	364	361	364
I00011	335	324	322	321
I00012	361	383	356	366
I00015	343	343	337	342

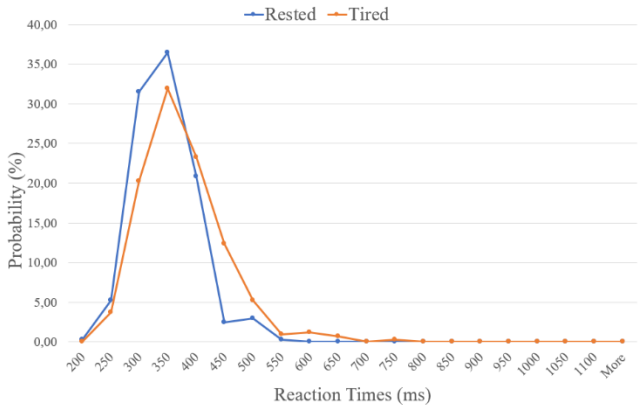

Figure 2. Probability distribution of RTs for all participants (Grand Average)

TABLE 4. DESCRIPTIVE STATISTICS OF RTS (MS) – TIRED AND RESTED STATE OF GRAND AVERAGE

Measure	Rested state	Tired state
Mean	347	376
Median	346	363
Mode	344	333
Kurtosis	1,1028	2,4728
Skewness	0,7463	1,1635
Range	324	489
Minimum	204	244
Maximum	528	733

B. Electrophysiological Data

Grand average P300 component of all participants is shown in Figure 3 for both rested tired states. Due to limited space, only Pz electrode is shown.

Due to convention in Brain Analyzer software, y axis is inverted (positive side is down, and negative is up). The red line represents responses to the deviant stimuli (red circle), and the black line represents responses to the standard stimuli (green circle). Because the participants are asked not to response or count green circles, there is no P300 component present.

In tired state, the amplitude of P300 wave peak is around 10 µV, while in rested state it is around 15 µV. However, the peak amplitude can be influenced by the noise in the signal, or by the different number of trials. Therefore, to compare the P300 evoked potentials in both states, we used mean amplitude measure, as defined by [5]. In Table 5 mean amplitudes on Pz electrode for all participants are given.

TABLE 5. MEAN AMPLITUDE IN 280 – 420 MS TIME FRAME

Participant ID	Mean amplitude (Rested state)	Mean amplitude (Tired state)
I0001	19,33	12,21
I0002	11,71	5,36
I0003	9,56	9,80
I0005	2,27	,00
I0006	2,70	1,94
I0007	9,16	9,02
I0008	16,31	13,73
I00010	13,32	13,32
I00011	10,03	8,42
I00012	10,10	7,18
I00015	12,29	14,63

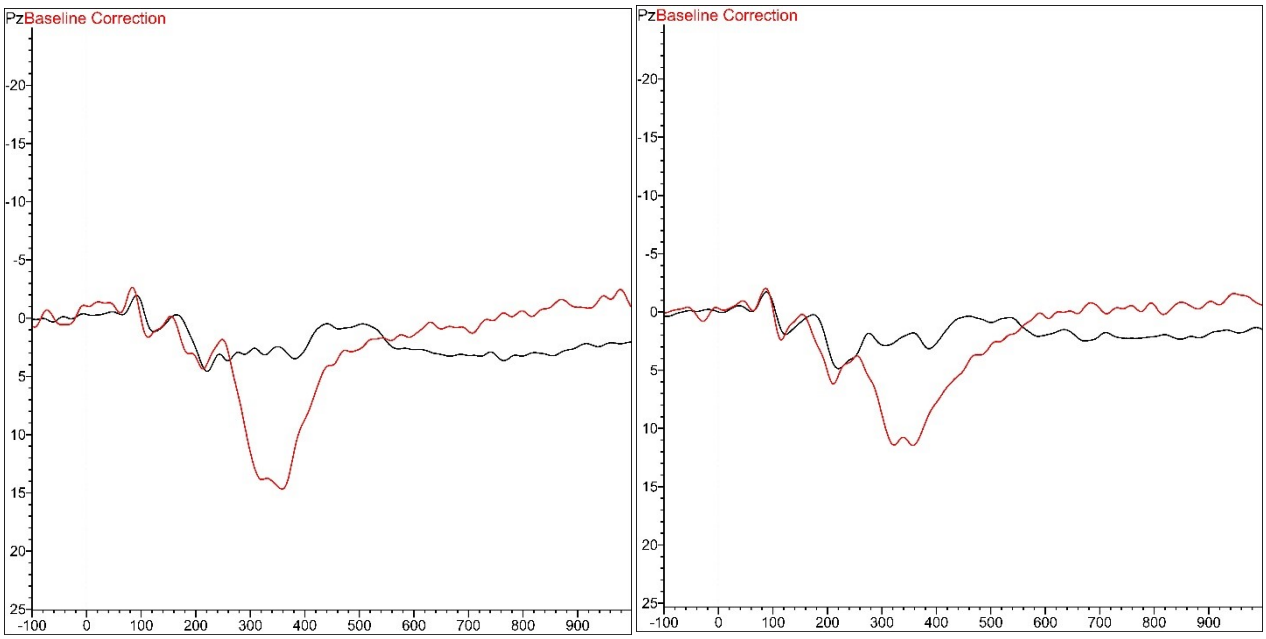

Figure 3. Response to deviant stimuli - P300 evoked potentials (red)
Left: Rested state; Right: Tired state

D. Statistical Analysis

In order to see statistical significance of our study, we have performed a paired samples t-test of mean amplitude values in tired state and rested state. The results are shown in Table 6. Due to the mean amplitude value in rested (10.61 μV) and tired state (8.69 μV) and the direction of the t-value, we can conclude that there was a statistically significant smaller mean amplitude in tired state $t(10) = 2.266$, $p < 0.05$.

TABLE 6. TEST STATISTICS OF P300 MEAN AMPLITUDE VALUES (S1 – DEVIANT STIMULI)

	Tired S1	**Rested S1**	**Tired S1 – Rested S1**
N	11	11	11
Mean	8.69 μV	10.61 μV	1.92 μV
Std. Deviation	4.80 μV	5.05 μV	2.82 μV
Std. Error Mean	1.45 μV	1.52 μV	0.85 μV
Paired Samples Correlations			
	Correlation		p value
Tired and Rested S1	0.838		0.001
Paired Samples Test			
	t	df	p value
Tired S1 – Rested S1	2.266	10	0.047

IV. DISCUSSION AND CONLUSION

The goal of this study was to examine the effects of the mental fatigue in undergraduate students during rested state and during examination period (tired state) on the P300 component of the of the event-related potentials and behavioral measures such as reaction time and number of errors. The effect was measured with the oddball paradigm in order to assess their visual discrimination. Subjects were placed into two sessions based on the several questionnaires aimed to assess their arousal state. These questioners where: Composite Scale of Morningness, Fatigue Assessment Scale, and Karolinska Sleepiness Scale. In the following, we first summarize the main findings and then discuss their implications.

CSM results show that 81% of the undergraduate students have score lower than 30, which places them in more eveningness type of persons. 72% of the participants reported to stay awake late at night. This is in line with research on age differences in the preference for morningness or eveningness where pupils and adolescents show a preference for evening hours [20]–[24].Unfortunately, due to small number of participants, we cannot conclude the optimal time for examination. However, numerous studies indicate that students with a morning preference achieve higher scores due to the earlier starting time of the university exams [25], [26]. Therefore, circadian preferences are valuable indicator for determining both optimal time for lectures to improve learning and starting time for exams to ensure optimal performance.

Based on FAS scores, we can conclude that self-assessment of overall fatigue level did not changed statistically significant in tired and rested state. Overall, participants indicated moderate level of fatigue. This was expected given that FAS examines how often fatigue has affected participant during the past 4 weeks and interval between the first and second experimental session was not longer than 3 weeks.

On the other hand, KSS self-assessment of overall sleepiness level was statistically higher during the examination period. Furthermore, statistically significant results were found in analysis of the P300 evoked potentials. Our results show that the mean amplitude of the P300 is lower in tired group. These results indicate that mental fatigue is related to decreased activity of the central nervous system. More precisely, decrease of the P300 amplitude which has been related to delayed cognitive information processing. In addition, mean and median measures of RT indicate that students in tired state are slower than in rested state (around 29 ms). However, the probability distributions of RTs reflect that slowing of reactions was primarily due to increased probability in longer RTs [17]. Probability for both tired and rested states is highest around 350 ms, but there is a greater probability that tired students will take more time for some answers.

There are several limitations to be consider in the future work. First, the number of participants should be increased. Although the statistical power can be achieved for EEG measurements, more students are needed to examine the effect of self-repot data on differences in electrophysiological processing. Furthermore, future work should include time of day when measuring P300 component. That way, the effect of morningness-eveningess can also be discussed in terms of optimal examination period. Also, an experimental paradigm with a controlled exam scores can enlighten the effects of examination period on students' performance as well.

In sum, our results lend further support to the effect of mental fatigue and sleepiness on the undergraduate students' cognitive information processing after the examination period. In addition, these results demonstrate that future research on mental fatigue and sleepiness in student population should focus on circadian preferences when determining optimal learning outcomes.

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PAPERS

Using modern web frameworks when developing an education application: a practical approach

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***Abstract* - Nowadays the technology evolves rapidly and with it, the computing devices are becoming more powerful, flexible and capable of performing complicated and tangled tasks. This results in a significant shift in the way applications are designed and developed. Yet modern web frameworks manage to cope with this client-side complexity by adopting a mindset oriented towards the design of robust and complex applications that can be delivered quickly with a high level of security, scaled easily, and extended simply. As part of our research on developing an educational application, that supports university students enrolled in Web development course, we made an overview and comparison of the existing technologies, in terms of frameworks, libraries, programming languages and deployment options, adopting a practical approach. Apart from outlining the results, a sample blueprint of the application architecture of the educational application is also proposed in this paper.**

Keywords - Modern web frameworks, Web development, Progressive Web Applications, Single Page Applications, Web Application Frameworks

I. INTRODUCTION

In the past decade we are witnessing a rapid technological growth and evolution. We are constantly seeing emerging media and new trends which also affect the capability and performance of the computing devices. The blending between the physical and virtual world is present and inevitable. From powerful smart devices, rise of artificial intelligence (AI) algorithms and Internet of Things to autonomous vehicles, home appliances or any kind of electronic device with embedded software performing complicated and tangled tasks, we are connected together and able to exchange data. This, expectedly, leads to a significant shift in the way applications are designed and developed.

As part of our research on developing an educational application, that supports university students enrolled in Web development course, we made an overview and comparison of the existing modern frameworks and technologies for development of web applications that address this client-side complexity, adopting a practical approach. We would aim to explain popular concepts and techniques, as well as also push further to answer some vital questions along the way - considering the existence of a well-maintained documentation, presence of an active community, decide between a framework or library, track-record of the team supporting the framework - corporations or enthusiasts, possibilities to easily test and deploy, and last but not least, we would also consider the flexibility and learning curve from practitioners point of view.

The main goal of this paper is to identify a suitable modern web framework that can be used when designing and developing an educational application that supports university students enrolled in Web development course. That's why the paper is structured as follows. First, we introduce some general concepts and key differences related to the development of Web applications and majority of terms considering Single-Page Applications (SPA), Progressive Web Applications (PWA) and more in Section II. In Section III, we introduce some popular and modern web frameworks and libraries, as we make a comparison and analysis of their popularity including statistics from different resources. Then in Section IV, we focus on developing a better and in-depth assessment in order to ensure that the comparison and evaluation of the technologies are as objective as possible, as we reference various criteria in the context of our research. Finally, in Section V we propose a sample blueprint of the architecture of the educational application, based on the researched frameworks, together with summarized outcomes of our study and a work-in-progress.

II. BACKGROUND AND GENERAL CONCEPTS

The Web development process has been evolving and transforming significantly over the past decades. To some extent this change is determined by the technological progress and the advancements that enable and enhance mobile and emerging technologies. Modern web applications have not only higher user expectations and greater demands but they are also expected to be available 24/7 from anywhere in the world, and accessible from any device or screen size. Web applications must be secure, flexible, and scalable to meet urge in demand, and capable in handling complex scenarios and rich user experiences built on the client using JavaScript, and communicating efficiently through web APIs.

There are two general approaches to building web applications today: traditional web applications that perform most of the application logic on the server, and single page applications (SPAs) that perform most of the user interface logic in a web browser, communicating with the web server primarily using web APIs. A hybrid approach can also be implemented, in a way that it can host one or more complex sub-applications with SPA structure within a larger traditional web application.

In the context of our research, we would focus mainly on the development of Single-Page Applications (SPA) incorporating Progressive Web Applications (PWA) techniques. We choose this approach because of our target demographics – students of Generation Z (Gen Z), characterized as multi-taskers with preferences for digital and interactive environments when conducting a teaching process, increased visual learning ability and tendency to consume most of the information on mobile devices. That's why we aim to develop a reliable and capable for working offline solution, fast in terms of responding to user interactions quickly, and engaging and capable to deliver a native app-like experience.

Along with defining SPA and PWA, we would also be highlighting the differences in comparison to the traditional approach. We would skip the techniques when it comes to developing native applications and/or universal applications, mainly because throughout the paper we mention the possibilities to easily migrate and extend the functionalities of existing modern web frameworks and libraries towards that, but also because we would introduce the concepts of PWA, considered a hybrid application.

A. Single Page Applications (SPA)

Nowadays, most of the websites are using SPA which is a web application that sits on top of a single page like any other desktop application. In SPA all the components like CSS, images, scripts and any other required resources are loaded at one time at the initial page load and then appropriate content/components get loaded dynamically depending on the user interaction. Once the user has loaded an initial version, after that every subsequent request will take very less amount of time because it is refreshing that particular part or region of a page rather than reloading an entire page/application. The control remains on one page until the user is on that website and that single page communicates with the server behind the curtain [1].

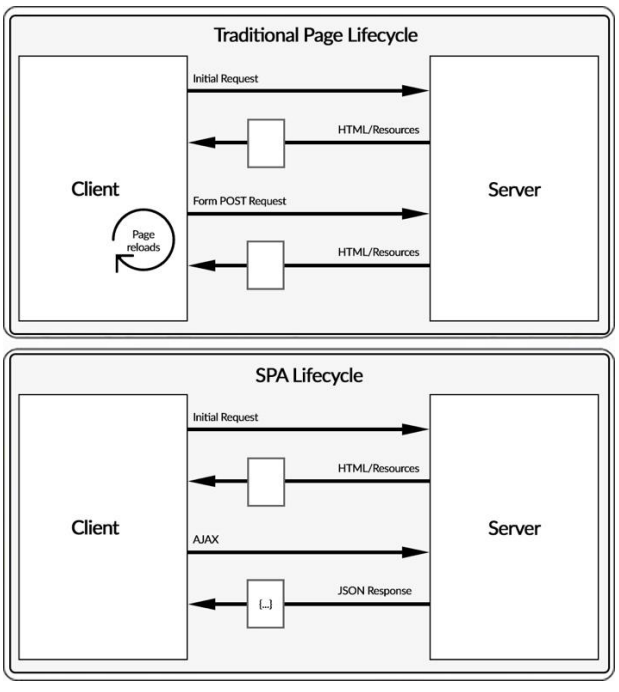

Figure 1. Traditional vs SPA Page Lifecycle comparison

SPA enables a more flexible way of dealing with data while enhancing the user experience with interactive interfaces. In order to understand SPA better, a sample of the Client-Server Request-Response Cycle is presented in Figure 1.

It's possible to extend the SPA to a Multi-Page Application (MPA) adopting, in a way, the traditional approach but this means that every change, for example, displaying the data or submitting data back to the server, requests rendering a new page from the server in the browser. This is recommended for larger and complex applications with various and many levels of user interfaces and components, combined with other good practices and approaches in terms of optimization and performance.

B. Progressive Web Applications (PWA)

Progressive web applications are the new standard in the modern era of web development. They're pure web applications built with the very web technologies (HTML, JS & CSS) but behave as a hybrid i.e. somewhere between web and native apps.

In order to make an application progressive, technically, there are some requirements that define what a PWA is [2]:

- Service Workers for offline caching - the ServiceWorker is responsible for most of the core features associated with PWA. The worker is registered on a user's first-page visit. It consists of a JavaScript file embodying lifecycle hooks for business logic and cache control. The service worker is responsible for caching all files, serving push notifications, content updating, data manipulation and more. It's important to understand that this script works independently of any app or website already existing on the web server, working with event listeners and commands such as "fetch", which resembles HTTP "Get/Post/Set" commands.
- Application Shell - The application shell is defined by the Google Web Fundamentals group as the minimal HTML, CSS, and JavaScript powering a user interface, categorized by fast loading time, cached, and displaying dynamic content, as data is pulled from external APIs.
- Web App Manifest - The purpose of the manifest file is to expose certain modifiable settings to app developers. By providing a data extract in JSON format, it's possible to cache this information with the help of the service worker, and then use the app shell to load CSS rules to deliver an offline version with full UI capabilities. Any time a visitor loads a new page, the service worker will cache the JSON extract anew, and store it physically in the app shell. This app shell is a self-contained wrapper that has all necessary style sheets, scripts, images, fonts and HTML outputs required for a user to render a complete page without loading anything else. Compared to a website, a PWA has the capability of still showing

data when the users are no longer connected to the internet.

- Security through HTTPS - By having a secure connection to the PWA, users can feel relatively safe by allowing permissions and since the network requests are routed through the service worker script, adding https to the server helps to mitigate certain vulnerabilities such as snooping. While this requirement might be focused mainly on adding safety from hijackers, having a secure connection also helps build trust with users.
- Framework Agnostic – the above-mentioned requirements can be applied within any modern framework or library.

A single page application (SPA) is usually a base or part of PWA, unless the SPA approach is not used for a static webpage.

III. MODERN WEB TECHNOLOGIES AND APPROACHES

In Section II, we introduced some general concepts in terms of defining and classifying applications. In this section, we would focus on some of the popular technologies when developing applications for the Web.

In the paper so far and further, we vastly use the term "technologies" to refer to different approaches to developing applications based on either framework, library or programming languages. That's why before we continue, it's important to point out the difference between a library and a framework. In general, the key differentiating feature is the matter of control - frameworks set rules on how your project has to be structured, whereas libraries are building blocks that can be used anywhere.

This being clarified, let's continue with an assessment of the proposed innovative web frameworks.

A. React

React is a declarative and component-based JavaScript library for building user interfaces [3]. Originally released in March 2013, it was developed and is maintained by Facebook. Online references point out that it's also implemented by other leading and innovative companies as Airbnb, Uber, Netflix, Twitter, Pinterest, Reddit, Wix, Paypal, Tumblr, Walmart and others [4].

Some of the key features of the library lay in the ability to design simple views for each state of the application which can be efficiently updated on data changes and the right components can be rendered when needed. It also provides the possibility to build encapsulated components that manage their own state and then compose them into more complex user interfaces. The component logic, on the other hand, is written in JavaScript using a syntax extension called JSX and instead of templates, rich data can be easily passed through the app, thus keeping the state out of the DOM. JSX is a preprocessor that adds XML syntax to JavaScript as JSX tags have a tag name, attributes, and children. Although React can be evoked and applied without JSX, JSX makes the usage of React a lot more structured and convenient.

React can also be rendered on the server using Node.js and power mobile apps using React Native. Node.js is an open-source and cross-platform JavaScript run-time environment that executes JavaScript code outside of a browser, enabling server-side scripting and rendering dynamic web page content before the page is sent to the user's web browser.

In September 2017, Facebook released React Fiber together with React 16, that was described as an ongoing reimplementation of React's core algorithm, aiming to increase its suitability for areas like animation, layout and gestures, and ensuring faster rendering and backward-compatibility.

B. Angular

Angular is a TypeScript-based JavaScript framework, developed and maintained by Google, originally released as AngularJS in 2010 [5]. Angular (also known as Angular 2+, Angular 2 or ng2) is the rewritten and mostly incompatible successor to AngularJS (or AngularJS 1.x), introduced in September 2016 as version 2. The newest major release is version 7.

As a framework for dynamic web applications, Angular adapts structural and modular approach and implements features like two-way data binding, dependency injection, simple template syntax, code generation, RESTful API and AJAX handling, higher performance achieved via code splitting and component router, and others.

Online references suggest that Angular is used not only by Google but also by Forbes, Udemy, Lynda and others [6].

C. Vue

Vue is one of the most rapidly growing and gaining popularity JavaScript frameworks in 2016. Vue is described as an intuitive, performant and composable Model-View-View-Model (MVVM pattern) for building interactive interfaces [7]. It was first released in February 2014 by ex-Google-employee Evan You as a progressive framework for building user interfaces. Unlike other monolithic frameworks, Vue is designed from the ground up to be incrementally adoptable. The core library is focused on the view layer only and is easy to pick up and integrate with other libraries or existing projects. On the other hand, Vue is also perfectly capable of powering sophisticated Single-Page Applications when used in combination with modern tooling and supporting libraries [7].

Ever since its release, Vue has been quite a success, especially given the fact that it's developed and maintained by a team of dozen core developers. Vue is used by Alibaba, Baidu, Expedia, Nintendo, GitLab and others [8].

D. Popularity and statistics

As already mentioned in the previous subsections, all of the above technologies are supported either by big

companies and/or communities. Yet it's interesting to analyze their overall popularity among developers and practitioners.

According to the 2018 StackOverflow survey, Angular is loved by 36,9% and React is embraced by 27,8% of the surveyed developers, as JavaScript is leading in general for sixth year in a row as the amost commonly used programming language, with overall of 69,8% in the "Most popular technology" category [9]. Although React and Angular are voted and sharing close results in the category of popular "Frameworks, Libraries, and Tools", Vue hasn't occupied a place in any of the above although its potential is present.

Another interesting statistic that should be considered and is even more helpful, in terms that from it we can conclude the actual interest in a specific technology, is the number of downloads for the given npm packages as shown in Figure 2 [10].

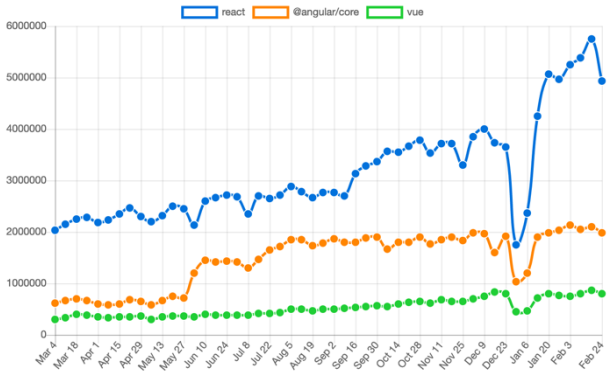

Figure 2. Number of downloads for the given npm package for the past 1 year, available at https://www.npmtrends.com/

Another tool we could use for comparison is Google Trends reporting, although it's not that precise in terms that various names and versions of the technologies exist. Though we can limit the search terms to "Programming" category which can highlight a specific pattern as shown in Figure 3:

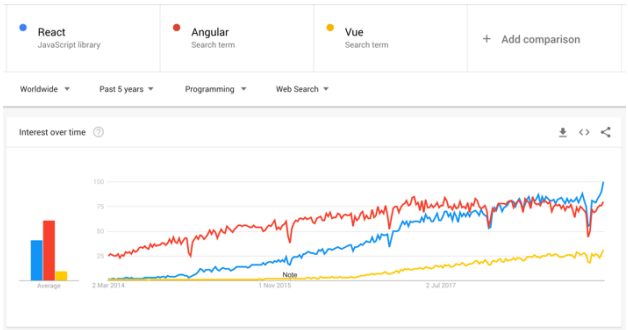

Figure 3. Google Trends comparison for the given search terms for the past 5 years, available at https://trends.google.com/

From the above data, we can approximate that React and Angular has a steady trend in terms of popularity and development, while Vue as technology introduced late 2014, are still emerging and gaining recognition.

IV. Comparison and Evaluation

In the previous section, we outlined some of the modern and popular web technologies that are used nowadays when approaching the design and development of a web application. Yet in the plethora of JavaScript frameworks and emerging technologies, sometimes it can be difficult to choose objectively the right one. In most cases, each application can be tackled in different way and some technologies can be more appropriate for one type of applications while alternatives might be suitable for others.

In order to make a better assessment and choose the right one for our need, we would also consider other criteria and investigate the main features in terms of the ability to work with components, programing language and templating logic, state management approach, data-binding alternatives, universal and native applications bridge, presence of detailed documentation and other.

A. *Directives and components*

All of the proposed technologies are based on the concept of Web components. A component could be a package, a service, a resource of some type, or a module that encloses a set of functions or data, and can be reused either within the application itself or in combination with other components. It is further defined as a set of web platform APIs that allows the creation of new, custom, reusable, encapsulated HTML tags to use in web pages and web apps. Custom components and widgets build on the Web Component standards can work across modern browsers, and can be used with any JavaScript library or framework that works with HTML. Web components are based on existing web standards, as features to support web components are currently being added to the HTML and DOM specifications, allowing easy extension of HTML with new elements with encapsulated styling and custom behavior [11].

Components are called directives in Angular. The title of this subsection is deluded on purpose, as we want to emphasize on the fact that after Angular 2 the directive system is an implementation of the Web Component concepts.

A simple example could be a form component, consisting of several input components and a button component with various properties (like placeholders, values, etc.) that can be easily reused with different data sets on another page or view of the application.

B. *Programing language – TypeScript vs. ES6 vs. ES5*

It's important to point out that React focuses on the usage of Javascript ES6, Vue on Javascript ES5/ES6, while Angular steps on TypeScript.

ECMAScript (or ES) is a scripting-language specification standardized and trademarked by Ecma International, and created to standardize JavaScript in a way to foster multiple independent implementations. JavaScript has remained the best-known implementation, together with JScript and ActionScript. On the other hand, TypeScript is an open-source programming language developed and maintained by Microsoft, and it's a strict

syntactical superset of JavaScript, and adds optional static typing to the language.

Some of the key differences between ES6 and TypeScript are that TypeScript supports all primitive data types and variables within three scopes (global, class and local) while ES6 doesn't support all of the types and is limited only to the global and local scopes. Yet in terms of decision-making statements, loops and modules, there isn't much difference. Performance tests, reported by online references, suggest that ES6 is faster than TypeScript in terms of small projects and applications, yet TypeScript performs sanity checks for bugs and syntax errors on compilation which makes it a better choice for complex applications [12]. We're not focusing on ES5, mainly because Vue supports ES6 too. Yet the major differences between the two versions tackle a lot of the limitations of the core language, making it easier for development. For example, ES6 introduces Arrow functions, Object manipulation, Asynchronous Function, Module exports and imports, Template literals, etc.

C. Templates

It's important to point out some differences in terms of templating and logic. React uses a JSX, an XML/HTML-like syntax that extends ES so that XML/HTML-like content can co-exist together with the JavaScript/React code. The syntax itself is intended to be used by preprocessors to transform HTML-like text found in JavaScript files into standard JavaScript objects that a JavaScript engine will parse. On the other hand, there have been debates as this approach confronts with long-standing best practices, namely separating UI templates and inline JavaScript logic.

The Angular templates are enhanced HTML with special Angular attributes called structural directives (like ngIf or ngFor).

In its documentation, Vue introduces the concept of "single-file components" as templates, scripts and styles are placed in one file but ordered in three different sections. However, it's not that strict as Angular and also allows the usage of JSX.

D. Framework vs. Libraries

We've already pointed out the difference between a framework and a library, but in the context of this assessment, it is important to emphasize on the fact that Angular is a full-featured framework, while React is a library and Vue is defined as a library that can be scaled to a framework depending on the approach.

Angular is a complete solution, meaning that a developer can start working on the go, without taking any considerations regarding routing, other packages or modules. On the other hand, React and Vue are flexible backed up with various packages and alternatives to choose from, but thus every project requires a decision-making process regarding its architecture, and for an inexperienced developer that can lead to confusion and frustration.

E. Other concepts

Other concepts and approaches that we should consider can be summarized below:

- State management – State management is a concept that refers to the state of one or more graphical user interface (UI) elements like text fields, buttons, etc. that depend on the state of other UI elements. For a complex application, state management can be complicated and can require a certain level of understanding. Vuex is state management library for the Vue, NgRx is the state management library for the Angular and Redux is a general-purpose state management library that can be used with any of the above or other View-based libraries, but is very commonly used with React.
- Data binding - A key difference between React and Angular is the data-binding technique - one-way vs. two-way data-binding. Angular's two-way data-binding changes the model state when the UI element is updated, while React updates the model first and after that it renders the UI element. Angular's method is cleaner in code and easier for a developer to implement, yet React's way results in a better data overview and debugging. Vue supports both one-way data-binding by default and two-way data-binding.
- MVC - The model-view-controller pattern (MVC) is a popular design pattern that splits an application into three interconnected parts: model, view and controller. Angular as an MVC-framework has MVC out of the box. React only has the View – as the Model and Controller are up to the developer.
- Dependency injection - Angular includes dependency injection, a design pattern in which one object supplies the dependencies (a service) to another object (a client). This leads to more flexibility and cleaner code.
- Flexibility - You can work with React or Vue by simply adding the Javascript library to the source code. This is not possible with Angular because of the defined structure and the TypeScript usage. React and Vue allow more control in terms of sizing an application by selecting only the things which are really necessary.
- Universal & native apps - React and Angular both support native development which makes the migration easier. Angular has NativeScript for native apps and Ionic Framework for hybrid apps, while React uses react-native-renderer package to build cross-platform iOS and Android apps, or react-native for native applications. Since all of the technologies render pages on the client which doesn't always result in good performance, all of them support server-side pre-rendering which enables better performance, overall user experience, and SEO.

F. Size & performance

Another criteria worth considering is the size of the packages and their overall performance. All of them come with a standard scaffold command-line interface tool, that can be installed as a bootstrap package and used to initialize, develop and maintain a respective application. From the installations we performed, we can summarize that the Angular framework is quite larger in size - the gzipped file is 143K, compared to 23K for Vue and 43K for React. In terms of overall performance, it's worth mentioning that both React and Vue take advantage of the usage of the Virtual DOM, which is supposed to improve performance in comparison with the direct DOM rendering system which Angular relies on.

From the above, we can conclude that Vue has a greater performance in comparison with the others, yet the results would depend on the specific case and application structure.

G. Testing

In terms of testing, both of the major testing frameworks - Jest and Mocha, work with React. Jasmine is the testing framework that's shipped with Angular, but it can use integration of Mocha or Karma. Vue lacks testing guidance, yet in their documentation is recommend using Karma.

H. Learning curve

Another non-technical but important aspect that we should consider when choosing a technology is the pace with which we can advance over time. Reference [13] suggests that from a practitioner's point of view the presence of a detailed documentation, with sample code and instructions is a base for easier adoption. Yet the lack of academic studies on the matter combined with the diversity of JavaScript frameworks makes it difficult to outline an exact pattern for evaluation of the learning curve.

Angular is often described as a framework with a steep learning curve although it has comprehensive documentation. This is due to the fact that the concepts and approaches might turn difficult and confusing, even if a developer has a deep understanding of JavaScript, and mainly because a better comprehension of the framework is required to explain certain processes and practices. In terms of set up, it can be installed effortlessly with a lot of included packages and prerequisites.

On the other hand, considering React being a library means that a lot of consideration and decisions have to be made upfront with regard to third-party packages and libraries.

Vue has a flat learning curve and is considered easier for junior developers or those migrating from other popular libraries like jQuery, but on a long-run, it can turn complicated if it's not approached accordingly. At first, it looks like a plain JavaScript, while introducing some new concepts which we've already discussed as: components, an event-driven-model, and one-way data binding, etc.

In terms of debugging, React and Vue are considered easier because of the project structure, less files and clear distinction between them and third-party libraries' code, while debugging an Angular application is considered complicated in terms of understanding the underlying model, as error reporting messages are supposed to be clearer and informative.

V. Blueprint of an Educational application architecture

When it comes to developing a web application with certain functionalities, we believe that all of the above-mentioned technologies could be a possible alternative. In the context of our study though, we want to develop an educational application addressing the following:

- Purpose – to introduce a side tool that can enhance the learning process in non-obtrusive way, and even better – to deliver a native app-like experience, with some game design elements to boost retention and engagement.
- Users - as we mentioned in Section II, our target group are students of Generation Z (Gen Z), enrolled in Web development course, that would be able to access the application anytime and anywhere.

We want to use an Agile approach and keep the application simple, and enhance functionalities over time. It could be implemented as a quiz-based application where students can answer various questions in order to test their knowledge on a certain topic and advance over time.

In terms of the performed analysis in the previous sections, we decided to develop our application with Angular, mainly because it's a full-featured framework that comes packed with a lot of functionalities out of the box, which allows further scalability, it's also well-documented and have enterprise support. As we mentioned in the above sections, Angular takes advantage of the model-view-controller design pattern and web components. We use a component-based architecture for the application, which is common. Our main component is the AppComponent that triggers different views based on user interactions. Views on the other hand can evoke other partial components. Angular components are TypeScript classes that have a Component decorator marked over them. Decorators are a design pattern as MVC that is used to separate modification or decoration of a class without modifying the original source code. In AngularJS, decorators are functions that allow a service, directive or filter to be modified prior to its usage [5]. In addition, inside these decorators, we can define what Angular calls a meta-data, which includes different assets - the template, styles, selectors, etc.. On a component level, apart from the AppComponent, we also have a SignUp and Login components to gather users' data and access the application, and also separate components as Courses Component, Topics Component, Questions Component and Activity Component to fulfill the quiz and manage progress. A common scenario is when a user interacts with the application and trigger changes on the model calling the controller. The controller, on the other hand, handles user interaction and business logic, manipulates the model and interacts with the server as data is supplied

by a JSON-file/REST API. Angular detects the model changes and updates the user view, for example we suggest using a filter for random question generation. A sample and basic blueprint of the architecture, and explained behavior is proposed in Figure 4:

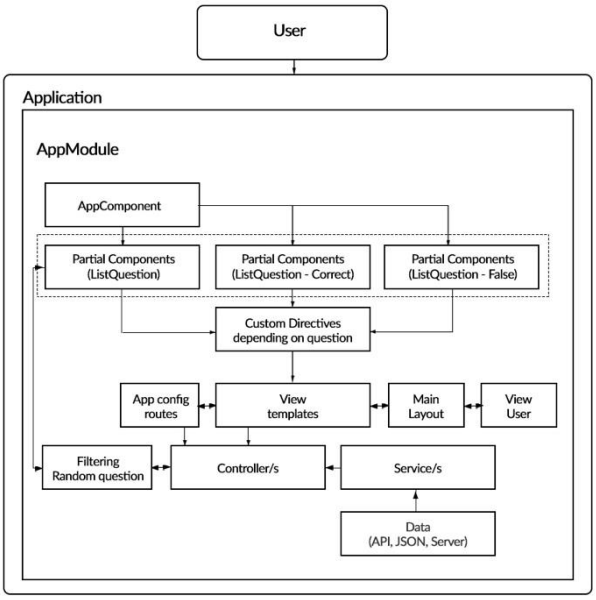

Figure 4. Sample architecture

VI. Conclusion and Further work

In this paper, we have conducted a research and analysis of some of the existing modern web frameworks, as our primary goal was to identify a suitable modern approach that would allow us to quickly develop and easily scale an educational application that supports university students enrolled in Web development course. Although we have referenced some non-scientific works and existing online resources, scrutinized with particular care, we find that this is mandatory for outlining and staying up to date with the latest development trends. We believe that this paper would be beneficial for fellow-researchers familiar with JavaScript in general but looking for a solution in the plethora of JavaScript frameworks that would allow them to prototype, build and deploy an application with ease.

An actual implementation of the application is in the process of testing with several groups of students, as we plan to use experiments to assess and wrap the results in subsequent follow-up research.

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Development of an Autonomous, Intelligent and Adaptive E-learning System

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***Abstract* - Autonomous Intelligent and Adaptive E-learning Systems (AIAESs) are a generation of learning systems that include the individuality and personalization of the student in the learning process, similar to what happens in a traditional individualized lesson with one teacher and one student. This paper reports the design and development architecture of an AIAES, the main objective of which is to improve the information literacy of adolescents. Computer systems such as AIAES need to provide the same or at least similar, instructional and interactional advantages as those found in the traditional human tutoring process, which has proven successful, and has represented the most efficient method of learning and teaching. Development of an AIAES, therefore, implies an interdisciplinary approach that connects various fields, including Computer Science, Cognitive Science, Artificial Intelligence, and Functional Literacy to fields connected to education. The developed services for intelligent analysis of various metadata provide the AIAES with the ability to adapt the learning course based on an individual learner's learning abilities in the learning process.**

Keywords – e-learning systems; Intelligent and Adaptive E-learning Systems;

I. INTRODUCTION

Terms such as digital and information literacy are used to describe the current and future knowledge and skills required to enable an individual to use Information and Communication Technologies (ICT) efficiently. Digital Literacy (DL) is "*the awareness, attitude and ability of individuals to use digital tools and facilities appropriately to identify, access, manage, integrate, evaluate, analyze and synthesize digital resources, construct new knowledge, create media expressions, and communicate with others in the context of specific life situations, in order to enable constructive social action*" [1]. Information Literacy (IL) is defined as "*a set of abilities that allow individuals to recognize when information is needed, and to locate the required information, evaluate it and use it effectively.*" [2]. IL can also be defined as "*a set of skills, attitudes and knowledge necessary to know when information is needed to help solve a problem or make a decision, how to articulate that information need in searchable terms and language, then search efficiently for the information, retrieve it, interpret and understand it, organize it, evaluate its credibility and authenticity, assess its relevance, communicate it to others if necessary, then utilize it to accomplish bottom-line purposes*" [3].

Today, just using contemporary ICT for surfing, social networking and communication are not enough. An information literate individual must be able to learn how to utilize different ICTs efficiently in order to search for, retrieve, organize, analyze, evaluate information, and then use it for everyday problem-solving tasks. An information literate person must be able to (1) Determine the extent of information needed, (2) Access the required information effectively and efficiently, (3) Evaluate information and its sources critically, and incorporate selected information into their knowledge base, (4) Use information effectively to accomplish a specific purpose, and (5) Understand the economic, legal and social issues surrounding the use of information, as well as access and use information ethically and legally.

The term *digital natives* tags a generation born during or after the introduction of ICT into daily routines. Digital natives' skills are frequently believed to be overlapping with IL skills and competencies. However, research shows that ICT experiences do not necessarily contribute to Information Literacy [4]. Moreover, several recently published studies show that IL is still below acceptable levels. For example, Stanford researchers found that students have trouble judging the credibility of online information [5]. The International Computer and Information Literacy Study revealed that, among other findings, many "digital natives" are not digitally competent, and that being born in the digital era is not a sufficient condition for being able to use ICT in a critical, creative and informative way [6]. The study [6] also revealed that, on average, girls outperformed boys in computer and information literacy, and that teachers who used ICT in their classes not only taught more effectively but also developed a more transversal computer and information literacy in their students.

IL can be regarded as both work-specific and generic and is a prerequisite for the fulfilment of the demands of lifelong learning in the future workplace, as well as for the realization of personal choices. In the existing literature, we have not been able to identify an existing e-learning system integrating services for identification (diagnosis) of IL levels at the secondary school level [7] and services for the improvement of IL of adolescents. Recently AI systems found their way in education as an association of intelligence with machines, which can think strategically [8]. However, search in peer reviewed journals shows that applications of AI in education are now in an early phase, and without clear answers and triangulated solutions, especially with association with the rising of importance of social networks in education which "focus mainly on the incorporation of social features and do not yet provide

personalized and adaptive tutoring (p.1)". In order to raise interest in solutions provided by the application of AI [9], our approach to connect AI with Information Literacy can be regarded as promising.

The main purpose of this work is to design, develop and establish an Autonomous, Intelligent and Adaptive E-learning System (AIAES). Such intelligent IL e-learning environment should provide advanced services enabling its application as a self-educational tool, or be included in the school-based educational process. The architecture of the system will allow self-assessment based on descriptors as listed in the work of Dolničar et al. [10], assigned formative tasks and final assessment of learning outcomes. All functionalities of the system are planned to be able to adapt to a student's previous learning experience, individual progress and tempo, cognitive level, and personal preferences. At the recent stage of design of the AI, specific research questions and follow up hypotheses are foreseen. However, they are not yet operationalized in a testable format. In generic form, the questions are going to be formalized around the ideas of effects on learning outcomes, suitability, applicability, and acceptability of AI in teaching/learning contexts, and a number of personal factors affecting it.

II. Autonomous, Intelligent and Adaptive E-learning Systems

The traditional human tutoring process has proven successful, and has represented the most efficient method of learning and teaching since the beginning of teaching. However, teaching and learning processes are changing, and have become flexible and adaptive [11]. In existing literature, researchers mostly agree that new learning technologies have the potential to transform education and training. Recent developments of modern technologies and strong collaboration of scientists from different fields (e.g. Cognitive Science, Computer Science, Artificial Intelligence, Functional Literacy and fields connected to education) have contributed significantly to the development of advanced e-learning systems. By use of such a system, an individual can learn in different ways, mainly through self-learning and learning supported by various formal and informal educators. E-learning systems support e-learning when they provide learning contents, rules to guide learning and achievement thresholds, technologies to enhance learning, a learning environment to make students engaged in learning, and learning platforms and tools to serve learning [11].

Advancements in digital technologies and intelligent learning environments impact developments of contemporary e-learning environments significantly [12]. Autonomous, Intelligent and Adaptive E-learning Systems (AIAES) are the next generation of e-learning systems that model and understand the individuality and personalization of the learner in the learning process efficiently, similar to what happens in a traditional individualized lesson with one teacher and one student. AIAES are powerful adaptive educational systems providing services and modules for personalized learning for students with different backgrounds, abilities, behaviors and knowledge. The personalization in an e-learning system can be achieved by implementing different techniques, such as intelligent agents (e.g. [13], [14], [15]), tag-based recommendation systems (e.g. [16], [17]), data mining algorithms [18], and others.

Such systems are based on Artificial Intelligence for providing individualized instructions based on a learner's characteristics, learning habits and preferences so that each individual learner gets learning contents and instructions that best meet his/her personal needs. AIAES is able to provide an immediate and efficient solution to a student's learning problems, and help the student to achieve maximum learning gain. Within AIAES, the content is in accordance with the cognitive learning approach, and the system provides services for intelligent analysis (collection of various variables and metadata), which enables Machine Learning and the ability to adapt to the learning course based on the learner's individual characteristics and abilities in the learning process. Such system will overcome weaknesses of self-assessment instruments for assessment of IL as proposed by [19].

An AIAES' architecture must contain the following modules: (1) Student module (who to teach), (2) Domain module (what to teach), (3) Instructor module (how to teach), and (4) Interface module (the interaction environment). The student module is the basis for making an AIAES adaptive, and is responsible for managing the cognitive state through creating the student profile that includes information such as the student's personal data, learning preference, current knowledge state, etc. The domain module should provide an interesting environment that allows replacement of obsolete topics and tasks, and the addition of topics and tasks which best suits different target groups of learners. The instructor module is responsible for making instructional decisions related to the pedagogical aspects of learning such as (1) Correct choice of the teaching methods and learning materials that best suit the individual student's profile, (2) Assessing the cognitive state of individual learner, (3) Deciding whether the student is able to proceed to the next learning stage in learning, etc. The interface must provide a fully adaptable interaction environment based on the user's role preferences (e.g. a device, which can be a desktop computer, laptop, tablet PC, smartphone, etc.). Based on the prepared learning content and collected metadata about the learners' status, an information dashboard should be designed to provide important data aggregations in the form of visual analytics.

III. Development of an AIAES to Support Learning of Information Literacy

In the project Development, testing and validation of an Autonomous Intelligent and Adaptive E-learning System for the improvement of Information Literacy of adolescents [20], the Information Literacy was modeled with seven standards and corresponding performance indicators [10] (see Figure 2. s). The standards were adapted loosely from a reference list of the DigComp initiative [21]. The main difference was that IL was put in a wider context with the addition of Standards (e.g. safety) originally not considered as IL. For each performance indicator, several learning outcomes on different proficiency levels (basic, intermediate and advanced) were specified, resulting in almost 100 learning outcomes.

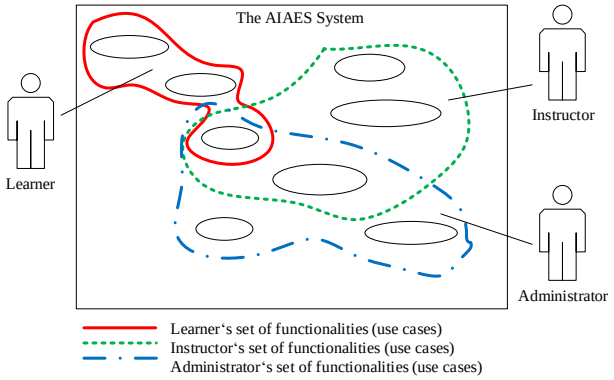

Figure 1. User types in the AIAES system

The design and development of the AIAES includes the development of modules, or functionalities, for different user types (Figure 1. provides a high overview of functionalities for different user types: Learner, instructor and administrator). A learner uses the AIAES for (1) Assessment of existing knowledge (2) Formative learning by consuming learning materials and performing learning tasks (3) Summative assessment of learning outcomes. Therefore, the AIAES must provide intelligent assessment services and immediate feedback at each progressive step, which are the basis for implementing an adaptive learning process. Individualized paths enable a learner to consume learning materials in line with learning capacity, individual preferences, cognitive level and knowledge. Instructors are allowed to use the AIAES in several optional but not exclusive ways. Because its major intention is to allow individualization in a process of learning, it was not designed for traditional teacher-centered lessons, even if it can be used for such purpose. The first option is to be used individually by the students, with teachers as a background and providers of help in need. The second option is the application of AIAES for assignment of homework or learning materials during the lessons. In order to provide better learner's performance supervision, the AIAES must also provide several intelligent services for monitoring and guiding the learner in the learning process (e.g. initial analysis and assessment of the learner's cognitive abilities and knowledge, supervision during the learner's studying process, collecting of metadata during the supervision, alerting and advising the student, etc.). Additionally, instructors need a dashboard, which displays all important information relevant to a learners' performance. The last is intended to be used as a template for preparing their own learning materials, contents and learning tasks to be used by the learners in their classrooms in a traditional way.

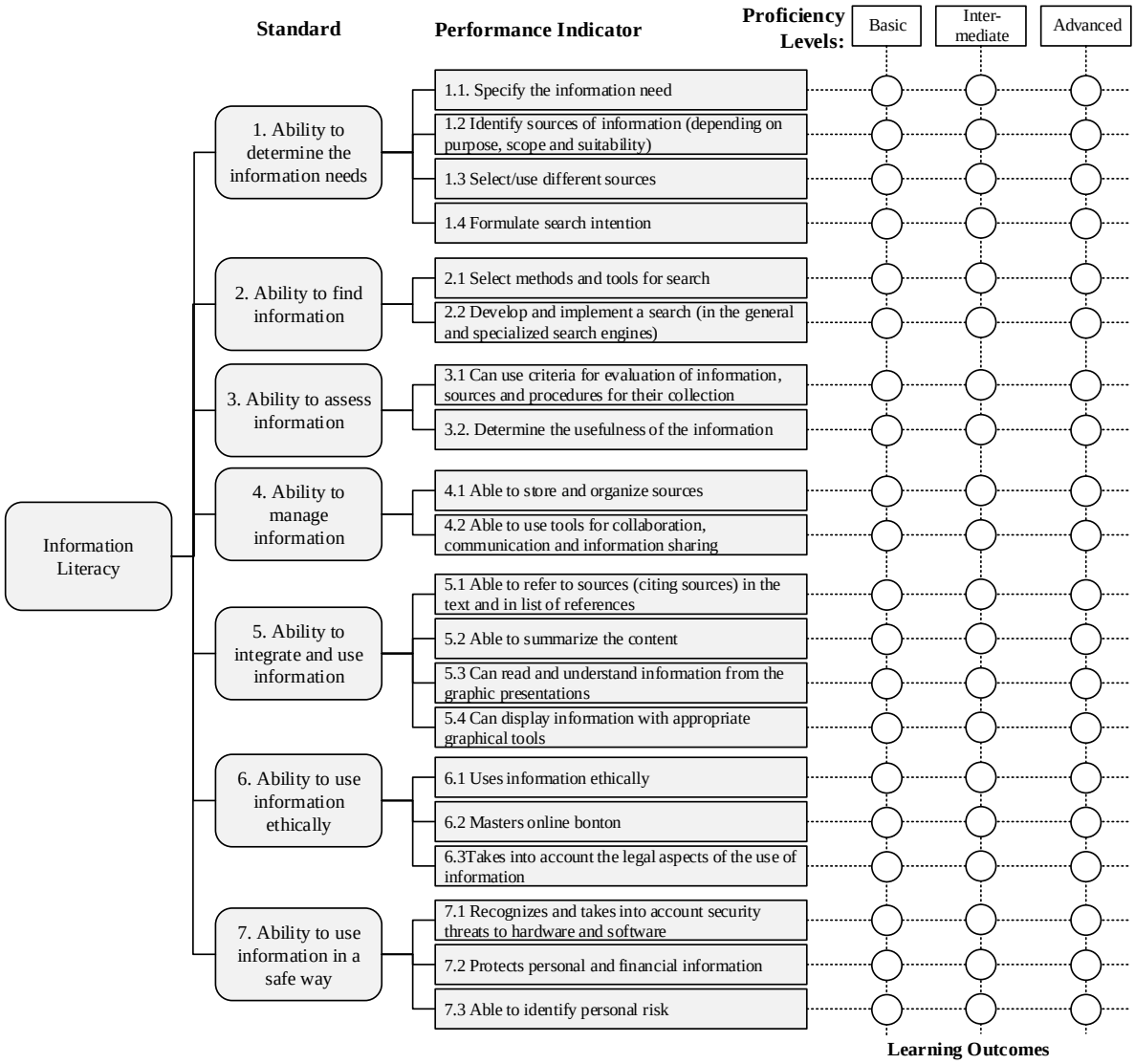

Figure 2. The proposed Information Literacy Schema

They are invited to communicate their tasks to the administrators to be included in the system. Administrators are responsible for managing users, basic system administration, including the administration of some basic entities, such as the definitions for proficiency levels, Standards, performance indicators, and learning outcomes.

Based on the proposed IL schema, the main entities for the AIAES were modeled in order to support the management of learning contents, lessons and learning tasks, in order to support an e-learning environment for the IL (see Figure 2. s). Standard entity is on the highest level of the conceptual model and is used to distinguish between seven different competences or dimensions of the IL. Each standard can cover various performance indicators, which in this project were modeled as a Performance indicator.

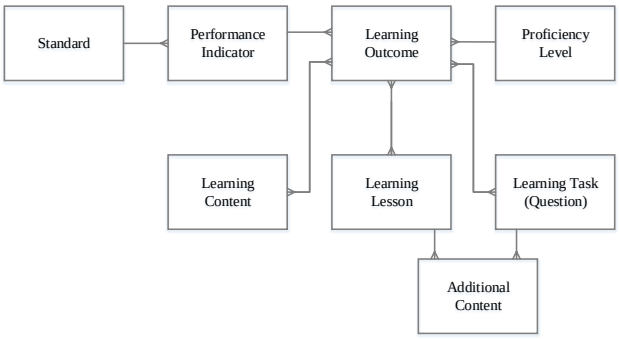

Figure 2. Abstract conceptual model of main entities in the AIAES¸

For each performance indicator, several learning outcomes (Learning Outcome) on different proficiency

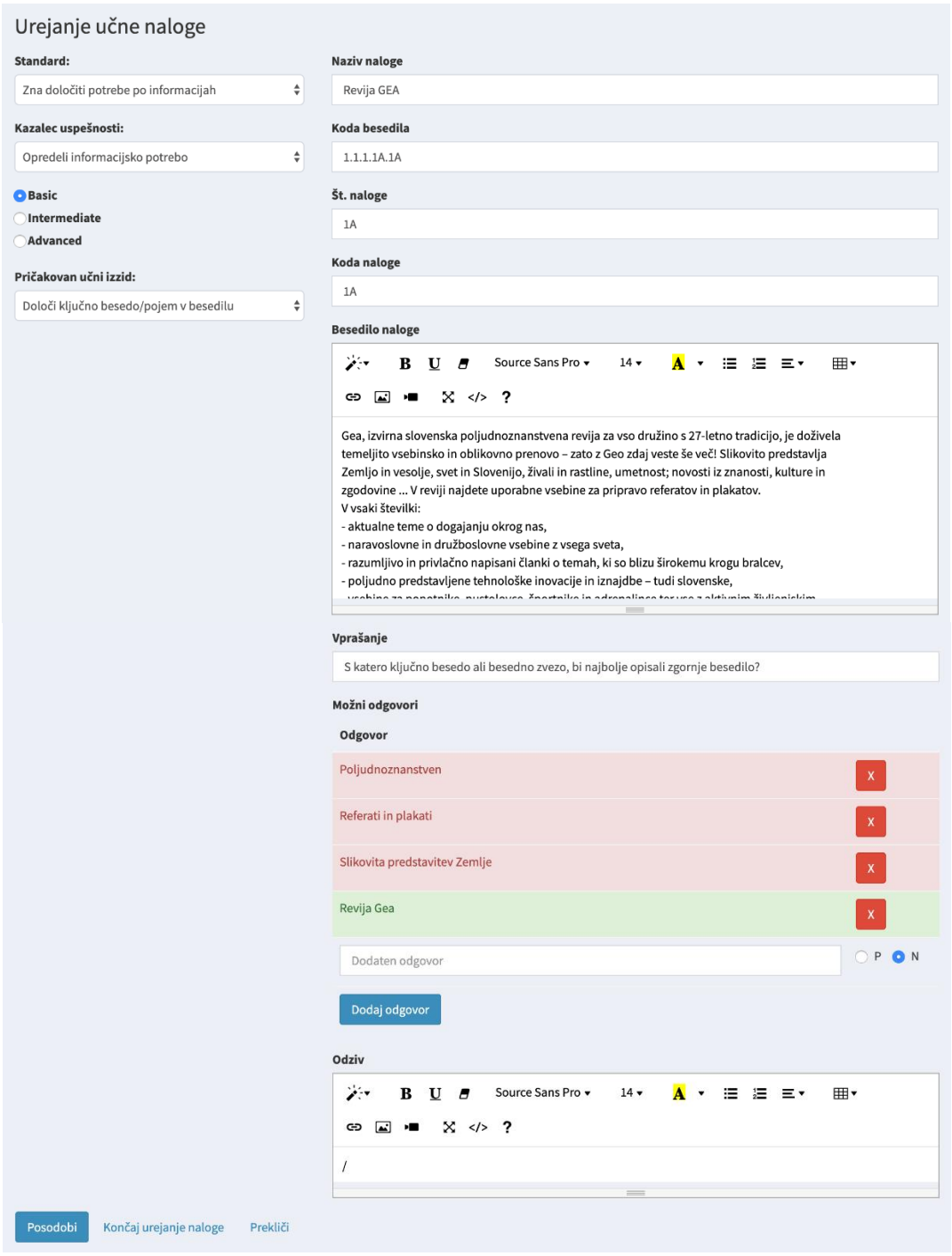

Figure 3. Management of a learning task (in the Slovene language)

levels (in this project, three proficiency levels were specified: basic, intermediate and advanced). For each learning outcome, various learning contents, learning lessons and learning tasks can be specified, where each of these can also be re-used for different learning outcomes. Additional content can be provided for a certain learning lesson and learning task, in order to provide a learner with an additional explanation if the basic content is not enough for comprehension.

For instructors, responsible managing of the learning contents, which includes management of IL Standards, proficiency levels, performance indicators, learning outcomes, learning content, learning lessons, and learning tasks, several management services were implemented (because of the space limit, only two of the management pages are shown in Figure 3. and Figure 4. s).

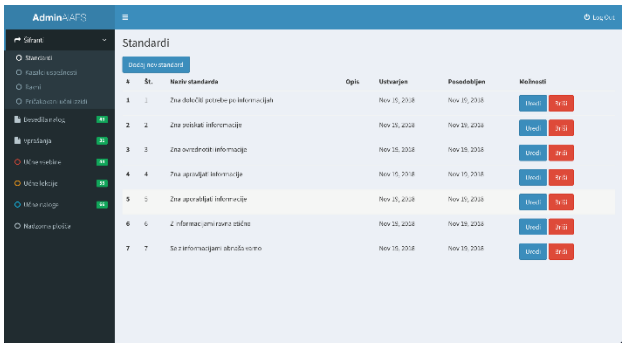

Figure 4. Management of IL Standards

We wanted the learning process to be optimized for each individual learner (i.e. personalized). This optimization is driven primarily towards the goal of achieving the best possible final outcome (final assessment of learning outcomes) with the least needed interactions between a learner and the system. For example, if a learner can achieve the same (or even better) final result without assigning him/her with a specific formative task, then the process which does not include this specific formative task is preferred. If, on the other hand, including a specific task into a learner's personalized learning process yields a better final result, then such a process is preferred.

As the personalization needs to be performed dynamically during the implementation of the learning process, the optimization is based on the results of already performed learning processes by other learners. All the data gathered from all already performed learning processes, can help us to determine the best sequence of different learning tasks automatically, which will, with the highest probability, result in the best result for the learner. In this way, the collective intelligence of a set of learners and their assessment results help us discover the common learning patterns of successful, as well as not so successful, learning paths throughout the set of different learning contents, lessons and tasks.

An example of a formalization of such a dynamic learning path, represented in a form of a dynamic decision tree structure, is presented in Figure 6. This example represents a situation where learning content with the code 1.1.1.1 is first presented to a learner on the basic proficiency level, who then proceeds to the question 1.1.1.1. If the answer is correct, then the learner proceeds to the intermediary proficiency level, and, if not, he/she is provided with more learning content at the same level. Such a decision tree is initially constructed manually in a way that represents a general learning process for an average learner. By gathering more and more data, the tree structure is being optimized towards the most efficient learning process for a specific learner, based on his/her results from given tasks.

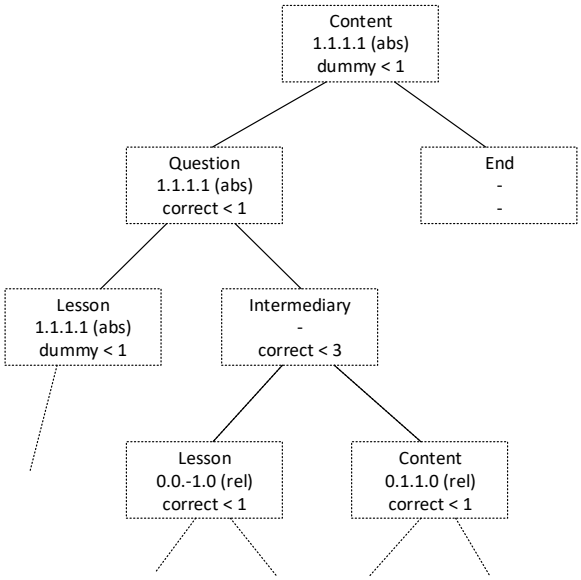

Figure 6. Dynamic decision tree structure for dynamic learning path formalization

As we wanted the developed AIAES to work in an automatic manner, without a need for unnecessary involvement of either the instructor or the administrator, the designed decision tree structure is also very appropriate for the implementation of the described learning process from the technical point of view. Using the pre-determined coding system, it references the specific learning content directly, i.e. lessons and/or tasks. While traversing along the tree structure, the system fetches the required content from the database, and provides it adequately to the learner. In this manner, the personalized and dynamic behavior of the system is achieved without a need to pre-determine a huge set of different learning scenarios.

The optimization of the dynamic learning path is done on several metrics gathered from each individual during their initial performance: The time spent on each exercise, the accuracy of the individual's answers in the assessment phase, and the individual's performance along the lessons. Some of the metrics are inputs into the validation phase, which checks if the individual student is actually participating in the process, or is the individual only rushing through the learning path with random answers. In addition, the optimization process takes the length of the learning path into account, so that the learning paths are as short as possible while keeping the content retention rate of the learned topic as high as possible.

IV. CONCLUSION

In the paper, we presented the process of design and the implementation of the Autonomous Intelligent and Adaptive E-learning System (AIAES) on the case of Information Literacy learning. We presented an

architectural overview of the proposed system, the architecture of the database, the actors that use the system, the flow of the use case of the system, and overview of the methods that take care of the adaptation of the learning paths for each individual student.

There are still numerous open questions and research potential in the learning path optimization subject, where one can apply meta-heuristic methods either just to optimize small parameters (such as time allowed for any particular question or set of questions, number of repetitions), or the whole learning path in general (the order of the questions and the lessons). Beside the meta-heuristic algorithms, data mining can be used here to evaluate the most appropriate questions and the lesson to be used in the learning paths that result in the best results of the students.

Evaluation of the system has not yet been performed, so both approaches need an extensive and wide experiment with the control group (learning paths set by experts – teacher), to validate if adaptive and intelligent learning paths perform better than well-structured human learning paths.

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Comparative analysis of faculties' websites accessibility based on an automatic evaluation

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***Abstract* - In the digital age, websites constitute an important source of gathering information. The website owners are responsible for providing the accessibility of their websites to all target groups of end users. This means that all web users can perceive, understand, navigate, interact and contribute to the Web. To ensure web accessibility, many concepts, guidelines and standards have been proposed, such as Section 508, Design for all, ISO/IEC 40500:2012, and others. This paper focuses on Web content accessibility guidelines (WCAG) and includes a comparative analysis of the accessibility of faculties' websites between 2018 and 2019. Therefore, the objective of this research is to investigate the WCAG 2.0 compliance level of faculties' websites in this time period. Web accessibility was assessed using an automatic evaluation tool, called the Web Accessibility Checker. Based on the results, recommendations for improving web accessibility are presented here.**

Keywords* - *Web accessibility, WCAG, Accessibility evaluation, Automatic evaluation, Evaluation tools

I. INTRODUCTION

Over a billion people are estimated to live with some form of disability. This corresponds to about 15% of the world's population [1]. In Slovenia, the percentage of people with disabilities is lower and involves between 12% and 13% of the population [2]. The number of students with disabilities at the University of Maribor has increased from 37 to 74 students over the last 6 years, which means less than 1% of all students. The real number of students with disabilities is definitely higher because a lot of students do not wish to label themselves and do not apply for special student status. Due to the increased number of documented students with disabilities attending the University of Maribor in recent years, the need for providing an accessible environment has become of crucial importance.

The University of Maribor is responsible for ensuring all students equal access to all educational opportunities. Therefore, students with disabilities should have equal physical access to buildings, classrooms, restrooms, and other facilities, as well as equal access to e-learning systems and websites. Consequently, websites should be accessible for students with disabilities, meaning that they are able to equally access and use web content.

Until today, many concepts, guidelines, and standards have been proposed to ensure web accessibility (e.g. WCAG, ISO/IEC 40500:2012, Section 508, Design for all, etc.). Nevertheless, existing research shows that web accessibility has a relatively low degree of compliance with guidelines and a large number of evaluated websites have accessibility problems [3][4][5][6] [7]. Therefore, on a practical level, web accessibility is still a problem and largely depends on developers and website designers. In [8] the authors identified the two most common challenges in implementing web accessibility among developers, which include a) the lack of accessibility awareness and motivation and b) the lack of training. Therefore, even though many instructions on how to ensure web accessibility are available, many web pages still remain inaccessible for certain segments of the population, especially for people with disabilities.

Because of an existing lack of support for people with disabilities, we are motivated to achieve an insight into web accessibility at higher education domains and verify if the faculties' websites are accessible for people with disabilities. Therefore, this paper focuses on whether the faculties' websites are compliant with the Web Content Accessibility Guidelines (hereinafter, WCAG), which present the de-facto standard [9] for web accessibility.

II. WEB ACCESSIBILITY

A. Definition

ISO 9241-171 defines accessibility as the "usability of a product, service, environment or facility by people with the widest range of capabilities" [10], while ISO 26800 defines it as the "extent to which products, systems, services, environments, and facilities can be used by people from a population with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use" [11]. In the web domain, the most well-known definition is published by W3C and it states "that websites, tools, and technologies are designed and developed so that people with disabilities can use them" [12]. More specifically, people (including people with visual, auditory, physical, speech, cognitive, and neurological disabilities) can [12]: (1) perceive, understand, navigate, and interact with the Web and (2) contribute to the Web.

B. WCAG

WCAG is the most established guideline published by W3C. It explains how to make web content more accessible to people with disabilities. Version 1 was published in May 1999; the second version was published in December 2008. In 2017, this version was also approved as an ISO standard ISO/IEC 40500 [13]. The latest version (2.1) was published in 2018. It includes all the recommendations from 2.0 and provides 17 additional success criteria, which relate to [14]: (1) mobile

accessibility, (2) people with low vision and (3) people with cognitive and learning disabilities. In this research, WCAG 2.0 was used.

WCAG 2.0 is built around four core principles [15]:

- *Perceivable* means that users must be able to perceive the information being presented (e.g. people who cannot hear well but can see content and people who cannot see well but can hear content).
- *Operable* means that users must be able to operate the interface (e.g. people who cannot use the mouse but can use the computer by typing or via voice).
- *Understandable* means that users must be able to understand the information as well as the operation of the user interface (e.g. people with cognitive disabilities need a clear and simple language).
- *Robust* means that users must be able to access the content as technologies advance (e.g. people who use different assistive technologies, such as screen readers).

Each principle is supported by guidelines and under each guideline, several *success criteria* describe what must be achieved in order to conform to these recommendations. These *success criteria* are classified into three conformance levels [15]:

- *level A* – includes 25 basic success criteria and presents the minimum level of conformance;
- *level AA* – includes 13 success criteria and presents the medium level of conformance;
- *level AAA* – includes 23 advanced success criteria and presents the highest level of conformance.

III. RESEARCH

A. Research goal

The main goals of this research were to investigate the accessibility of faculties' websites at the University of Maribor and to verify whether the faculties' websites were compliant with WCAG 2.0 between 2018 and 2019. In January 2018, the first web accessibility research study was conducted, while the second study was conducted one year later, in January 2019. To perform a valid research comparison between the two years, version 2.0 of WCAG was used in both investigations.

B. The investigated websites

Our research involved 17 faculty websites at the University of Maribor. Each website had a unique design and structure. Similar to existing research [16][17][18][19][20], the investigation considered only the entry web page (hereinafter web page), because it represents the first point of contact with users. If the entry web page displays some problems or it is not accessible, it would be very difficult for users to access other pages within the website.

C. Data collection protocol

Web accessibility was assessed using an automatic evaluation tool. Based on existing literature, there was a wide range of professional tools available to evaluate website's accessibility, such as the Accessibility Valet, Web Accessibility Checker, Cynthia Says, EvalAccess, FAE, MAGENTA, OCAWA, TAW, WAVE, Web Accessibility Checker, etc [4]. In this research, the Web Accessibility Checker was used, because it is the most commonly used open source web accessibility evaluation tool [21]. It allows researchers to automatically evaluate the accessibility of websites based on compliance with different guidelines, such as BITV, Section 508, Stanca Act, WCAG 1.0 and WCAG 2.0 [22]. In this research, we checked the compliance levels of faculty websites with WCAG 2.0 (conformance levels A, AA, and AAA).

IV. RESULTS AND FINDINGS

In general, over a timespan of one year, web accessibility improved on 59% of web pages, while it deteriorated on 29% of web pages. On 12% of web pages, web accessibility remained unaltered. The utmost improvements were detected on the web page of faculty 14 (see Figure 1), where the number of known problems decreased from 206 (2018) to 44 (2019). The biggest increase in the problems from 50 (2018) to 74 (2019) was found on the web page of faculty 6.

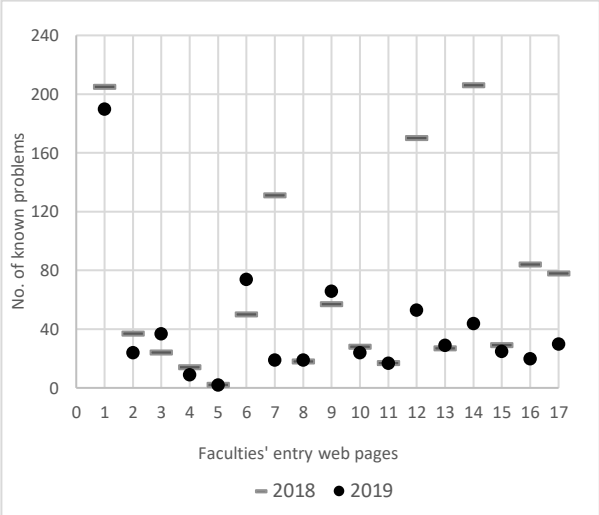

Figure 1. Web accessibility problems for faculty's entry web pages

The results (see Table 1) show that none of the web pages were fully compliant with WCAG 2.0 between 2018 and 2019. This means that all web pages had one or more than one web accessibility problem. In 2018, four of them had 20 or fewer problems, while in 2019 this number increased to six. In 2018, four web pages included over 100 problems per site, while in 2019, only one website with more than 100 problems was found.

As shown in Table 2, the most frequent web accessibility problems were identified at level A in both years, but the comparison between the years show a decreased number of identified problems in 2019 (2018: 710; 2019: 287). The number of identified accessibility problems at level AA was increased from 2018 to 2019 (2018:139; 2019:180), while the number of known problems decreased from 2018 to 2019 (2018: 328;

2019:215). On average, in 2018, one web page included 42 problems from level A, while in 2019 this number decreased to 17. Between 2018 and 2019, the number of known problems from level AA increased from 8 to 11, while the number of known problems from level AAA decreased by 6. The highest maximum number of accessibility problems (192) was identified at level A in 2018, while in both years a web page with no accessibility problems was detected at all three levels.

Table 1. Web pages grouped by the number of web accessibility problems

	Number of web pages	
Known problems	***2018***	***2019***
0	-	-
1-20	4	6
21-40	5	6
41-60	2	2
61-80	1	2
81-100	1	0
Over 100	4	1

Table 2: Web accessibility problems divided per conformance level

	Total No. of known problems		**Average per web page**		**Min**		**Max**	
Conformance levels	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***
A	710	287	42	17	0	0	192	62
AA	139	180	8	11	0	0	53	57
AAA	328	215	19	13	0	0	141	88
Total	1177	682	70	40	/	/	/	/

The most frequently identified problems between 2018 and 2019 are represented in Table 3 and Table 4. The same problems were identified in both years, but over the years there were differences in the percentages of their appearance on the web pages.

From conformance level A, the most frequently identified problem was the success criterion *Non-text Content*, which includes the recommendation that all non-text objects must have a text alternative with an equivalent purpose. This problem was found in 88% of web pages in 2018 and on 82% of web pages in 2019. The second most frequently identified problem was the success criterion *Link Purpose* (2018: 47% of web pages, 2019: 41% of web pages). This success criterion states that all link texts must be meaningful when read alone. The problem of the success criterion *Parsing* was found as the third most frequently identified problem. This success criterion states that user agents, including assistive technologies, can accurately interpret and parse content. In 2018, a less identified problem was the success criterion *Keyboard* (12% of web pages, which was decreased to 6% of web pages in 2019). This success criterion states that all functionality of the content is operable through a keyboard interface without requiring specific timings for individual keystrokes, except where the underlying function requires input that depends on the path of the user's movement and not just the endpoints. In 2019, two additional identified problems were found, namely the success criterions *Bypass Blocks* and *Page Title*. The success criterion *Bypass Blocks* recommends that the mechanism to bypass blocks of content, which are repeated on multiple Web pages, is available, while the success criterion *Page Title* states that web pages have titles that describe a topic or purpose.

Table 3: The most frequently identified known problems in 2018

2018	**Success Criterion**	**Avg. number per web page**	**Web page [%]**
A	1.1.1: Non-text Content	35	88%
	2.4.4: Link Purpose (In Context)	3	47%
	4.1.1: Parsing	1	47%
	1.3.1: Info and Relationships	1	29%
	3.3.2: Labels or Instructions	<1	29%
	3.1.1: Language of Page	1	18%
	2.1.1: Keyboard	2	12%
AA	1.4.4: Resize text	7	53%
	2.4.6: Headings and Labels	1	41%
AAA	1.4.6 Contrast (Enhanced)	19	59%

Table 4: The most frequently identified known problems in 2019

2019	**Success Criterion**	**Avg. number per web page**	**Web page [%]**
A	1.1.1: Non-text Content	14	82%
	2.4.4: Link Purpose (In Context)	7	41%
	4.1.1: Parsing	6	35%
	1.3.1: Info and Relationships	5	29%
	3.3.2: Labels or Instructions	5	29%
	3.1.1: Language of Page	2	12%
	2.1.1: Keyboard	1	6%
	2.4.1: Bypass Blocks	1	6%
	2.4.2: Page Title	1	6%
AA	1.4.4: Resize text	10	59%
	2.4.6: Headings and Labels	8	47%
AAA	1.4.6 Contrast (Enhanced)	7	41%

Surprisingly, the percentages of the appearance of problems from level AA were increased between 2018 and 2019. Therefore, in 2019 more web pages were found, where the success criterions *Resize text* and *Headings and labels* were violated. It was found that the text could not be resized up to 200 percent without assistive technology and that headings and labels did not describe the topic or purpose.

The most frequently identified problem from conformance level AAA was the success criterion *Contrast*. It recommends that the visual presentation of text and images of text has a contrast ratio of at least 7:1.

The percentage of the appearance was decreased from 59% to 41% between 2018 and 2019.

To summarize, although none of the web pages were fully compliant with WCAG 2.0 between 2018 and 2019, web accessibility nevertheless improved for 59% of web pages over the last year. Therefore, a decreased number of identified problems was detected on these webpages, especially with regard to the number of success criteria *Non-text Content* (e.g. Faculty 14: from 180 (2018) to 22 (2019); Faculty 16: from 75 (2018) to 11 (2019)) and *Contrast* (e.g. Faculty 12: from 141 (2018) to 0 (2019)). The increased violation of the same success criteria was also the main reason for worsened web accessibility, which was identified in 29% of web pages in the last year (e.g. *Non-text Content:* Faculty 6: from 53 (2018) to 62 (2019); *Contrast*: Faculty 3: from 0 (2018) to 16 (2019); Faculty 6: from 40 (2018) to 64 (2019)).

V. Recommendations for Web Accessibility Improvement

As mentioned in the previous section, the most frequently violated success criteria in 2019 were: Non-text Content, Link Purpose, Resize text, Headings and Labels, and Contrast. Based on these findings, the recommendations for web accessibility improvement related to the most frequently violated success criteria are presented in the following subsections.

A. Non-text Content

As stated in the document, Understanding WCAG 2.0 [15] the definition of *Non-text Content* criterion is: All non-text content that is presented to the user has a text alternative that serves an equivalent purpose. With alternative texts, users can access information because text can be rendered through any sensory modality (e.g. visual, auditory or tactile).

For images, input fields and areas of images an "alt" attribute should be added in HTML. For video or audio elements, a short description should be provided in the "name" attribute together with a (link to a) long description i.e. a text transcript of the audio. Controls and input (e.g. "search" or "submit") should also have "name" attributes.

There are some exceptions to the *Non-text Content* criterion, which need to be addressed differently. Tests that depend on using a certain sense (e.g. spelling, hearing, visual skill test) cannot be successfully executed with only an alternative text. Nonetheless, an alternative text should still be provided. CAPTCHA devices, which are used to confirm that content is being accessed by a person and not a robot, are unsolvable by users with certain disabilities. Therefore, a web page should include at least two different forms of CAPTCHA which will ensure that most people with disabilities will find a form they can use. Further exceptions are decoration elements, content used for visual formatting, or invisible elements that are not meant to be seen by the user. For those elements, alternative text should not be provided as it would distract people using screen readers from the content on the web page. An empty "alt" tag should be added to this kind of content.

When applying an alternative text, one must keep in mind that alternative text is a written replacement for non-text content and should provide the same information as the content that it represents. Therefore, alternative text should not be used for additional information or content.

B. Link Purpose

When applied properly, the *Link Purpose (In Context)* criterion helps users understand the purpose of each link, so they can decide whether they want to follow the link or not [15]. Whenever possible, the text of the link should provide the purpose of the link without needing additional context. When using an icon next to the link, both icon and text should be included in a single link (the "alt" text for the icon should be set to null, as the purpose of the link is visible from the link text). When only an image is a link, the "alt" text should provide context for the link. Links that point to the same destination should have the same description and links that point to a different destination should have a different description.

Exceptions are "read more" links that follow news or blog articles' summaries. In those cases, a screen reader can read the current paragraph to provide context to the link.

This criterion applies to the links that are provided within content (for standalone links, the criterion *Link Purpose (Link Only)* applies).

C. Resize Text

The *Resize Text* criterion states that users can resize text up to 200% without assistive technology and without a loss in content or functionality. This criterion enables users with mild visual disabilities to read the text (although users can benefit from scaling all content, text is the most crucial) [15].

When using quality HTML and CSS, as well as fluid design, no extra steps are needed for this criterion as modern user agents (e.g. browsers) already include the functionality for resizing. Nonetheless, web page authors should check how their content scales in different browsers when text is resized to at least 200%. All the content should remain visible, all functionalities available, and horizontal scrolling should not be needed.

One must keep in mind that zooming is not the same as text resizing, as the latter is a setting in a browser that is applied to all web pages. This setting simplifies visits to different web pages as it neglects to set the zoom for each web page. To enable the resize text setting, relative units (e.g. em, percent, named font size) instead of absolute units (e.g. px, mm, pt.) should be used in CSS to specify text size.

A way to implement this criterion is also to provide controls on the web page that allow users to incrementally change the size of all text up to 200%.

D. Headings and Labels

Headings and labels should clearly describe the topic or purpose so that users can easily find information and can understand different parts of the content [15]. This does not mean that headings and labels should always be provided, but if they are included in a web page, they should be informative. Nonetheless, all users will benefit

from well-structured and labeled content, with sections of text that are manageable in size.

One way to be concise with the *Headings and Labels* criterion is to use informative headings and subheadings (together with HTML h1 to h6 elements) and to label all interactive elements on a web page (e.g. sidebar widgets, forms, search boxes) with informative labels. If the structure of content in subpages is similar, then headings on subpages should also be consistent.

E. Contrast

Contrast criterion definition states that the contrast ratio between text (or images of text) and background should be at least 7:1. This enables users with moderately low vision to read the content without the help of assistive technology. The ratio is calculated in a way that does not include colour, so that users with a colour vision deficit will also perceive an adequate contrast [15].

To fulfill this criterion, one can use a contrast analyser (a variety of such a service is available online) to check the contrast ratio and change the text or background colour in CSS if needed. This criterion also applies to links that would change colour after the click.

Exceptions for this criterion apply to large text (18 points or 14 points bold text), where a ratio of 4.5:1 should be used. The ratio 7:1 does not have to be applied to inactive user interface components, text that is meant for decoration, or is not visible to anyone. Also, text that is a part of a logotype or a brand name does not have to meet the *Contrast* criterion.

VI. Conclusion

This paper offers an insight into web accessibility among higher education domains. The study investigated the accessibility of faculties' websites at the University of Maribor and verified if the faculties' websites were compliant with WCAG 2.0 between 2018 and 2019. The results based on automatic evaluation indicate that none of the assessed web pages reached all recommendations of WCAG 2.0 in this time period. Nevertheless, in the last year, the number of violated success crtireria decreased on 59% of web pages, while for 12% of web pages, the number of violated success crtireria remained unaltered. Unfortunately, the number of violated success crtireria increased for 29% of web pages.

According to the most frequent violations of WCAG 2.0 success criteria on faculty websites, the recommendations on how to meet specific accessibility requirements were provided. Most of the described recommendations coincide with good practices in web development and can be applied with relatively little effort. When the accessibility techniques are applied properly, all users (not only people with disabilities) can benefit from the improvements, as user interaction in general also improves.

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Development of a new improved model of ISO 20000 standard based on recommendations from ISO 27001 standard

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Abstract – ISO 20000-1:2011 is the most important standard for the management of IT services. ISO 27001:2013 is the most important standard for information security. This paper compares these two standards in the real environment of IPTV/VoIP service of Telecom operator in Bosnia and Herzegovina. This paper produces a new improved version of ISO 20000 standard in the field of information security based on recommendations from ISO 27001 standard in the field of information security. A new improved version of ISO 20000 standard is implemented in a real environment of Telecom operator and it produced a better results then the previous model.

Keywords: ISO 20000-1:2011, ISO 27001:2013, IPTV/VoIP

I. INTRODUCTION

Quality management systems are of great interest to the business of each organization. Today the most important standards from the area of management systems are:

- ISO 9001: 2015 – Quality Management System
- ISO 14001: 2015 – Environmental Management System
- ISO 20000-1:2011 – IT services Management System
- ISO 22301:2012 - Business Continuity Management System
- ISO 27001:2013 - Information Security Management System
- ISO 50001:2011 - Energy Management System.

At the center of this work are the standards: ISO 20000 (IT Service Management System) and ISO 27001 (Information Security Management System). The basic tasks within this research include:

- To examine all elements of ISO 20000 (IT Service Management System)
- To examine all elements of ISO 27001 (Information Security Management System)
- To complete a comparative analysis of these two management systems
- Through a comparative analysis, to identify the disadvantages of IT Service Management System based on the ISO 20000 standard (through actual measurement results)
- Through the comparative analysis, to take into the consideration the advantages of the Information Security Management System based on the ISO 27001 standard (through actual measurement results)
- On the basis of completed comparative analyzes, to create a new improved model of ISO 20000 standard based on the advantages of the ISO 27001 standard (through actual measurement results)
- To implement a new enhanced IT Service Management System based on ISO 20000 standard (a new enhanced version of ISO 20000 standard) in the real environment of IPTV/VoIP service in Telecom operator from Bosnia and Herzegovina.

Section II. shows IT Service Management System based on ISO 20000 recommendations and shows Information Security Management System based on ISO 27001 recommendations. Section III. presents research methodology which was used in this paper. Section IV. presents IPTV/VoIP model which was used as a reference model in this paper. Section V. describes the process of implementation of ISO 20000 standard in the reference model, while section VI. presents the implementation of ISO 27001 in the same reference model. Section VII. presents a comparison of achieved results and proposes a new improved model of ISO 20000 standard. Section VIII. is the conclusion of the paper while section IX. presents all references used in this paper.

This research has been done on ISO 20000-1:2011 while the new version of this international standard (ISO 20000-1:2018) has been issued in September 2018. The new version of ISO 20000 standard from 2018 keeps the same version of processes like the version from 2011 which is described in this paper so this is the reason while the same one can still be used for scientific research. The new version of standard ISO 20000-1:2018 only makes the difference in Annex SL standard which is not important for this paper, while the process structure important for this paper is the same one.

II. IT SERVICE MANAGEMENT SYSTEM AND INFORMATION SECURITY MANAGEMENT SYSTEM

The management system based on the ISO 20000 standard has a total of 13 processes that include [1] [2]:

1. Budgeting & Accounting Process - Financial Management Process
2. Capacity Management - Capacity management process
3. Availability Management - Service availability management process
4. Service Level Management - Contract management process
5. Service Reporting - The process of generating reports
6. Service Catalogue Management - IT service catalogue management process
7. Information Security Management - A process for managing information security
8. Business Relationship Management - The process of managing business relationships inside and outside the organization
9. Supplier Management – The process of supplier management and procurement
10. Incident Management and Request Fulfillment - Incident management process and user requirements process
11. Problem Management – A problem management process
12. Release and Deployment Management – A process for development and maintenance of IT services
13. Service Asset and Configuration Management - The process of managing IT Assets and Configuration units
14. Change Management - Change management process.

Although the ISO 20000 standard has a process of information security management (Information Security Management process), it still contains only basic information security implementation guidelines. There are no details related to the implementation of information security. Figure 1. shows processes inside this system.



Figure 1. Processes inside ISO 20000 standard

Information security management system based on the ISO 27001 standard has all the elements of information security that can be integrated within the existing ISO 20000 standard. In this way, a new improved model of the ISO 20000 standard can be developed, which should in fact be an original scientific contribution to this thesis.

The ISO 27001 standard contains the following organizational components:

- A5 – Policies for information security management
- A6 - Organizational roles in the management of information security
- A7 - Human Resource Management
- A8 - Asset management
- A9 - Logical Security (Subprocess)
- A10 - Cryptography (Subprocess)
- A11 - Physical safety and security of the environment
- A12 - Security of operations (Subprocess)
- A13 - Communication Security (Subprocess)
- A14 - Operational maintenance of the system
- A15 - Supplier management
- A16 - Security incident management
- A17 - Business Continuity Management System
- A18 - Law and Legislation Management

Research through this work from ISO 27001:2013 standards takes these four subprocesses: A9 - Logical Security, A10 - Cryptography, A12 - Security of operations and A13 - Security of Communications.

The following figure shows the life cycle of processes and activities for ISO 27001: 2013 standard:

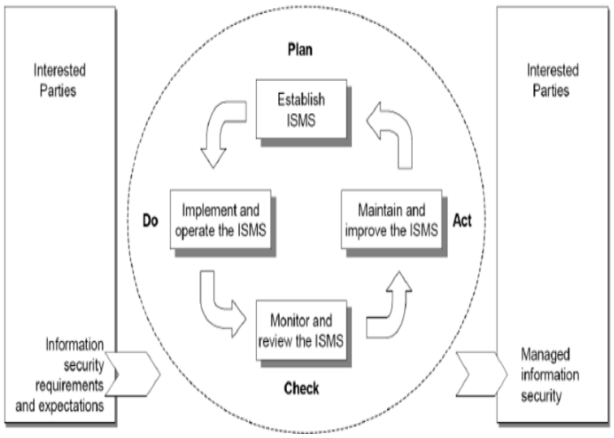

Figure 2. Lifecycle of processes and activities inside ISO 27001 standard

III. RESEARCH METHODOLOGY

The basic objectives of this research include:

- Theoretically study of existing standards ISO 20000-1:2011 and ISO 27001:2013
- Conducting a comparative analysis of the two existing standards
- Monitoring at the disadvantages of the information security view of ISO 20000-1:2011 standard through actual measurement results
- Integrating the benefits of ISO 27001:2013 standard with the existing Information Security Management process in ISO 20000-1:2011 standard (through actual measurement results)

- Creating a new enhanced ISO 20000-1:2011 standard with the benefits of the information security management process
- Based on the creation, implementing a new improved model of ISO 20000-1:2011 standard in the business environment of the IPTV/VoIP service of Telecom operator in Bosnia and Herzegovina.

The basic hypotheses to which this research relates include:

- Hypothesis 1 (H1): ISO 20000 is a very widespread standard in the IT world that has been increasingly used
- Hypothesis 2 (H2): ISO 20000 does not have a thoroughly elaborated process for managing information security
- Hypothesis 3 (H3): Information security is one of the main topics in today's IT world
- Hypothesis 4 (H4): ISO 27001 provides a set of detailed recommendations in the field of information security
- Hypothesis 5 (H5): Previous research has shown that it is possible and necessary to make numerous changes from the aspect of information security for ISO 20000
- Hypothesis 6 (H6): There are four subprocesses from ISO 27001:2013 that can be taken to improve any other standard
- Hypothesis 7 (H7): Create a new improved ISO 20000 standard model
- Hypothesis 8 (H8): Apply the new ISO 20000 standard model in the practical environment of the IPTV/VoIP service of the Telecom operator.

The basic principle of the methodology in this research is based on a comparative analysis between existing international standards: ISO 20000-1:2011 and ISO 27001:2013 in the field of information security management processes. The basic concepts of research methodology include:

- Theoretical study of existing ISO 20000 and ISO 27001 standards
- Comparative analysis of existing ISO 20000 and ISO 27001 standards in the field of information security management by using actual measurement results
- Creation of a new improved ISO 20000 standard model based on comparative analysis and benefits of ISO 27001 standard by using actual measurement results
- Implementation of the new ISO 20000 standard in the practical environment of the IPTV/VoIP service of the Telecom operator
- After applying in a practical environment, evaluating the benefits of the new improved ISO 20000 standard model compared to the old ISO 20000 standard model.

IV. REFERENCE MODEL

For the research covered by this work, the IPTV/VoIP service with the Telecom operator was taken. The selected IPTV/VoIP service of the Telecom operator consists of the following eight levels:

- Level 1 - Middleware system - a system that is responsible for administering all IPTV users through which a connection with the Central information system of Telecom operator and the Billing system
- Level 2 - Video on Demand system - a system that is responsible for adding, editing and deleting video content as a very important element of each IPTV service
- Level 3 - Real Time Encryption system - TV channel encryption system (a very important segment for measurements that have been made)
- Level 4 - Verimatrix system - video encryption system (a very important segment for the measurements that have been made)
- Level 5 - Real Application Cluster - a database based on Oracle technology
- Level 6 - Diverto system - a system that is responsible for the administration all VoIP users through which a connection with the central information system of Telekom operator and the Billing system
- Level 7 - Statistical system - a system that measures TV and video content ratings and is a very useful function in management (a very important segment for the measurements that have been made)
- Level 8 - Monitoring system - TV and video monitoring system as well as terminal equipment (Set Top Boxes) located on the end-user side.

Figure 3. shows the IPTV/VoIP service model of the Telecom operator, which implemented the implementation of the ISO 20000-1:2011 and ISO 27001:2013 standards, as well as all reference measurements.

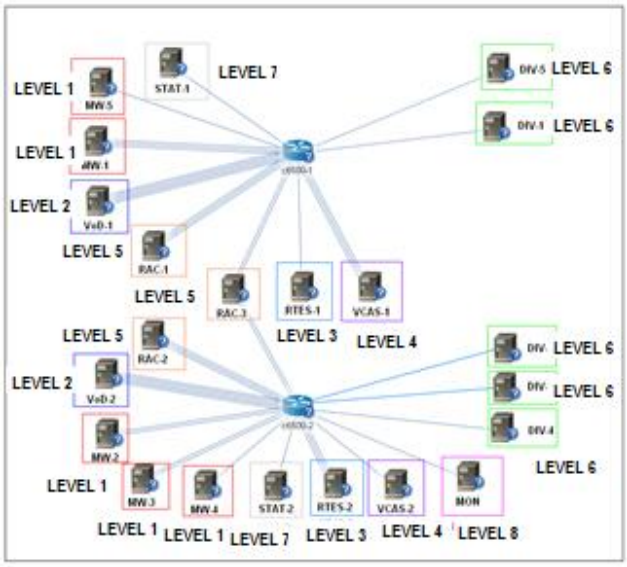

Figure 3. Reference model used for research

V. IMPLEMENTATION OF IT SERVICE MANAGEMENT SYSTEM IN THE REFERENCE MODEL

The implementation of the ISO 2000 standard process together with the set of activities, metrics and metrics results are shown in the table below [3] [4]:

TABLE 1: APPLICATION OF ISO 20000 STANDARD IN THE BUSINESS ENVIRONMENT OF IPTV/VOIP SERVICE OF TELECOM OPERATOR

The name of process	**Activities needed for the implementation**	**Key Performance Indicator (KPI)**	**KPI Result (The percentage of the measured value)**
Budgeting & Accounting	Implementation of modules for: budgeting, billing and accounting	Allowed time period needed for the implementation is 90 days	85%
Capacity Management	Realization of capacity plans for: business, IT services and IT components	Allowed percentage of the successful prepared capacity plans	91%
Availability Management	Measurement of work of IT services through logs on servers	Time period of availability of IT services on all services should be greater than 95%	92%
Service Level Management	Prepare the contracts between all organization units inside the same company	The percentage of all signed contracts between all organizational units is 90%	100%
Service Reporting	Every month, the IT service report is sent to the company management	The permitted percentage of generated reports sent to the Company's management is 99%	100%
Service Catalogue Management	Business catalog of all IT services and technical catalogue of all IT services were prepared	Updating the business and technical catalogue of the IT service is done regularly on a monthly basis	100%
Information Security Management	Implementation of security policy in practice: logical security, cryptography, security of operations and security of communication	Updating and controlling security policies is done regularly on a monthly basis	65%
Business Relationship Management	Creating modules in the information system for collecting and analyzing complaints come from users	Percentage of resolved complaints by users resolved in a time period of less than 48 hours	99%
Supplier Management	Creating modules in the information system for collecting bids from suppliers and evaluating offers	Percentage of the procurement process that has been completed in accordance with legal acts and within the allowed time period after the implementation of the module	97%
Incident Management and Request Fulfillment	Implementation of Service Desk tools for analyzing, collecting, processing and solving incidents and requests for service by the user	The percentage of incidents and requests for service resolved within a 48-hour period	98%
Problem Management	Implementation of Service Desk tools for analysis, collection, processing and troubleshooting by users	Percentage of problems resolved within a time period of 48h	100%
Release and Deployment Management	Creating a working procedure for implementing new applications, system components, and network components of the IT service	The maximum allowed time period for the implementation of a new application, system component, or network component of the IT service must not exceed the time period of 3 months	92%
Service Asset and Configuration Management	Realization of a database containing information about IT equipment within the company	Percentage of IT components that are included within the Database	91%
Change Management	Implementation of the Service Desk tool for analyzing, collecting, processing and solving changes by users	The percentage of changes resolved within the 48-hour period	97%

VI. IMPLEMENTATION OF INFORMATION SECURITY MANAGEMENT SYSTEM IN THE REFERENCE MODEL

The implementation of the ISO 27001 standard process together with the set of activities, metrics and metrics results are shown in the table below [5], [6], [7], [8], [9]:

TABLE 2: APPLICATION OF ISO 27001 STANDARD IN THE BUSINESS ENVIRONMENT OF IPTV/VOIP SERVICE OF TELECOM OPERATOR

The name of process	**Activities needed for the implementation**	**Key Performance Indicator (KPI)**	**KPI Result (The percentage of the measured value)**
Logical security	Implementation of employees' identity management modules as well as administrators of their accounts	There is a record of the identities of all employees and their account administrators	100%
Cryptography	All passwords within the information system must be encrypted by an asymmetric algorithm	The percentage of passwords within all information system modules that are encrypted	99%
Security of operations	Create logs that will monitor the operation of each individual module of the information system	Percentage of information system modules that have their logs from which they can monitor their work	95%
Communication security	Create access lists between all IT property components to allow or prohibit the entry of unauthorized persons	The number of security incidents related to unauthorized access must always be zero	100%

VII. COMPARISON OF MEASUREMENT RESULTS

All processes within ISO 20000-1:2011 standards, except for the process of Information Security Management, have results in implementation that is above 90% of the implementation success. Only the Information Security Management process achieved an unsatisfactory result of 65% in the measurements, which is not a satisfactory achieved result.

The processes within the ISO 27001:2013 standards have achieved the implementation success of 98.50%, which is a significant and good result. It is evident that the Information Security Management process of the ISO 20000-1:2011 standard achieved the result of 65% of the

performance, while the processes in ISO 27001:2013 achieved the result of 98.50%, which is more than 33.50% better performance compared to the adequate process in ISO 20000 standard [11].

Since ISO 27001: 2013 is the reference standard for information security, and since it has achieved a satisfactory result on the IPTV/VoIP service model of the Telecom operator, the proposal is to create a new improved model of ISO 20000-1:2011 standard [12].

The new improved ISO 20000-1: 2011 standard model will have a completely identical structure and process schedule as well as the original model shown in Figure 1. In its scheme of process, the Information Security Management process will remain, only the same process will now include four subprocesses from ISO 27001:2013 that do not exist in the original ISO 20000 standard [14], [15]: logical security, cryptography, security of operations, and communication security. For all four subprocesses will be done in the second round of measurements as well as the measurements completed in the first round.

The original scientific contribution achieved through this work is a new enhanced model of IT Service Management System based on the ISO 20000-1:2011 standard. The new improved ISO 20000 standard has been improved only in the field of Information Security Management process [10]. Recommendations for improving the existing ISO 20000 standard are taken from the standard that defines information security management in details (ISO 27001:2013 standard). A new Information Security Management process has been added with four subprocesses [14]: Logical security, Cryptography, Security of operations and Communication security.

Then the implementation of the new ISO 20000-1:2011 standard on the same reference model was done through the same key performance indicators to see the new achieved result:

TABLE 3: IMPLEMENTATION OF THE NEW IMPROVED ISO 20000 STANDARD MODEL ON THE IPTV/VOIP SERVICE MODEL

The name of process	**Activities needed for the implementation**	**Key Performance Indicator (KPI)**	**KPI Result (The percentage of the measured value)**
Budgeting & Accounting	Implementation of modules for: budgeting, billing and accounting	Allowed time period needed for the implementation is 90 days	85%
Capacity Management	Realization of capacity plans for: business, IT services and IT components	Allowed percentage of the successful prepared capacity plans	91%
Availability Management	Measurement of work of IT services through logs on servers	Time period of availability of IT services on all services should be greater than 95%	92%
Service Level Management	Prepare the contracts between all organization units inside the same company	The percentage of all signed contracts between all organizational units is 90%	100%
Service Reporting	Every month, the IT service report is sent to the company management	The permitted percentage of generated reports sent to the Company's management is 99%	100%
Service Catalogue Management	Business catalog of all IT services and technical catalogue of all IT services were prepared	Updating the business and technical catalogue of the IT service is done regularly on a monthly basis	100%
Information Security Management: Logical security	Implementation of employees' identity management modules as well as administrators of their accounts	There is a record of the identities of all employees and their account administrators	100%
Information Security Management: Cryptography	All passwords within the information system must be encrypted by an asymmetric algorithm	The percentage of passwords within all information system modules that are encrypted	99%
Information Security Management: Security of operations	Create logs that will monitor the operation of each individual module of the information system	Percentage of information system modules that have their logs from which they can monitor their work	95%
Information Security Management: Communication security	Create access lists between all IT property components to allow or prohibit the entry of unauthorized persons	The number of security incidents related to unauthorized access must always be zero	100%
Business Relationship Management	Creating modules in the information system for collecting and analyzing complaints come from users	Percentage of resolved complaints by users resolved in a time period of less than 48 hours	99%
Supplier Management	Creating modules in the information system for collecting bids from suppliers and evaluating offers	Percentage of the procurement process that has been completed in accordance with legal acts and within the allowed time period after the implementation of the module	97%
Incident Management and Request Fulfillment	Implementation of Service Desk tools for analyzing, collecting, processing and solving incidents and requests for service by the user	The percentage of incidents and requests for service resolved within a 48-hour period	98%
Problem Management	Implementation of Service Desk tools for analysis, collection, processing and troubleshooting by users	Percentage of problems resolved within a time period of 48h	100%
Release and Deployment Management	Creating a working procedure for implementing new applications, system components, and network components of the IT service	The maximum allowed time period for the implementation of a new application, system component, or network component of the IT service must not exceed the time period of 3 months	92%
Service Asset and Configuration Management	Realization of a database containing information about IT equipment within the company	Percentage of IT components that are included within the Database	91%
Change Management	Implementation of the Service Desk tool for analyzing, collecting, processing	The percentage of changes resolved within the 48-hour period	97%

	and solving changes by users		

VIII. CONCLUSION

The Information Security Management process with its four subprocesses has achieved the final implementation result of 98.50%, which is more than 33.50% of the successful implementation compared to the 65% result achieved in the first measurement. All other processes from ISO 20000-1:2011 standards have resulted in an identical result as in the first measurement [10], [11].

From this it is quite evident that a new improved model of ISO 20000-1:2011 for the Information Security Management process has been created based on the recommendations and key activities of ISO 27001:2013 standard. The new enhanced model was created on the Telekom operator's IPTV/VoIP service model [10].

The next research in this field must rely on other reference models. Examples of other reference models that can be considered for research include: Enterprise Resource Planning System for the production company, Service Desk system for Waterworks, Customer Relationship Management System at Company for production and distribution of electrical energy, Document Management System for IT companies [11]. If the results of these surveys achieve a satisfactory result such as the result achieved on the reference model of IPTV/VoIP services, then ISO will have all the elements to revise the existing ISO 20000-1:2011 standard in the field of Information Security Management [12]. Figure 4. shows a new improved model of the ISO 20000 standard, which at the same time represents the original scientific data of this produced through the completed measurements.

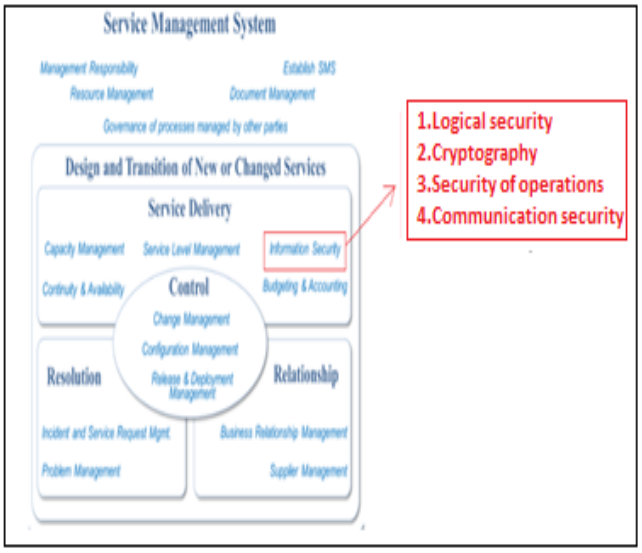

Figure 4. New improved model of ISO 20000-1:2011 standard

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Smart Tools in Software Engineering: A Systematic Mapping Study

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***Abstract*—Software development processes such as waterfall development model have been around for over fifty years, but still, even modern software development approaches, such as DevOps or Test-driven development, fundamentally rely on the same principles and phases as everything before them. Yet, the modern world imposes new challenges for software businesses, and new ways of digital distribution require new ways of resource provisioning and ability to reduce the time-to-market to its absolute minimum. In this study, we identify and analyze the technologies which may be useful for software companies to ease the development and maintenance work by assisting the experts to collect relevant information and observe issues before they cause process disturbances. As a result, we describe a mapping study, which identifies different approaches to developing a smart software engineering tools applying potential technologies such as artificial intelligence, cloud-based service models, adaptive measurement, and other approaches, which could offer significant benefits to the software development process.**

I. Introduction

The software development environment is a socio-technical system [1], meaning that the process activities in the development of software are related to both the human aspects and technology. From the viewpoint of organizations, the software development principles have changed only to a small degree during the last fifty years; the waterfall approach was already known in the seventies [2], and even the more recent Agile methods are based on the project management principles first applied during the same era [3]. Even the innovative process models such as DevOps or Continuous Integration are more or less successful implementations of principles first presented in early agile models such as Extreme Programming (XP) [4].

However, the difference between the formal methods and methods-in-use has been acknowledged at least since from the nineties (for example [5]). In fact, there are survey studies from the software industry which indicate that the amount of formal methods and certified practices are in decline [6]. Similarly, the new business models such as digital distribution, self-publishing and free-2-play, with the technological innovations such as cloud computing and powerful tablet systems, change the way the software companies should operate, what types of tools they actually need [7] and the design challenges these companies face. In the more general level, there also is pressure on the managerial scalability aspects, to which concepts like Scrum of Scrums (for example [8]) try to find an answer. On the software engineering tools, even the established and traditional tools such as the UML notation face criticism for being unnecessarily complicated and hard to use efficiently (for example [9]). Overall, it seems that the technological innovations, new business aspects and organizational change needs will present a challenge to the software organizations.

To assess these challenges, we formulated a systematic mapping study based on the question how could the technological innovations affect the software development ecosystems and software processes?. To approach this problem, the following sub-problems were been identified:

- What technological innovations are currently studied to affect the software business in the near future or have recently affected the software industries?
- What are the recent modern software engineering tool-related innovations?
- How could the end-product quality and maintainability be promoted with the smart tools? What technological innovations would actually be useful for the software industry in practice?

The approach to answer to these research questions was in literature-based systematic mapping study (SMS), applying the widely accepted SMS process method to assess the recent innovations and scientific works regarding the different types of smart tools and smart development environments of the software engineering discipline.

Rest of this paper is structured as follows: Chapter 2 discusses the related works and concepts, and Chapter 3 presents the systematic mapping study approach. Chapter 4 presents the results and observations made from the literature, and the Chapter 5 discusses the meanings, risks and implications of the results. Finally, Chapter 6 closes the paper with summary and conclusions.

II. Related Work

The difference between the formal methods and methods-in-use has been acknowledged at least since from the nineties (for example [5]). In practice this means that the state-of-the-art software development and real-life-applied software process tends to supersede the existing codified standards and practices. Additionally, there are concerns that all process models have shortcomings [10], and that the process models tend to be really laborious to implement successfully even in the mature and professional organizations [11]. Similarly, even traditionally well-known and applied software design tools such as the UML2 notation face criticism for being

unnecessarily complicated and hard to use efficiently (for example [9]). For some areas of software industries, they even lack central components such as GUI design notations, or support for non-functional requirements [12]. In this sense, the search for more efficient software engineering tools and smart systems to aid the development work would be welcome.

In a survey study by Hynninen et al. [6] the different types of software development and quality assurance tools and processes were analyzed. Their main discovery was that while the amount of different types of development and testing tools was generally on the rise, while the amount of different formal process models and application level of certification training was on decline. Similar observations were made also by, for example, a survey by Garousi and Zhi [13]. In both studies, the rising trends in general were the agile approaches, with tools promoting automated activities and faster reaction times to the shifts in the customer demands or system requirements. Additionally, some areas of software industry, such as the entertainment software industry, do not necessarily even benefit from the application of the tools designed with the traditional software engineering mindset [7], and in any case, the major component of the software lifecycle costs is the maintenance, not the pre-launch development work [14].

III. Research approach

To assess the current state and recent trends of the smart tools for software engineering studies, one of the first steps in the systematic mapping study was to identify the appropriate venues and sources from which to collect the data material [15]. After a few trial searches with several databases and search engines such as ACM digital library or IEEExplore to assess the feasibility of our search terms, we decided to focus on the Google Scholar as the main data source because of its domain-neutral approach and large database. The utilization of the separate scientific publishers would have required searches from various different sources, leaving us with possibly biased results since these databases do not cover other works or other publication venues other than the ones the publisher endorses. The utilization of Google Scholar gave us less biased results while it cannot access absolutely all of the existing scientific data - it has a large pool of documents spanning probably most of the different domains from any research paper search portals. This approach also minimized the amount of duplicates and near copies, different versions of the same paper.

The objective of a systematic mapping study is to refine and summarize the collected data with a further analysis to present publishable results. In our mapping study, we applied the process model as defined by [16], since it is well-known and applied in software engineering domain. The Petersen model has six process steps; definition of the scope, search for paper pool, identification of primary documents, classification, data extraction and documentation. These process activities are summarized in the Table 1.

The research question definition was accomplished by assessing the amount of recent works discussing the smart tools and software engineering in the different publication venues. This research work was conducted by one of the authors, who also established the inclusion and exclusion criteria. After it was confirmed that there were significant document pool for the scope of the study, the decision to commit to a SMS study was made.

The search for primary studies was conducted on Google Scholar by formulating a list of rules and keywords. The initial search keywords were smart tools and 'software engineering' in the title or abstract of an article. This was a logical starting point as we were trying to gain knowledge on the recent studies regarding smart tools and technologies. Since the topic was very open-ended, we also added "smart IDE" to the second round of search to expand the document pool. Additionally, since we wanted to observe what were the recent trends and works in the smart tool research, we decided to add publication year limitation of "after 2015" to our research requirements. These search rounds are summarized in the Table 2.

These searches were conducted in January 2019 and were not restricted by any rules or filters except the limitations mentioned earlier, after 2015 and in English. That means in this stage we included all the articles regardless of, for example, the publication forum, type or the discussed technology or purpose.

We did not conduct any manual search beyond pilot studies with keyword feasibility, nor did we perform snowballing, since recent study by Petersen et al. [16] has found that database search is the most used and appropriate approach, with snowballing with far less used strategy. In our case, it was certain that we would have found more potential documents via snowballing, but since we wanted to focus on the most recent studies, we assessed that snowballing the reference lists would not have been very useful in our case since the recent documents probably do not reference other recent documents.

The screening and identification process was conducted manually by the research group. In this step the objective is to identify the primary documents from the pool of all documents generated by the search process. We followed the inclusion criteria principles similar to the Petersen et al. recommendations [15]: If the abstract explicitly mentions smart tool, smart IDE and software engineering or something similar, the paper was included into the primary documents. Only in the cases, where the appropriate terms appear in the keywords or index terms, but the abstract clearly indicates that the research work does not discuss software engineering, the paper was excluded. In this step, some sanity checks such as removal of the duplicate entries, and removal of partial, broken or non-peer-reviewed entries was also conducted.

Keywording by abstracting was conducted by one of the authors manually to minimize the amount of misclassifications. The keywording was done in two steps; in the first step all of the papers are classified by their content and context. After the initial set of keywords are given, they are grouped into larger abstract terms to establish categorizations. The categorization process is fairly similar to the open and axial coding steps of

TABLE I
SYSTEMATIC MAPPING STUDY STEPS, AS DEFINED BY PETERSEN ET AL. [15]

Step #	Process Activity	Output
1	Define research question, identify relevant forums	Defined the scope of the study
2	Conduct search for primary studies in the topic	The paper pool of the study (all papers)
3	Screening and identifying primary papers	The pool of primary papers
4	Keywording using abstracts	Classification of the papers
5	Data extraction and mapping process	Systematic map, statistical data
6	Documentation of the systematic map, analysis of results	Systematic mapping study

TABLE II
SEARCH ROUNDS AND CRITERIA FOR THE INCLUSION TO THE PAPER POOL. RESULTS FROM GOOGLE SCHOLAR

Round #	Search string	Other criteria	Documents
1	”software engineering” AND ”smart tools”	In English, since 2015, publication, citation data or patent	117
2	”software engineering” AND ”smart IDE”	In English, since 2015, publication, citation data or patent	7

the Straussian Grounded Theory [17]. In addition we applied a classification scheme and data extraction form to minimize the noise and ambiguity generated by having different types of documents and origin domains in the document pool.

Data extraction and mapping process consisted of several different measurements and metrics. The systematic mapping of the primary documents and their keywords were compiled for the visual presentation of our work by assessing the application domain besides software engineering, the type of research work done, the evidence provided by the work and the applied technology. These aspects were mapped and documented to a number of tables and diagrams which are presented in the next chapter.

IV. RESULTS AND OBSERVATIONS

Based on our analysis of the recent works on smart tools of software engineering, our research team identified a pool of 124 different documents consisting three scientific books which were compilations of scientific articles. By including these book chapters as separate documents, a total of 137 different documents describing the different types of documents discussion software engineering and smart tools was discovered. Out of these document, 48 documents (35.0 percent) were books or book chapters, 40 documents (29.2 %) journal articles, 22 (16.9 %) conference papers, 17 (12.4 %) thesis works and 10 (7.3 %) patents.

After classification and assessment, we accepted 54 documents as our pool of primary papers since they discussed software engineering and smart tools in some degree or form, bringing the inclusion rate to 39.4 percent. Since this study only included scientific sources, patents and thesis works were excluded from the further analysis regardless of the topic they discussed. Out of the primary documents, majority discussed one or more of the most five most common categories: Internet of Things or big data in general, metrics generation tools to assist design or development, different forms of artificial intelligence, recommendation tools to manage process or system analysis work either by analyzing the process or the architecture with smart tools. These are listed in Table 3. In addition, 11 papers were technology or solutions reviews in general, discussing the existing systems and existing smart solutions to solve different domain- or software engineering related development process issues.

TABLE III
THE MOST COMMON IDENTIFIED SMART SE-RELATED TECHNOLOGY CATEGORIES

IoT, Big data or distributed systems	12 (22.2 %) out of 54 papers
Metrics generator, programming or design assistance tool	11 (20.4%) out of 54 papers
Artificial intelligence or machine learning	11 (20.4 %) out of 54 papers
Recommendation tool (knowledge management, classification system or root cause analysis)	10 (18.5%) out of 54 papers
System analysis tool (process or architecture)	7 (13.0%) out of 54 papers

Observations from the different papers discussing the smart tools of software engineering are summarized in Table IV. The three most common attributes of the all analyzed papers were related to their content; the majority of the publications were theoretical papers discussing the smart technologies in general (64.8 percent) whereas implementations or proof-of-concepts were 29.6 percent of the works. In addition, 51.9 percent of the publications discussed the smart technology in other contexts besides software engineering. From these paper the impact to the manufacturing industry was most common theme, the second place being IoT and Healthcare-related systems.

In the assessment of the impact of smart tools, 9 publications discussed the performance differences between the ’traditional’ systems and the ’smart’ tools replacing them. Six publications included some form of assessment for the costs or needs based on real case study example, while 3 publications included no evidence or measurement data on the impact or efficiency of the applied smart technology.

TABLE IV
THE MOST COMMON OBSERVED ATTRIBUTES OF PUBLICATIONS RELATED TO SMART TOOLS OF SE

Theoretical paper concerning the technologies	64.8% (35)
Implementation, or proof of concept, for smart technology	29.6% (16)
Review of existing technologies and smart solutions	20.4% (11)
Application domain related to Manufacturing industry	18.5% (10)
Application domain related to Internet of Things	16.7% (9)
Application domain related to Healthcare	16.7% (9)
Performance evaluation between 'traditional' and 'smart' system	16.7% (9)
Case-study on costs and need to adopt a smart tool	11.1% (6)
Case study with no evidence or assessment presented on the impact of 'smart' technology	5.6% (3)
Survey or study on the users of smart tools	5.6% (3)

V. DISCUSSION AND IMPLICATIONS

Based on our observations, the results of this mapping study indicate that the term 'smart' is usually understood as some form of 'decision support system' in the publications. Smart tools are usually applied in two fields - Industrial IoT and software engineering. In software engineering, Smart tools are mostly applied in static analysis to generate metrics or further insights into the system structure. In the beginning of this study, our research team devised three main branches of 'smart tools'; 1) the tools which can adapt to solve different types of problems, 2) the tools which provide additional insightful information and 3) the tools, which guide the user and prevent common types of errors. Based on our observations, the recent studies seem to focus on the second category, providing more insight to help process management or to gain more useful information from the performance and architecture of the existing system. Based on our original research question *how could the technological innovations affect the software development ecosystems and software processes?* the results seem fairly straightforward: the current trends of smart tools seem to work towards providing more metrics and more information to the developers, with the IoT and big data-based solutions, and artificial intelligence-based metrics generators, being common topics. Based on these observations a tool which can create novel and accurate information from the current state of the system could be one of the outcomes combining the current trends, and enabling improvement of the overall quality of the software products and services it measures.

Obviously, this SMS study is not perfect and it has some shortcomings. For example, Grant and Booth [18] define systematic mapping study to have weaknesses in the lack of synthesis and in-depth analysis especially when compared against other research approaches, broad overall descriptive level and risk of oversimplifying the results of the studies. Overall, these limitations cannot be disputed, but they are recognized and there are ways to minimize their risk for the study validity. In our case, we selected a search tool which was not domain-specific, and avoided defining the "smart tool" to very restrictive degree. Basically, our only requirements were that the publication discussed software engineering-related topic, and was recent work, while self-identifying as discussing "smart tools". In general, the decision of using Google Scholar as the sole source of documents due its convenience, low cost, and broad coverage has been discussed by [19] and considers this approach of acceptable quality. For criticism, Giustini & Boulos [20] argue that the Google Scholar finds only approximately 95% of the articles in the controlled test group, and includes a large number of irrelevant objects. For our purposes of finding out what the "smart tools of software engineering" are, the accuracy of 95 percent was acceptable, since our aim was to gather articles from as wide range as possible instead of precision since we deliberately did not want to narrow the search criteria too much. From the 137 documents we ended up rejecting 83, mostly because they were not academic or research-based sources, or they did not discuss topics related to the software engineering discipline. Additionally, we did not evaluate the quality of the found documents in this study. As suggested by Petersen et al [16] and Kitchenham & Charters [21] the quality of articles should not be considered a major component in the systematic mapping studies, since the objective is to collect general information regarding the topic and research directions related to it, not to conduct an in-depth systematic literature review, which analyzes and discusses the publications and trends in detail.

VI. CONCLUSIONS

This systematic mapping study identifies the different types of smart tools and smart technologies, which are the current trends of software engineering research, while assessing how these technologies could assist the development and support of the software products and services. The need for this study origins from the observation that the applied tools, infrastructure and business models are evolving, and already now some areas of software industry are unable to successfully apply the organizational model intended to enable better organization practices and reach the intended end-product quality, or lack feasible tools to observe the overall state of their system. In general, the existing tools may not support the actual real-life needs, or at least could be improved.

Based on our observations, the current state of the smart tool research focuses on theoretical works, with a number of implementation projects or case studies discussed. The most "relevant" smart technologies are Internet of Things, big data or artificial intelligence-related tools, in many occasions providing in depth data or measurements to assist the development or design work. Additionally, recommendation systems or analysis tools exist, but the most common types of tools focus on providing novel information over existing domain, not -for example- in error prevention or adjusting to the different types of related problems. Based on these observations, for example smart analyzers and metrics generators as quality assurance assistance tools were proposed.

The application of these results could help in the development of new operational models or development tools to supplement the existing industry-adopted software development ecosystems. In any case, the results provide insight into the ways to further develop the software engineering tools and support systems towards the more technology-adapted approaches, and pinpoint areas of interest and innovations for the research of modern computer-assisted software engineering tools.

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PRINCE2 vs Scrum in digital business transformation

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Abstract – This paper compares two project management methodologies PRINCE 2 and Scrum in a case study of digital business transformation. There is no universal methodology, that could work for all projects, but digital transformation or Industry 4.0 indicates new management strategies, for which right framework is almost mandatory. Paper also emphasizes that digital transformation of an organisation can not be just an IT project. In case study we discuss budget, time and value for a project. We analyzed project of digital transforamation of insurance company, where we had case study of issuing a travel insurance policy. PRINCE 2 definitely provides wide range of guidelines that help managing project, but all the documentation demands certain knowledge, usually more time, and not lot of flexibility in project control. On the other side, Scrum does not provide enough documentation, and it' better for small projects, with fast delivery needs. Every methodology goal is efficiency and effectiveness, and we try to give guidelines which one to use, based on simple comparison.

Keywords: project, project management, PRINCE2, Scrum, digital transformation

I. INTRODUCTION

Project can be defined as an attempt to achieve some results, using available resources, in defined time period [1]. According to [1] and [2], the first thing we need to pay attention to is the project category – knowing category eases understanding trends and allows the project size to be determinated.

Choosing right project methodology, as explained in [3] is not easy. The main goal of any methodology is to achieve efficiency and effectiveness, using steps that can be repeated. In last ten years agile methods became popular way for overcoming the uncertainty of the project. Identifying what is a business project requirement, adapting and providing adequate resources is what is most important for selecting the appropriate methodology.

Digital business transformation refers to intensive use of digital technology and digital resources as a tool for creating new income, new business models or new ways of doing business, in general. A digital business transformation arises when company simultaneously and in short time period performs significant changes in business activities like strategy, structure, business processes, business model or organizational structure. It is usually change where digital technologies connect business processes, enabling competitive advantage for a company [4] [5].

Any business can get digitally transformed. Digital business is result of digital transformation – adaptation to digital economy. Company can use digital technology and still not get digitally transformed – eg.it is possible do make an order using company's website, not over mobile phone, but that means more of using classic ICT, not digital business transformation [6].

Section II represents basics of digital strategy in a company and emhasizes that digital transformation can not be project for IT only. In Section III we provide theoretical comparison of PRINCE2 and Scrum as two project management methodologies, and give introduction to Section IV which represents case study. Section V represents conclusion, and Section VI are references used in this paper.

II. DIGITAL STRATEGY

Digital strategy in business means developing those activities that will support main strategic goals and allow them to be realized in three ways:

1. Efficient support of digital technology to existing business model (run the business)
2. Using digital technology to change existing business precesses (change the business)
3. Making innovative business models applying digital technology (reinvent the business) [4]

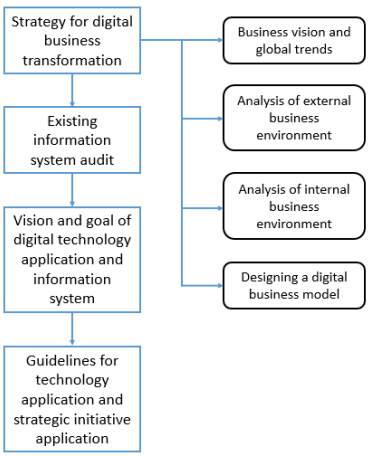

Figure 1. Phases of developing strategic plan of digital business

Diagram shows that digital business transformation is not and never can be only IT project. Management has to be involved, although many companies are starting agile change processes in their Diagram shows that digital business transformation is not and never can be only IT project. Management has to be involved, although many companies are starting agile change processes in their IT areas. Agile management can be promising approach for a number of application, but strict agilization does not necessarily lead to the desired goal [7]. It is importat to consider the situation of specific organization and the environment it operates in. Study by Westerman [8] has identified that executives transform three key areas of their companies: customer experience, operational processes and business model like in diagram:

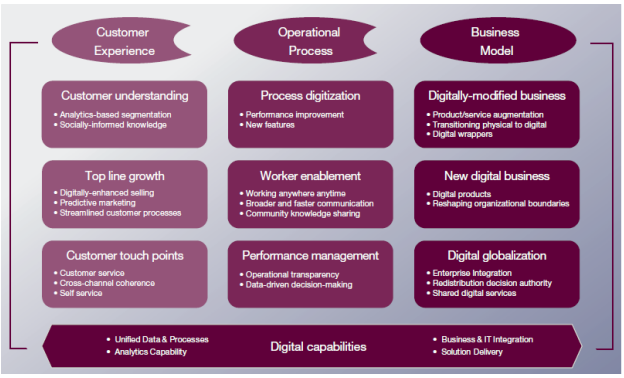

Figure 2. Building blocks of digital transformation [8]

According to [9], studies identify three central challenges for digital transformation: Lack of perceived urgency to begin the transformation; Coordination and leadership issues such as having unclear or conflicting roles, responsibilities and goals; Ineffectiveness of IT to respond to change. As explained in [10], innovators usually have to decide do change business that worked for even decades. But we cannot forget that analog companies have good start point they are sometimes not aware of: data. This report suggests that there are five distinct methodologies that can be applied to develop new business model:

1. Scenario-based design
2. Epicenter-driven design
3. Unorthodox design
4. Customer-centric design
5. Mirrored design

Both [4] and [9] advice using Dr.Kotters'es eight steps to digitally transform organization: Establish a sense of urgency; form a powerful guiding coalition; create a vision; communicate the vision; empower others to act on the vision; plan for and create short term wins; consolidate improvements and produce yet more change; institutionalize new approaches.

III. PRINCE2 VS SCRUM

Every methodology goal is efficiency and effectiveness. Methodology should be simple and easy to understand and learn. It should make it possible to warn about problems in the early stages of the project, and to be scalable, adaptable and upgradable

Information systems projects need effective project management discipline to be successful. The consequences of failure are expensive, and failure factors may include a mix of people, technology and methodology issues. PRINCE2 is more than 20 years old methodology, and some organizations consider themselves too small for PRINCE2, but choosing Scrum just because of that cannot be justification [11] [12]. Scrum is usually used as synonym for agile methodology. Agile manifesto was created in February 2001, in Utah, US, so it's not as young as we could imagine in the beginning. Manifesto was published to define the lightweight development approach [13]. As shown in [11], [13] main differences between agile principle and other project management methodologies are:

TABLE 1: DIFFERENCES BETWEEN PRINCE2 AND SCRUM

Feature	**PRINCE2 Project Methodology accents**	**Agile/Scrum principle**
Typology	Plan-based	Adaptive based
Business case	Multipurpose, better for large projects	Multipurpose, best for software development
Learning	Previous experiences (previous project's notes remain for future projects)	Analysis is given after each sprint. Experience can be applicable in next sprint
Roles and responsibilities	Project executive, Project manager, Senior User, Senior Supplier, Project Support, Project Assurance, etc.	Scrum master, Product owner, team
User involvement	Role of the Senior user is part of the steering board or project committee	Role of the Product owner, who is accountable for maximize product's value and team's work
	Active user involvement is slightly accented	Active users are part of the development team itself
Requirements dealing	Change management is established as a rigors process and change is typically exceptional	Changes are usual part of the project
	Fixed budget, fixed scope, following plan	Requirements evolve, budget burn-chart
	No or low requirement prioritization, there is only Business Requirement Statement Baseline	Requirements prioritization in each iteration, planning at each iteration start
	Project Requirements aligned with project plan must be approved by project board	Agile development teams capture high level requirements in workshops, working together in a highly collaborative way so they all team members understand the requirements as well as each other
Life cycle	Project beginning	Project vision
	Project initiation	Road map
	Managing project, setting borders and project sustainability	Sprint planning, development, daily meetings, sprint audit, sprint retrospective
	Project closing	

IV. CASE STUDY

We have analyzed digital transformation of business firm using Microsoft Project Standard 2016 for graphic presentation and help in assigning resources to tasks or managing timetable. It's essential to make a model for measuring project's productivity first.

We compared budget, time and value as interconnected limitations for any project.

Usually company's management has no adequate knowledge and competencies in recognition of strategic opportunity provided by intensive and innovative us of information and communication technology. It can lead to not investing enough money in project and human resources with adequate training and knowledge, or not providing feasibility study and putting too much money and other resources to project where we do not know what to expect and what are cost-benefit results.

It's management's task to provide "value assurance" as shown in [14]:

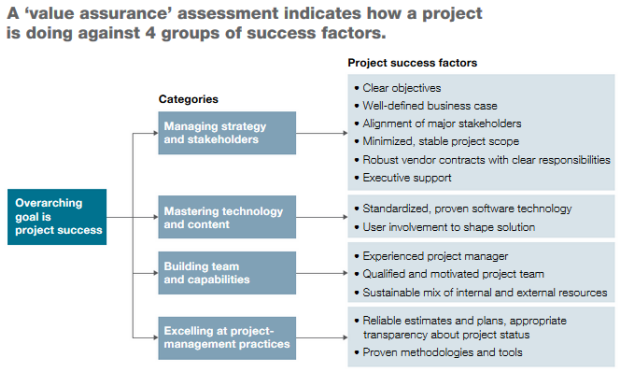

Figure 3. Four groups of success factors

Management can be guilty for project's failure if it has no knowledge and expertise in managing project itself. Manager has to know how to organize and lead teams, but team work is there most important.

Wrong estimation of project duration is usually connected with optimistic duration assessment. It can also be manager's fault, as said in [4] if it is caused because of his inexperience or personal goal which he cannot ensure. Also, stakeholders can have unreal expectations and put even unfinished project to production. If project starts in wrong period, when company has most work, and has no time to adapt to changes, it can be considered faulty time management as well.

For quality value estimation, we have to have mechanisms for measuring impact of a project on company's business. The best way to do this is audit.

Our analysis is for project of digital transformation, using PRINCE 2 and Scrum for same project. We measured digitalization in an insurance company of 450 employees, where we analyzed digitalization of process of issuing travel insurance policies. Company has sales department, counting 300 employees, where other 150 are in back office, but all others sector have to have access to system, some for reporting, finances for managing financial data etc. Main challenge for teams or team leaders was educating top management and having them provide adequate environment and all sources needed for a project, of course, their main concern was business continuity. Insurance itself is conservative business, but with high potential in processes of digitalization and improvement of their business. In company we analyzed the main problem was diffusion of company's business units or profit centers across the country.

We provide results of our analysis in following discussion:

TABLE 2: MAIN BUDGET DIFFERENCES BETWEEN PRINCE2 AND SCRUM

Feature	PRINCE2 Project	Scrum
Budget	Fixed budget	Requirements evolve, budget can be changed within the box
Certification	PRINCE 2 specific education, not available in neighbor countries	No extra education needed, could be provided with own IT team
Documentation	Additional space for storing, and providing adequate presentation of documentation (project plans included)	Keeping only essential documentation
Stakeholder	Must be defined – the company in our case	Not necessarily defined - company

If we analyze only what is cheaper, budget is definitely on Scrum's side. We had to provide project management with great knowledge in project management for PRINCE 2. Also, every decision had to be made with company's board first, then with management, and in the end with project management. Product ownership is established on the project management level for Scrum. Additional education for PRINCE 2 is not negligible cost.

We used period of 152 days for completing project using PRINCE 2. We had 24 weeks for Scrum, and two Scrum teams, one for development, one for quality assurance. One sprint lasts for 15 days. Environment where project held was not included in consideration, we didn't investigate if there was a peak for business we analyzed. We had all needed resources, so it did not affect our research in any way. The major difference in using time was – the final project was released in the end with PRINCE2. We had incremental release with Scrum. We cannot decide which one method is better, just observing period used for finishing project. Number of days or weeks does not matter here – it cannot be used as an advantage.

Internal audit for company was provided, and it followed the framework for Internal Audit Effectiveness – International Professional Practices Framework – IPPF.

Audit followed main process model of auditing itself: planning of internal audit, critical examination and business evaluation, reporting, follow up the results. By definition [4] quality of information system is a relative category that measures the deviation of its realistic function for the ideal. Some of parameters we can measure are: number of incidents in defined period, count of active incidents, average time for dealing with incidents, open and closed problems ratio, count of changes that are not reported using official procedure. Measuring of information system quality is complex procedure where the ideal system function should be determined. It's said in [4] that internal system quality is insured by internal system control, and level of that quality is determined by its internal revision. Critical examination and business evaluation in our case included revision: does IT work in accordance with business goals, to what extent it effectively and effectively supports the business goals, which controls support information system. Object of analysis was state of information system in case of selling travel insurance policies, risk evaluation in observed state and attempt to guide management to improvement of current state.

System quality and risk management comparison is partly described in following table:

TABLE 3: SYSTEM QUALITY AND RISK MANAGEMENT COMPARISON

Feature	PRINCE2	Scrum
Quality planning	Project quality plan can be considered as an equivalent of the quality management plan. It is fully covered with PRINCE 2 – all expectations are documented	We could not precisely define customer's expectations regarding quality in Scrum
Quality assurance	Provides adequate documentation internal auditors can use as foundation for audit	No documentation for internal auditors is provided. Quality assurance can be modified during project itself –team can easily change focus if previous is not adequate
Quality control	Provides logging and documents quality reviews	Does not necessarily provide logging
Risk management	Problem is assumption that same approach can be used on all projects	If risk is shown, team will try to work on it
Risk identification	Provides risk log to assist in controlling risks. That helped managing risks	It was discussed in team meetings
Sorting risks	Suggests high, medium and low scoring, but no analysis techniques were available	Instant reaction to a risk was provided

IT in our examined case got to wanted goal. The main business goal was to digitalize process itself, reduce costs, and show rapid business expansion in a short period of time. In a goal to achieve those auditors followed standards – it was necessary not only because of regulatory measures, but to intensify consciousness of need to manage risks. In our comparison both methods satisfied company's expectations, provided convenient information system and created base for achieving business goals. Auditors provided report, based on verifiable and factually correct analysis. Of course, the report was not available until the end of the project, and the greatest value of that report were lessons learned. Advice for company's management was to use Scrum or some other agile methodology for project where such short period of time is provided, and results are needed to be shown soon, or we proclaim project unsuccessful. Price, which is the most important item, especially for non-technical users, such the management usually is, is also on Scrum's side.

V. CONCLUSION

Choosing one particular method or approach can not guarantee success of a project. PRINCE 2 definitely provides wide range of guidelines that help managing project, but all the documentation demands certain knowledge, usually more time, and not lot of flexibility in project control. On the other side, Scrum does not provide enough documentation, so auditors have no help by method itself. Also, PRINCE 2 is definitely created for large projects, which need lot of tailoring, but small project, with fast delivery needs should use some other approach. Scrum in our case study was almost entirely information technology solution, with minimum management engagement, what for fast delivery need in projects can be shown as advantage.

Both PRINCE 2 and Scrum demanded preparations, Scrum maybe even more, but PRINCE 2 demanded exeprienced team members, with special education, what was one of the main outlay if we consult top management. The environment in which transformation is carried out can determine what methodology to use – company like insurance company may seem like one for PRINCE 2, because of all the regulations and complexity of a business, but project that would take too much time, or be too expensive, must be abandoned, no matter how good or valuable documentation or sucessfull project would be. Management has to manage expectations in business, not provide good results for audit. Audit is tool we can use for measure the project's sucess, but it must not be purpose of the project. In the end, great managers would use method or combination that would make the goal achievement.

A. Future work

The best results would be combining those two approaches, or using one as base for other future projects managed by different method. For example, great

documentation from PRINCE 2 could be great knowledge base for guiding some project using any agile method. That could definitely be a direction for future research. Also, some audit mechanisms or guidebook could be used for future reviews. Analyzed literature does not cover area of insurance at any point, and we see great potential in that area, both for survey and maybe testing some other methodologies.

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Bridging the gap between software architecture and business model development: A literature study

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***Abstract*—The software architecture plan describes the high-level structure and logic of a software system. The architectural plan acts as a constitution and dictates the fundamental principles of the system; therefore, the plan also eventually determines which kinds of business models the software system can support. In the modern mercury business, there is need for experimentation in business model and flexibility in architecture. This paper uses a systematic literature review method to collect primary studies from the extant literature addressing business models and software architectures. The aim is to summarize the current knowledge. The selected primary studies (n=10) are qualitatively analyses and synthesized. The results show that the area remain mostly unaddressed and there is need to develop new methods to support flexible architecture design, tools and development methods.**

***Index Terms*—software architecture; business model; mercury business; literature review; software-intensive business**

I. Introduction

In the modern industry, the speed of changes has been drastically increased [1]. This is even more evident in the software-intensive businesses [2, 3], where ability to swiftly react to changes and adopt new innovations can be a crucial competitive advantage. For example, Järvinen et al. [4, p. 65] describe the new phenomenon as a 'mercury business' where software-intensive companies are actively looking to find *"new grooves where to flow to grow new business"*. As pointed out by Järvinen, et al. [4], for a company to be able to work in mercury business, changes are requested into organization, leadership and culture of the company.

In addition to the organizational issues and capabilities in the software development processes, mercury business also requires that *software architecture* of a product or a service needs to support incremental development and changes in the business model of a product [4]. The software architecture description of a software system denotes the elements that constitute the software system, their properties as well as the relationship between the elements [5]. Thus, the software architecture, in the end, also dictates which kind of a *business model* can be implemented with the software system.

While there are plethora of studies focusing on how an architecture design should meet the (fixed) business goals [c.f. 6], to the authors' best knowledge, a more limited research stream has focused on discussing how an architectural design can support business model experimentation. To map the existing academic knowledge, this paper presents a systematic literature review on works addressing relationships between business models and software architectures. More specifically, we address the following research questions:

RQ1 What extant literature report on the relationship between software architecture and business model?

RQ2 How software architecture design, according to the extant literature, can support business model experimentation?

To answer the presented questions, we performed a literature study. The primary studies were collected with systematic literary study method [7] and addressed via thematic analysis. The final set of primary studies consists of 10 articles published between 2001 and 2017. We restrict our focus specifically on software architectures and we do not included, e.g., system architecture studies.

The remaining of this paper is structured as follows. Section II reviews literature and defines the central concepts for this study. It is followed by the description of used research process in Section III and the results in Section IV. Finally, Section V presents the analysis and discussion of the results while Section VI concludes the study.

II. Background

A. Software architecture

Software architecture, which describes high-level structure and logic of a software system, has several different definitions in the existing literature. According to the IEEE Standards Association, a software architecture is *"The fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution."* [8] Therefore, an architecture is not only about the static structure, but it also includes the functionalities and the dynamic structures of the system. It describes how the parts of the system interact with each other. The software architecture is also a guideline for the developers: it describes rules and principles regarding how to develop a system using the given architecture and imposes some restrictions on the future evolution of the system.

Another way to look at software architectures is to note that the process of designing an architecture always involves

making several important design decisions. Following this reasoning, Bosch considers the software architecture as a set of major design decisions [9]. Because the architecture aims to fulfill the quality requirements for the system, the most pivotal design decisions are usually quality-related. A good architectural description should explain how the architecture meets the technical and the business expectations set for the system through the design decisions. Justifications for the major decisions should also be included.

For different purposes, the architecture can be described on several levels of detail and from different points of view. Architectural models and diagrams can either show how the system has been divided into parts (static description) or how it behaves during execution (dynamic description). Different points of view in architectural description often serve specific stakeholder groups. For example, in order to implement the system, a developer wants to see how the system has been organized into software modules (logical view). On the other hand, a system engineer might want to see what the topology of the component on the physical layer of the system looks like (physical view). [10] This way, a well-documented software architecture also facilitates communication between stakeholders [11].

Software architectures often make use of architectural styles. An architectural style refers to *"a general, reusable solution to a commonly occurring problem in software architecture within a given context"* [12]. The concept is very similar to the idea of design patterns, but architectural styles have broader coverage in the architecture. An architectural style defines and delineates some essential elements and principles in a given software architecture, guiding the implementation process and keeping the developers from exercising too much unnecessary creativity. For example, in the layered architecture style, components within a system are organized into horizontal layers, and each layer has a specific role within the system. A layer forms an abstraction around its functionality, so a layer does not need to be concerned with the internal implementation of any other layer [13].

B. Business model

The literature of business models spring from the field of strategic management. To define the concept simply, a business model is a blueprint of a business organization. That is, the business model aim to illustrate how a company operates and makes money [14].

More formally, a business model can be defined as *"[...] the rationale of how an organization creates, delivers and captures value"* [15]. That is, the business model of a company should describes the ways how a company produces value (e.g., what benefit the product or the service brings to the customer or what problem it solves); how the offered solution is delivered and distributed to the customers; and how the company makes profitable business out of the offered goods or services.

While there are dozens of different business modelling notations and tools presented [14, 16], the Business Model Canvas by Osterwalder and Pigneur [15] is the most often used. The canvas consists of nine building blocks: (*a)* Key partners, (*b)* Customer segments, (*c)* Value propositions, (*d)* Channels, (*e)* Customer relationships, (*f)* Revenue streams, (*g)* Key resources, (*h)* Key activities, and (*i)* Cost structure.

Business models have been reduced to, e.g., a set of actors, activities, and interfaces [17]. Furthermore, often seen simplification equates the term 'business model' with, e.g., the revenue or pricing model of a product [c.f. 18]. In the terminology used in this paper, the revenue model of a company consists of one or more revenue streams [16]. A revenue stream defines how the company is getting compensated from the services or products offered [19].

As the terminology related to the business models is not established, also the concept of 'pricing model' is sometimes used to depict similar or partly overlapping concepts [c.f. 20]. In general, the pricing model defines how the service or a product is priced (eg., what components are included into pricing, whether payment flow is frequent or single). As in the case of SaaS domain, often studies have been addressing pricing models enabled by the architecture [cf. 21].

C. Related work

To the best of authors' knowledge, no previous literature study has been presented in this area. However, there are a few studies addressing the gap. For example, the book by Luke Hohmann [22], titled *Beyond Software Architecture*, divided a software system into technical (i.e., *tarchitecture*) and market architecture (i.e., *marketecture*). According to Hohmann [22, p. 51], marketecture *"is the business perspective of the system's architecture. It embodies the complete business model, including the licensing and selling models, value propositions[...]"*.

Furthermore, Arsanjani [23] argued the need to bridge the gap between business modelling and software architectures already in 2001. Losavio et al. [24], for example, have argued that architecture of a system needs to be agile enough to support changes in business model.

Finally, Laatikainen and Ojala [25] as well as Laatikainen [21] have addressed the relationship between software architecture and pricing models in SaaS solutions. Furthermore, they noted the lack of work addressing this area. As put by Laatikainen [21, p. 13], *"[a]lthough the relationship between a software architecture and its pricing model is important to understand, this topic has not yet been investigated in the literature."* This study is motivated by their observation, yet the scope is extended from pricing models to business models.

III. Research Process

In order to map the current academic knowledge on the phenomenon at hand, we decided to use systematic literature study to collect the material. The systematic literature study is, according Kitchenham and Charters [7], a method to systematically and in a replicable way collect primary studies from the extant literature. SLRs are used to summarize

existing evidence, pointing gaps of knowledge and provide a framework and position for future research activities [7].

The systematic literature studies can be categorized into two groups [26]: On the one hand, Systematic literature reviews aim to collect all available evidence to answer to a specific research question. Systematic mapping studies, on the other hand, aim to offer a broad review of evidence that is available on the specific topic. As this study's aim is to point out current knowledge of bridging the gap between the software architecture and the business model research streams, this study uses the latter approach. Furthermore, as this study's aim is to broadly map the current knowledge, we decided to use electronic searches on large publication databases instead of manual searching form the selected venues.

In this study, we follow the guidelines given by Kitchenham and Charters [7] for systematic studies in software engineering. We designed the research process which accommodated the following six phases:

1. **Prestudy.** In this phase, we performed initial searches as well as selected from the authors' previous experience a set of papers that are discussing about the phenomenon on the hand. The prestudy phase showed that there should be enough primary studies for the literature review. In addition, the prestudy phase produced a set of papers that are used calibrate the search term. The selected set consisted of three peer-review papers.
2. **Search term formation.** In this phase, we constructed the search term to be used in the searches. Based on experimenting with different keyword and search string combinations in order to find maximum number of related works (including the pre-selected publications that should be found with the searches), we ended up using the following Boolean search term:

   ```
   ("software architecture" OR "SaaS
   architecture") AND ("revenue model"
   OR "pricing model" OR "business
   model")
   ```

   That is, the left-hand side of the search term aims to include the software architecture research papers. We selected to use both 'software architecture' and 'SaaS architecture' terms as in the SaaS literature stream, this term is often used to depict the architectural decision instead of the base concept. The right-hand side of the search term similarly aims to include different the business model aspects. As discussed in Section II, the terminology is a bit muddled and we decided to use three different terms in order to capture studies addressing different aspects of business models.

   Finally, we decided to focus the searches the abstract, title and keywords. Based on the testing with full content, too many false positive results were returned in the test searches.
3. **Electronic searches.** We decided to use the following peer-reviewed literature databases:
   - Elsevier's Scopus database
   - IEEE Xplore Digital Library
   - ACM Digital Library
   - ScienceDirect

   From the electronics search engines suggested by Brereton's et al. [27], we did not use Google Scholar (as its results are not replicable), EI Compendex and Inspec (lack of access). Naturally, the search terms used were adopted to the capabilities of each electronic search engines. The searches were performed in January 2019.
4. **Selection.** We decided to use the following inclusion criteria when selecting the articles: 1) Studies addressing both software architectural as well as business model (as the terms are explained and understood in Section II) and their interplay; 2) Peer-reviewed articles; and 3) Articles written in English were included.

   Similarly, we used the following exclusion criteria: 1) Commentaries, prefaces, panel summaries, presentation notes, etc. non-peer reviewed content; 2) Studies not clearly discussing about the phenomena from the field of software production; and 3) Studies focusing on business models that can be presented as an abstract model and transformed from the model to an executable code; while these kind of studies can be useful for future considerations, they often consider business model in a lower abstraction level than what is mean in this study. These kinds of papers are excluded.

   The decision to include or exclude is done in two separate parts.

   4.1 Abstract and title. Firstly, we evaluated the papers based on their titles and abstracts. If a paper cannot be judged to be included or excluded based on these attributes, it was included for the next step.

   4.2 Full paper. Secondly, the full studies were evaluated.

   I both evaluation parts, the same aforementioned inclusion and exclusion criteria were used.
5. **Snowballing.** After the usage of inclusion and exclusion criteria, the select primary articles are read through. From all articles, further relevant primary studies are selected with the backward snowballing technique [28]. In this, we evaluated the bibliography of each selected articles and studied all potentially related articles by hands. The same inclusion and exclusion criteria are used than in the previous phase.
6. **Analysis.** In the last phase, the final set of primary articles are studied. In this phase, all duplicates are removed. In this study, we use conceptual-analytical approach [29]. That is, the articles are read through and summarized. The reporting in the following section is based on the synthesized results.

IV. Results

A. Descriptive statistics

The total number of studies matched in the four electronic databases is 277 (includes duplicates). Table I shows the

TABLE I
THE NUMBER OF ARTICLES FOUND IN ELECTRONIC SEARCHES (SEE PHASE 3), AND NUMBER OF ARTICLES SELECTED BASED ON TITLES AND ABSTRACTS (SEE PHASE 4.1) AND STUDIES SELECTED BASED ON EVALUATION OF FULL PAPER (SEE PHASE 4.1). THE TOTAL NUMBERS INCLUDE DUPLICATES.

Database	Search	Abstracts selects	Full paper
Scopus	144	61	8
Xplorer	99	37	4
ACM	29	1	1
ScienceDirect	5	2	1
Total	*277*	*101*	*14*

TABLE II
THE SELECTED PAPERS.

ID	Authors	Ref.	Year
P01	Gruhn & Weber	[30]	2005
P02	Ketola	[31]	2014
P03	Knodel & Manikas	[32]	2016
P04	∗Laatikainen & Ojala	[25]	2014
P05	Lechner & Schmid	[33]	2001
P06	Liu et al.	[34]	2008
P07	Moore & Mahmoud	[35]	2009
P08	Naab	[36]	2011
P09	∗Ojala	[37]	2016
P10	∗Silvander et al	[38]	2017

∗ denotes papers used in the seed set.

numbers of matched found in different search engines as well as the number of studies evaluated based on abstracts and full studies.

A large number of studies (101, including duplicates) were included into the full paper review phase due to the ambiguousness of the terms used. For example, several papers used the concept 'business model' to loosely describe any business activities that are modelled. For example, a business process of any kind and its model are referred as a business model.

The final set of papers selected for this study contains 10 unique studies. All of the studies used in the seed set for calibrating the search term were among the included articles. Furthermore, snowballing did not produce new hits to the final set. The selected papers are listed in Table II. All papers have been published from 2001 to 2017.

B. Summary of selected studies

In the following, we will shortly summarize the selected ten primary studies and how they address the questions at hand. Gruhn & Weber [30] shares the observation that there is a lack of work addressing the gap between revenue model and architecture. As a result of their paper, they propose a reference architecture for a certain kind of subscription-based revenue model.

Ketola [31] proposes of using the measurement approach, more commonly known in the mobile game development field, to adapt the business model of a product and guide also the software development process.

Knodel & Manikas [32] discuss, in their position paper, on the benefits of a reference architecture of a software ecosystems to stakeholders, activities and aspects, including the business model.

Laatikainen & Ojala [25] also note the lack of previous work addressing the connections between SaaS architecture and business models. They address how a software architecture design enables or limits the use of different pricing models in 5 cases. Their case study is among only empirical studies in this domain.

Lechner & Schmid [33] address that how an online business should take communities and their organizing into account and that the system's architecture should support this.

Liu et al. [34] discuss on the business models and software architecture in the context of e-business services. They illustrate how a traditional three-layered architecture works well, in a simple setting, to implement a business model of a common e-business service.

Moore & Mahmoud [35] propose a reference architecture that implements the needs of trusted broker for SaaS applications. The architecture is based on the needs of the business model.

Naab [36] notes that the current software architecture design methods are not able to provide flexibility required by modern business models. Thus, he outlines a proposal how to develop a method that takes the flexibility requirements better into account.

Ojala [37] studies software renting, as a pricing model, in the cloud computing with 37 interviews. Based on the study, he shows that some software architecture decisions can either limit or enable different pricing and revenue models of the product. Furthermore, he discuss that changes in revenue model are easier to implement than changes in the architecture.

Silvander, Wilson and Wnuk [38] propose on the use of context descriptions for improving architectural flexibility for being able to react to changes in business model. They report anecdotal evidence supporting their proof of concept.

V. DISCUSSION

A. Key findings

We summarize our key findings in the following:

(*i*) The area is basically unaddressed. Despite a number of studies observing the lack of work during the last two decades [eg. 23, 25, 30, 37], there is only a few studies even discussing the topic. Only two studies are based on empirical evidence.

(*ii*) The little focus, that there has been, is scattered. Some of the studies addressed specific domains and solutions with a reference architecture, some focused on pure SaaS products and their revenue models. A more holistic approach is totally lacking.

(*iii*) Also, there is total lack of usable tools, processes and models for practitioners. While business flexibility and the need for change has been noted in several papers, none has offered a practical guidelines for the professionals.

Thus, to answer to the presented two research questions: First, the extant literature does not report much on the interplay between business models and software architecture (RQ1). A few studies have been presented, yet their focus has either been on niche areas or in restricted solutions. Second, the extant literature does not report much for supporting business model experimentation (RQ2). Naab [36] notes the lack of flexibility in the methods and Silvander et al. [38] propose a method to improve flexibility. Yet, the latter work seems still to be in its starting phases and no concrete support is yet offered. However, the discussed approach seems to be promising and it will likely to lead some new oppenings in the area.

As this study showed that the intersection of business model and software architecture research remains basically unaddressed with only a handful studies even discussing the area, there are lots of promising research avenues to study.

For example, the software architecture should support experimentation. As noted in several of the paper reviewed, often the flexibility in architecture and lack of its support in the current model was seen as a problem. This is even more evident area to improve when the latest development in the minimum viable product (MVP) concept is acknowledged [cf. 39]. Thus, new openings supporting fast and flexible architecturing—and building MVPs efficiently—are needed.

B. Limitations

Naturally, there are certain issues limiting this study. First, a literature study is as good as its primary material and used search terms. For example, authors of the primary studies might use different keywords than those identified in this study. In the computing discipline, authors are known to use witty titles as well as complex and inharmonious terminology [c.f. 40], which cause both false positives (i.e., studies included in the search phase while they should not be) as well as false negatives (i.e., studies excluded in the search phase while they should not be).

Secondly, this study is limited by the used databases. For example, only ACM Digital Library has indexed the book by Hohmann [22], which remains still as the largest authoritative reference for crossing the gap between business models and software architecture. Thus, the selection of the used publication databases is crucial for any systematic literature study. In this study, we tackled this limitation by using four large publication databases. Yet, some work might have been omitted due to the used selection.

Thirdly, a somewhat large number of false positives were found due to the popularity and ambiguous of the terms used. Especially the term 'business model' proved to be a general term used to describe several different concepts (cf. 'contrast' in Shaw and Gaines' [41] model). This might indicate that probably not all relevant terms have been included into the search term.

VI. Conclusion

This study explored the intersection of the software architecture and business model research streams by using the systematic mapping method. A total of ten studies were found. This study shows that there is an undeveloped research area addressing the connections between business models and software architecture, yet several scholars have requested that the area should be addressed as the modern business sets new requirements for flexibility and speed.

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Ontology as a Modeling Tool within Model Driven Architecture Abstraction

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***Abstract* - This paper is focused on automatic transformation process of top levels of Model Driven Architecture (MDA) within the information system development phase. System architects are always trying to find easier, complex and more united way of information system development. Although the Model Driven Architecture (MDA) provides a set of guidelines for the structuring of specifications it also comes with challenging tasks of transformations between the various levels of abstraction. The primary objective of this work is to design a universal automated approach within the Computer Independent Model (CIM) and Platform Independent Model (PIM) manual transformation. The manual process of the transformations within MDA could be automated using ontology model with the combination of mapping rules and Extensible Markup Process Definition Language (XPDL) and Extensible Markup Language Metadata interchange (XMI) conversion.**

Keywords – Model driven architecture, Computer independent model, Platform independent model, Ontology, Information system development

I. INTRODUCTION

The process of IS development is a permanent task of software architects and developers who are trying to develop innovative solutions. On the other hand, there are the users, whose demands are challenging and lead to the exploring of new approaches of IS development. Therefore, developers are interested in creating flexible and easy to maintain information systems that can meet the requirements of users in the shortest possible time.

One of the widely used methodology among others is MDA which brings various advantages to IS development. MDA represents fundamental paradigm based on creation of models and subsequent transformations between these models. MDA specifies four levels of abstraction:

1. Computation Independent Model - CIM
2. Platform Independent Model - PIM
3. Platform Specific Model - PSM
4. Implementation Model - IM

The first three levels are graphical models, the last level is made of program code.

As was mentioned in [1] within the usage of MDA in IS development it is important to remember:

- In the first level – CIM a real (business) system of an organization is modelled and represents implementation environment of the IS that is being developed. The most common approach is to model business system with process map in some formal language. In [2] for CIM modelling there is used DFD notation, in [1] there is used Business Process Modeling Notation (BPMN). Process map is created on the basis of a consistent verbal description of the processes. PIM models are created from process map that represents CIM level model.
- According to [1] PIM level is created by two types of diagrams - use case diagram and context diagram of classes, also referred also knows as business entity diagram. Design models are created in a Unified Modelling Language (UML). A set of design patterns is a general and does not specify any particular technology. That is why it is platform independent.

According to the information above CIM level can be appropriately represented as a BPMN diagram and CIM level as a UML diagram. Additionally, the authors of [3] state that CIM level represents business viewpoint which can be easily understood even by non-IT professionals, while PIM level represents software design viewpoint.

Creating models using MDA for the development of IS in general ensures:

- systemic approach,
- complexity,
- transparency,
- methods of visual expression of IS requirements,
- methods of detecting lifecycle of the IS development.

Specific processes which should be included in the IS need a logical and efficient interconnection of data, information and knowledge which can be reached through the implementation of knowledge management. One possible approach in processing knowledge management is using of ontology.

The expression "ontology" has its origins in philosophy where it is used in the context of the question of existence and being. "What is?", "What does it mean to

be?", "What is the meaning of existence?" - These questions address ontology in philosophy. It might seem that it is an abstract topic and there is no room for ontology in the IS development. Actually, that is not true. According to the definition often used by an American scientist in the field of knowledge-based systems and artificial intelligence Gruber [4] ontology is an explicit specialization of conceptualization. The term conceptualization generally expresses a system of terms and concepts which model the specific part of the world. Specification of the conceptualization must be explicitly expressed. Another definition by Gruber says that ontology is a specification represented by dictionary that is used for sharing discussions about the domain: definition of classes, relations, functions and other objects. [5]

II. Ontology and Enterprise Architecture

The development of IS is closely related with the concept of enterprise architecture. Enterprise architecture can be characterized as a comprehensive set of key elements which create the organization. This definition, however, is considerably general. According to ISO/IEC 42010 is the definition of enterprise architecture by [6] described as follows:

Enterprise architecture is an approach, concept, medium and instruments which express the fundamental arrangement of relations between business and information system which leads to the fulfillment of the mission of the organization while respecting the surrounding environment and principles formulated in the design and development of the system.

Enterprise architecture often suffers from a lack of semantics which is reflected in issues with communication between people and between systems or even directly between people and systems. One possible solution to the problem is the enterprise architecture ontology.

Enterprise architecture ontology consists of three layers [7]:

1. Ontology of business terms.
2. Components ontology of enterprise architecture.
3. Ontology of relations between the components of the enterprise architecture.

According to authors [7], after application of this approach it is expected that humans and systems will be able to clearly and accurately understand enterprise architecture. This approach could support integration and cooperation in many organizations but also among organizations.

According to [8] ontology can be also used in the area of semantic reengineering of business processes - actually in the transformation of ontological models to non-ontological models of business processes in order to ensure interoperability between the real needs of the organization and process business models.

III. Capturing Knowledge within MDA

Modeling CIM level within MDA is followed by transformation into PIM. The transformation process itself uncovers problematic issues relevant to information systems development which are as follows:

1. How to capture the functionality of specified information system?
2. How to transfer functional criteria directly to system design?
3. How to ensure adaptive change functionality criteria?

Existing solutions for modeling CIM level in BPMN language and subsequent transformation into the PIM level, in many cases, are not suitable for the implementation of knowledge management because these solutions cannot adequately capture the semantics of the activities performed.

BPMN modeling language in the model driven architecture is not primarily designed for modeling knowledge and semantic accuracy of created models cannot be verified. Another problem is to preserve the semantics in the transformation between levels. Knowledge modeling support in the development of knowledge IS could provide ontologies. Therefore, in further solutions we focus on using of ontologies for the development of not only knowledge-based information systems.

The CIM level in the model driven architecture expresses implementation model of IS environment. In the modern information society, regardless of the type implementation environment, CIM level reflects models of information and data, their efficient processing, switching and transforming to knowledge. All the activities of all companies and institutions are based on the collection of large amounts of information that are stored as data as well as the necessary knowledge for the operation, management and innovation. This fact thus pushes the ontology to the forefront in the field of IS development, especially knowledge-intensive IS.

According to the mentioned statements use of ontology could bring a new approach in the IS development.

IV. Research Problem

Personalization of IS solutions can be combined with notion of enterprise architecture that will be used as a term to highlight the business connections of the organization or enterprise and developing information systems. General paradigm of complex IS development is currently the architecture of the system in accordance with ISO/IEC/ IEEE 42010: 2011 [6] and specified therein architectural framework, set up of the required views for the developing IS and the interrelationship of views. Partial views create architectures, which are generated in the relevant modeling languages.

Information systems for the promotion of knowledge management are intended to promote knowledge techniques for decision support, learning and action. The

topic of knowledge-based systems is broad and contains various problems of their implementation - the overall process of development, alignment of the requirements and needs of users, applications, knowledge of different methods, integration with conventional technologies, software development tools, decision-making mechanisms, user interaction, acquisition and representation of knowledge, language and programming environment, technology implementation expertise and system architecture.

From the level perspective of model-driven architecture knowledge management as a method belongs to CIM level which in the architectural context of the development IS represents Business architecture. CIM level modeling in BPMN language and adhere to the strict rules of transformations between models CIM and PIM for modeling principles of knowledge management cannot always express the semantics of data. If we consider modeling according to the principles of knowledge management it is the modeling of information, data and knowledge. Information and knowledge belong in the architectural context to business architecture, data belong to software architecture which in the MDA represents PIM level.

If ontology can deal with relationships in CIM (information and knowledge) and the transformation of CIM-PIM (information - data) it could be more appropriate instrument for the application of the MDA principles, because it will not be necessary to create transformational relationships between CIM and PIM level.

V. Use of Ontology as Modeling Tool within MDA

Using ontology as a modeling tool in MDA can remove the necessary transition between levels CIM and PIM using graphical modeling languages. Unification of CIM and PIM levels requires unification at the level of notation. It is therefore important in the single ontological writing (model) also select elements which are able to represent and capture relevant information from both levels.

A. Modelling CIM and PIM Levels Using Ontologies

The CIM level is often expressed in terms of BPMN diagrams. In contrast, the PIM level is usually expressed in UML. Both notations (BPMN and UML) are quite extensive and comprehensive and to capture such notation would be beyond the scope of this paper. Therefore, we are focusing on several specified and frequently used elements and diagrams.

Data elements and models were extracted from the process for managing science and research at the University of Žilina. Selected BPMN elements are as follow:

- Swimming lanes,
- Pool,
- Activities,
- Process start,
- Process end,
- Decision block,
- Parallel branching,
- Timer.

Selected elements of UML diagrams use cases:

- Actors,
- Use case,
- Association.

Ontology created with the elements mentioned above should consist of the following components:

- ID element,
- Name,
- Element type,
    - Start (Start),
    - End (End),
    - Activity (Activity),

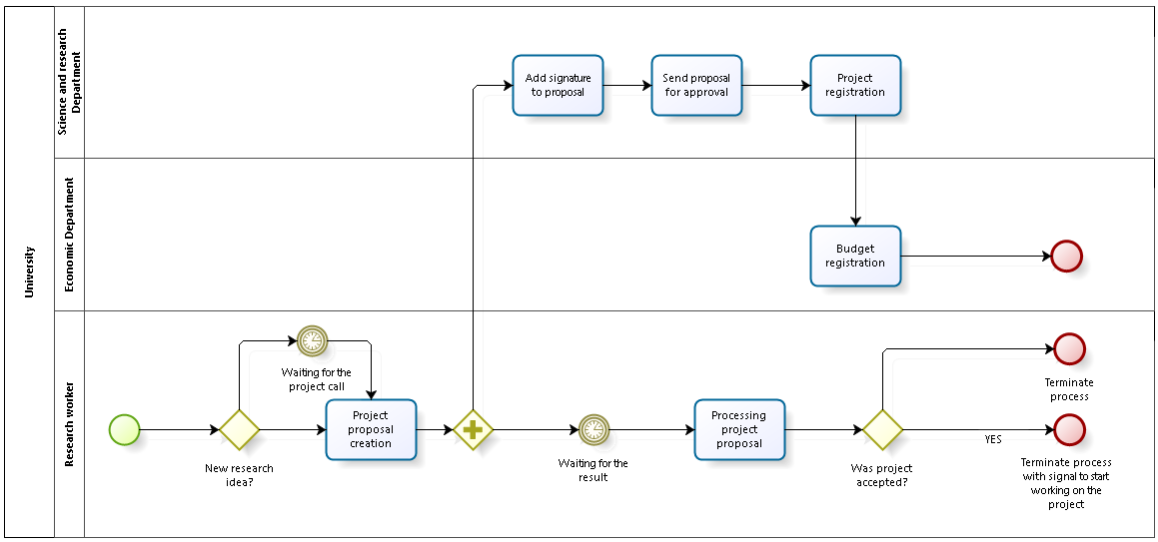

Figure 1. Selected parts from BPMN process for managing science and research at the University of Žilina – prepared within the project [9]

Element ID	1
Name	-
Type	Start
Source ID	-
Target ID	2
Administrator	Research worker
Owner	University

Element ID	6
Name	Waiting for the result
Type	Timer
Source ID	5
Target ID	7
Administrator	Research worker
Owner	University

Element ID	11
Name	Add signature to proposal
Type	Activity
Source ID	5
Target ID	12
Administrator	Science and research Dep.
Owner	University

Element ID	2
Name	New research idea?
Type	Decision
Source ID	1
Target ID	3, 4
Administrator	Research worker
Owner	University

Element ID	7
Name	Processing project proposal
Type	Activity
Source ID	6
Target ID	8
Administrator	Research worker
Owner	University

Element ID	12
Name	Send proposal for approval
Type	Activity
Source ID	11
Target ID	13
Administrator	Science and research Dep.
Owner	University

Element ID	3
Name	Waiting for the call
Type	Timer
Source ID	2
Target ID	4
Administrator	Research worker
Owner	University

Element ID	8
Name	Was project accepted?
Type	decision
Source ID	7
Target ID	9, 10
Administrator	Research worker
Owner	University

Element ID	13
Name	Project registration
Type	decision
Source ID	12
Target ID	14
Administrator	Science and research Dep.
Owner	University

Element ID	4
Name	Project proposal creation
Type	Activity
Source ID	2, 3
Target ID	5
Administrator	Research worker
Owner	University

Element ID	9
Name	Terminate process
Type	End
Source ID	8
Target ID	-
Administrator	Research worker
Owner	University

Element ID	14
Name	Budget registration
Type	Activity
Source ID	13
Target ID	15
Administrator	Economic Department
Owner	University

Element ID	5
Name	-
Type	Parallel
Source ID	4
Target ID	6, 11
Administrator	Research worker
Owner	University

Element ID	10
Name	Signal to start working on the project
Type	End
Source ID	8
Target ID	-
Administrator	Research worker
Owner	University

Element ID	15
Name	-
Type	End
Source ID	14
Target ID	-
Administrator	Economic Department
Owner	University

Figure 2. Data proposal for ontological model

- Timer (Timer),
- Parallel block (Parallel)
- Decision block (Decision)

- Source ID,
- Destination ID,
- Performers,
- Owner.

Specific data are presented in the Figure 2.

B. *Data for ontological model*

Data sample used to fulfill ontological models are created directly from the information obtained from Management of science and research at the University of Žilina. These processes have been proposed in the project Development of human resources with the support of an integrated information system for the evaluation of scientific research results [9]. Proposed data are in the Figure 2.

C. *Ontological models*

Data presented in Figure 2 were used to create a specific ontological model written in the OWL language. Since the creation of OWL file is too large to be put clearly and shown in a whole within this paper, the sample part was selected, dealing with the element with ID 4 showed in Figure 3 below.

D. *Mapping CIM level to ontology*

Ontological model which was briefly described in the subsection *C* can now fully cover the information that

```
<! - Http: // ... / ontologies / 2016/3 / UniverzitaOntology # 4 ->

<owl: NamedIndividual rdf: about="http://.../ontologies/2016/3/UniverzitaOntology#4">
   <rdf: type rdf: resource="http://.../ontologies/2016/3/UniverzitaOntology#Element" />
   <rdf: type>
      <owl: Restriction>
         <owl: onProperty rdf: resource="http://.../ontologies/2016/3/UniverzitaOntology#hasType" />
         <owl: hasValue rdf: resource="http://.../ontologies/2016/3/UniverzitaOntology#Activity" />
      </ owl: Restriction>
   </ rdf: type>
   <rdf: type>
      <owl: Restriction>
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      </ owl: Restriction>
   </ rdf: type>
   <rdf: type>
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            <owl: Restriction>
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            </ owl: Restriction>
            <owl: Restriction>
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               <owl: hasValue rdf: resource="http://.../ontologies/2016/3/UniverzitaOntology#3" />
            </ owl: Restriction>
         </ owl: intersectionOf>
      </ owl: Class>
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   <rdf: type>
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   </ rdf: type>
   <rdf: type>
      <owl: Restriction>
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      </ owl: Restriction>
   </ rdf: type>
   <Name>Developing the project proposal</Name>
</ owl: NamedIndividual>
```

Figure 3. Selected parts of ontological model written in OWL language

represent both CIM and PIM level of abstraction. Afterwards the mentioned ontological model can be mapped to specific CIM/PIM levels in graphical notation (BPMN or UML).

BPMN notation provides a universal graphical notation for modeling business processes. To store BPMN models we use XPDL standard (standardized by WfMC group) which allows saving of whole definition of BPMN process through specific XML files. XPDL is a generally accepted format, which is used in tools for modeling business processes.

To create a business model from ontological model we have created an application which automatically generates XPDL document describing business processes from owl file.

In order to map the ontological model to business processes with elements specified in subsection *A* – (lanes, pool, activities, process start, process end, decision block, parallel branching and the timer) it is necessary to define mapping rules and structure for XPDL file.

Mapping uses object properties defined in ontological models:

1. The swimming lane is mapped through *hasAdministrator*,
2. Pool is mapped through *hasOwner*,
3. Type mapping elements takes place through property *hasType*, the specific type may be represented by one of the following:
    a. Activity - value Activity
    b. Start - value Start
    c. End - value End
    d. Decision block - value Decision
    e. Parallel branch - value Parallel
    f. Timer - value Timer
4. Element names are mapped across the property *hasName*,
5. Mapping linking elements is solved through the features *hasSource* and *hasTarget*.

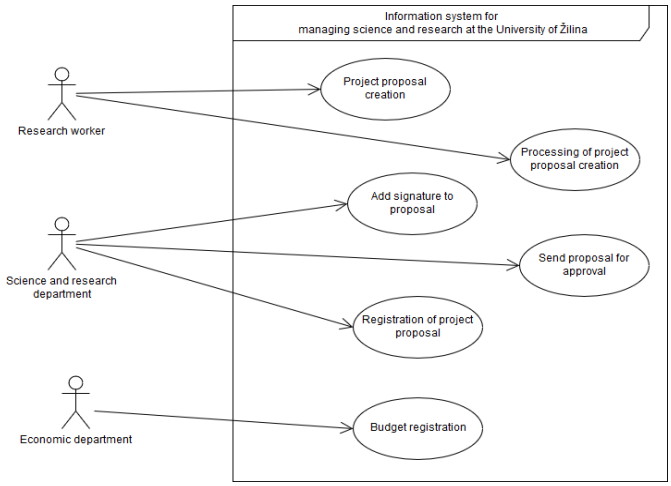

Figure 4. Use case diagram automatically generated from OWL file

XPDL structure in this case must contain the particular elements like: *Pools*, *Pool*, *Lanes*, *Lane*, *WorkflowProcesses*, *WorkflowProcess*, *Activity*, *Event*, *StartEvent*, *EndEvent*, *IntermediateIvent*, *Condition*, *Route*, *Transition*. This XPDL file can be then opened directly in various BPMN modelling tools which support XPDL file format.

E. Mapping PIM level to ontology

One model that is used to represent the level of Platform Independent Model - PIM is the Use case diagram. Models expressed in UML language (including Use case diagram) are usually stored in XMI file - the generally accepted standard by the Group OMG.

In order to map the ontological model to diagram use cases with elements specified in subsection *A* - *actor*, *use case*, *association* it is necessary to define mapping rules and structure for the XMI file.

Mapping uses following object properties defined in ontological models:

1. Actors are mapped through *hasAdministrator*
2. Use cases are mapped through *hasType* - value Activity
3. Association mapping is based on the previous two points, because each activity is assigned administrator - thus it is possible to clearly determine the association.

XMI file structure can be quite complicated, involving a large number of elements and attributes. Finding an appropriate XMI structure for our purpose was carried out on the basis of experiments. After the finding the right structure we have created application that can map creation of ontological model to XMI file.

This file can be open in various modeling tools which support UML notation and allow to import the XMI format. The imported UML diagram from generated XMI file mapped from ontology is shown in Figure 4.

VI. CONCLUSION

Presented solution of ontology mapping the CIM and PIM level showed how is possible to use the ontology as a modeling tool within the MDA.

Ontological model can be mapped to Computer Independent Model (CIM) and also to a Platform Independent Model (PIM). Consequently, this approach enables to represent these models in a full-fledged graphical form. In addition, the whole process of CIM-PIM modelling is much faster and there is no need for transition between levels of CIM and PIM. In order to fully eliminate the transformations, it would be necessary to extend to the mapping rules of the whole spectrum of the CIM and PIM levels in respect of any notation, restrictions, conventions, standards and file types. Nevertheless, this solution can integrate, clarify and accelerate the design, creation and maintenance of business process and use case diagrams in terms of CIM-PIM transformation and provides a platform for further development in this research area.

The advantage of the proposed solution is that any changes in the specifications of the information system proposal are made directly within ontological models and then subsequently these changes are automatically reflected through mapping into the CIM and PIM levels. Due to this fact it is not necessary to manually edit all models every time when the change within IS specification/functionality occurs.

The mentioned benefits are opening new possibilities for the development of information systems in terms of their general design (with emphasis on knowledge-based systems) and in terms of architecture and management of model transformation between CIM and PIM levels.

ACKNOWLEDGMENT

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Continuous Integration in Distributed Applied Software Packages

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Abstract – The paper addresses a new approach to supporting the continuous integration of modules for distributed applied software packages (scientific applications) that are developed in the Orlando Tools framework. We consider the packages for implementing experiments in heterogeneous distributed computing environments that integrate Grid systems, cloud platforms, and resources of public access supercomputer centers. Such packages are characterized by the modular structure, intense change of algorithmic knowledge implemented by modules, computations scalability, and execution in heterogeneous resources. In the packages, computational processes are represented by problem-solving schemes that closely correlate with the workflow concept. The essence and novelty of the proposed approach come from the merge of a methodology creating the packages with the modern practice of software development based on continuous integration. We automate and unify module assembly processes on both the dedicated servers and package developer machines through using the specialized virtual machines. In contrast to the well-known tools, we support the synthesis of the test problem-solving schemes in the automated mode. The practical applications of the developed prototype of the continuous integration system show the significant reducing the time of debugging, testing, and deploying the package modules.

Keywords - heterogeneous environment, scientific applications, modular approach, continuous integration, subject knowledge

I. INTRODUCTION

An applied software package (scientific application) is a set of applied programs (modules) designed to solve the defined class of problems in the specific subject domain. The package modules implement models and algorithms for solving these problems. In such a package, the computational process is described by a problem-solving scheme, which determines information and logical relations between modules. A particular case of the problem-solving scheme is the workflow scheme [1].

The progress of distributed computing technologies has led to significant changes in the architecture of applied software packages [2]. The architecture keeps the modular structure but becomes the distributed one oriented to a heterogeneous computing environment.

The hybrid models that combine cluster, grid and cloud computing in the unify environment provide the opportunity of sufficient increasing the efficiency and flexibility of the resource use. At the same time, it creates new challenges for the management of software packages in solving large-scale problems [3, 4]. These challenges are owing to the existing differences in the cloud and Grid computing models and the continued modifications of the software, hardware, and information resources of the environment [5-7]. The need for the package software evolution enhances these challenges.

Developers are working on the following problems:

- Reconfiguration of package environments,
- Modification of package software or developing new software taking into account a difference in cluster, grid and cloud resource characteristics,
- Supporting the correctness of interaction between different versions of software modules in problem-solving schemes,
- Determining the correct conditions of these versions,
- Integrating the changed sources of subject information with the data structures of packages.

Solving the aforementioned problems is related to applying methods and tools for continuous software integration [8].

The continuous integration support is a non-traditional capability of tools for the development of applied software packages including tools for creating scientific applications that are based on workflow [9].

Such tools are focused on the development of problem-solving schemes that have no changes or have minor changes. However, often, they are not ready to fully support the continuous integration combined with conceptual modeling that traditionally used in such applications.

It is related with the implementation complexity of obtaining and using the additional heterogeneous resources, complexity of structured knowledge about software and hardware infrastructure, and administrative policies in its nodes.

We propose a new approach to continuous integration of modules for distributed applied software packages and develop a special Orlando Tools framework [4]. In the proposed approach, we merge a methodology of creating distributed applied software packages with the modern practice based on continuous integration using subject domain knowledge. The main objective of our study is to ensure continuous integration for the packages whose domains are subject to intense changes in algorithmic knowledge used for solving problems.

The paper is structured as follows. The next section briefly reviews related works on the tools for continuous integration. Section 3 presents the architecture and main capabilities of the Orlando Tools framework used for the development of distributed applied software packages. The main aspects of the proposed approach to continuous integration in Orlando Tools are considered in Section 4. Section 5 presents the experimental analysis of applying the developed prototype of continuous integration. Section 6 highlights the conclusions of the paper.

II. Related Work

The modern software development requires a variety of tools to increase its speed and quality and minimize the possible troubleshooting in the further applying the developed software [10]. Nowadays, there is a wide spectrum of universal tools supporting different functions of continuous software integration. Among them, for example, there are CircleCI [11], Jenkins [12], TeamCity [13], Travis [14], GitLab [15], systems described in [16, 17], etc. The main functions of continuous integration tools are receiving, storing, and testing software versions including the preparation and processing of the test data.

Well-known tools of continuous integration are CruiseControl [18] (no supported) and CircleCI. At the same time, some free tools have significant functional limitations (TeamCity) and do not provide user support with detailed documentation (Coverity and Hound CI [16]).

Notice, that many systems do not function under OS Windows (CircleCI and Buddy [19]), which very popular among developers and end-users of packages.

There are significant difficulties with combining tools for implementing different functions into a joint continuous integration environment due to the use of various models and formats of the data representation, and information and computational models that describe the processes of continuous integration (Travis [14] and BuildMaster [19]).

GitLab and Jenkins are the most popular systems for continuous integration, but they lack the conceptual modeling tools needed to support operation at the subject domain level. There is no well-known experience in the practical use of these systems related to distributed applied software packages. Based on the survey works [9, 20-22], we can also conclude that workflow management systems do not provide their users with advanced specialized tools of continuous integration.

Based on the analysis of the aforementioned tools, we conclude that there is a wide set of disjoint software that implements functions (or their restricted combinations) of continuous software integration. In this regard, the continuous integration tools that proposed in the paper and unified into the uniform technological sequence are aimed for a partial solving the above-listed problems.

III. Development of Distributed Applied Software Packages

We developed the Orlando Tools framework to support large-scale scientific and applied researches [4]. This framework enables the development of distributed applied software packages and provides tools for the creating subject-oriented computing environments for executing packages [23]. Within such environments, various computing infrastructures that support both Grid and cloud computing are integrated.

In the paper, we represent a new subsystem of the Orlando Tools framework. This subsystem supports continuous integration of modules for distributed applied software packages.

We consider continuous integration in the context of developing a special class of the packages that provide the opportunity of the active evolution of algorithmic knowledge by developers and end-users.

The package modules can be developed and modified by different developers and end-users. The development and maintenance of each package consist in merging the actual versions of the modules into a general problem-solving scheme for nodes with different computational characteristics. This process can be performed from several times a month to several times a day.

Fig. 1 shows the updated Orlando Tools architecture that now includes the following main components:

- User interface to other Orlando Tools components (it implemented as a web application based on the JavaScript and PHP languages),
- Conceptual model designer that provides the capability for declarative description of the algorithmic knowledge, information about hardware and software infrastructure, and parameters of administrative policies in environment nodes,
- Subsystem for continuous integration of modules,
- Knowledge base that contains the conceptual model,
- Executive subsystem that includes the interpreter of problem-solving schemes, scheduler of computational processes, and generator of jobs,
- Computations database that keeps all information about computational experiments: the problem formulations, problem-solving schemes, and parameter values.

The conceptual model, its knowledge layers, main model objects, relations between them, and various ways of problem formulations using this model are described in [23, 24].

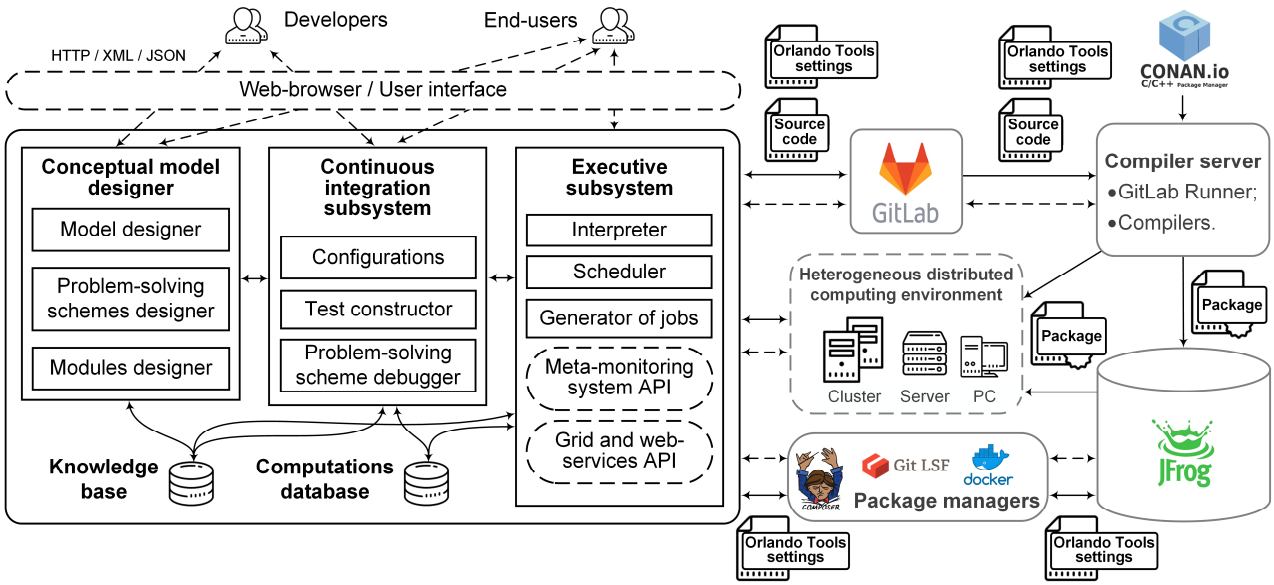

Figure 1. Orlando Tools architecture with a new continuous integration subsystem

We also provide the special Orlando Tools server for creating the subject-oriented computing environment for the developed packages. It supports the user interface and executive subsystem. The Orlando Tools server is represented in the form of a configured virtual machine with the preinstalled software of our framework (the server is available by request to authors). In the future, we plan to use alternative server configuration tools (for example, Ansible [25]). The server enables to include to the package environment the following components that differ in their software and hardware characteristics:

- High-performance computing clusters with the local job management systems (SLURM, HTCondor or PBS Torque),
- Computational nodes with the non-portable software under the OS Linux management,
- Clusters of dedicated resources (cloud) represented by the special Orlando Tools virtual machines, which host the package modules and software to manage their execution, personal computers, and high-performance servers,
- Remote computational and information resources available through the Grid or web-service API.

Challenges in the development and use of distributed applied software packages occur equally for both the developers and end-users. Developers and environment administrators should properly configure the environment for the reliable and high-performance package operations taking into account subject domain specifics for solved problems. They place the package components and external system software into the environment nodes and set their configuration parameters. When a package and other systems are configured, a significant difficulty for the end-users consists in the selection of a high number of parameters at the problem-solving process implementation (algorithms, values of their control parameters, compilers, input and test data, problem-solving schemes, target nodes, etc.) to optimize the distributed computing.

We add the new subsystem for continuous integration of distributed applied software packages to partially mitigate the aforementioned challenges. Through the special API, it provides interaction with external tools of continuous integration (see the right side of Figure 1), including source repositories, compilers, composers, program libraries managers, etc. This subsystem elicits the necessary information about the specifics of modules and environment nodes, in which these modules are executed, from the knowledge base and computations database.

IV. Continuous Integration with Orlando Tools

Generally, the process of developing applied software using Orlando Tools involves the following stages:

- Structural analysis of the package subject domain and designing the conceptual model including the specification of parameters, operations, and modules for this domain,
- Development and modification of the program code for modules that implement operations,
- Compiling, debugging and testing modules in the heterogeneous distributed computing environment,
- Placing compiled versions of modules in repositories or installing modules on resources,
- Modification of the conceptual model,
- Debugging and testing problem-solving schemes with the new or modified versions of modules.

Each stage requires efforts of the package developer. The coordination of different stages and support of informational and logical relations between the tools entail additional overhead costs. Multiple repetitions of these stages actualize tools to automate the process of continuous integration of modules of distributed applied software packages. We propose the following scheme of

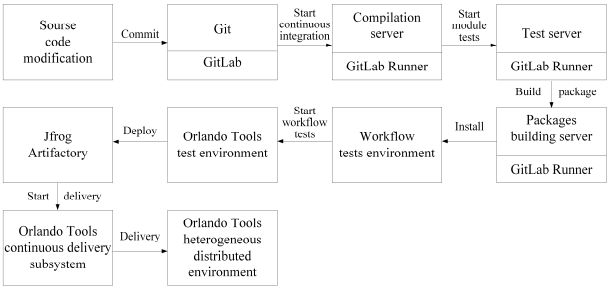

Figure 2. Data flow diagram of the Orlando Tools continuous integration process

supporting continuous integration of the package modules in Orlando Tools: Development and modification, Automatic installation and updating, Synthesis of test problem-solving schemes, Preparing the debugging and testing, and Debugging and testing.

Development and modification of the source code of the modules, compilation, debugging and testing are carried out automatically by Orlando Tools when changes related to the package modules are committed in the Git system [26]. Automatic installation and updating the modules on resources are implemented by the Orlando Tools executive subsystem. They are carried before or during the computational experiment depending on the end-user preferences. For the synthesis of test problem-solving schemes, we use the non-procedural formulation: Calculate Y knowing X, where X and Y are sets of parameters of the package subject domain. Selection of the modules to be included into schemes is implemented through wave methods of the computations planning over the conceptual model. It specifies the information and logical relations between modules in term their input and output parameters. Preparing the debugging and testing are based on the execution results obtained earlier and stored in the computations databases. During these processes, Orlando Tools uses data from completed experiments. Debugging and testing problem-solving schemes are complemented by additional operations to control the correctness of the modules execution. The data flow diagram of the Orlando Tools continuous integration process showed on the Fig. 2.

We apply the tools of the Git system for version control of the module source code of packages. [26]. It supports the rapid separating and merging versions of the module source code and includes visualization and navigation tools in the software development process, taking into account its non-linear history.

In Orlando Tools, we use the GitLab Self-Managed platform for the repository management. GitLab is the popular platform, which provides programming code analysis, error tracking, module versions testing, etc. In addition, GitLab provides advanced tools to manage modules testing within continuous integration. We implement module assembly processes both on the dedicated servers and on package developer machines using the pre-installed Gitlab Runner agent.

We apply Conan.io to manage the dependencies of the libraries that are used in the source code of the modules [27]. Conan.io is a portable package manager intended for C and C++ developers. In addition, it enables developers

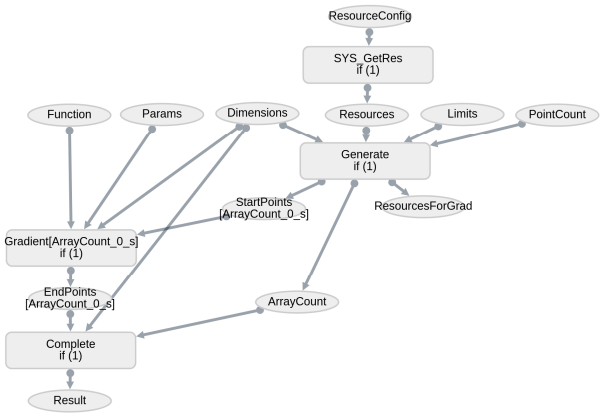

Figure 3. Problem-solving scheme

to manage builds from sources, dependencies, and precompiled binaries for any language.

We apply the JFrog Artifactory system to operate with binary versions of modules [28]. It provides the needed interfaces for interacting with various package managers (for example, Git LFS Registry [29], Docker Registry [30], and Composer [31]).

We develop the prototype of a system that realized the proposed scheme of supporting continuous integration, delivery, and deployment of the package modules in Orlando Tools. The interaction of Orlando Tools with the above-listed systems is implemented using special API. A comparative analysis of the main capabilities of GitLab and the developed prototype shows that last one provides new additional opportunities related to the features of the package's development are provided (Table I).

TABLE I. CAPABILITIES COMPARISON

Capability	GitLab	Developed prototype
Continuous integration of modules	+	+
Delivery of modules	+	+
Deployment of modules	+	+
Automation of synthezing test problem-solving schemes	–	+
Automation of the through continuous integration, delivery, and deployment that are applied to both the modules and schemes	–	+

V. EXPERIMENTAL ANALYSIS

We apply the prototype of the system for continuous integration of modules to develop the package of global minima search of multi-extremal functions [32]. The package includes modules that implement various modifications of the multi-start algorithm in the context of different multi-extremal functions (Griewank, Rastrigin, and other test functions [33]).

Fig. 3 shows one of the schemes for solving the optimization problem described above. It includes four operations. *SYS_GetRes* supports the resource allocation for the problem-solving scheme execution. *Generate* generates a set of initial points for the multi-start algorithm. *Gradient* carries out descent from the initial

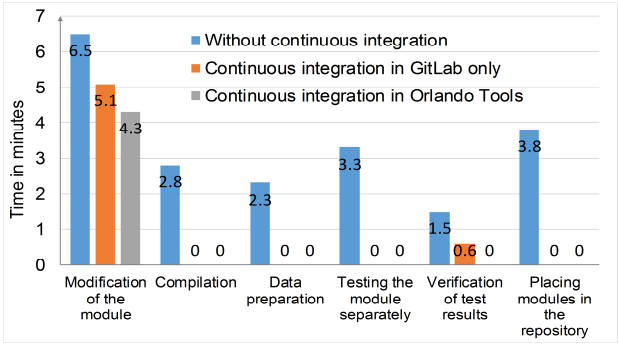

Figure 4. Time spent to the module modification

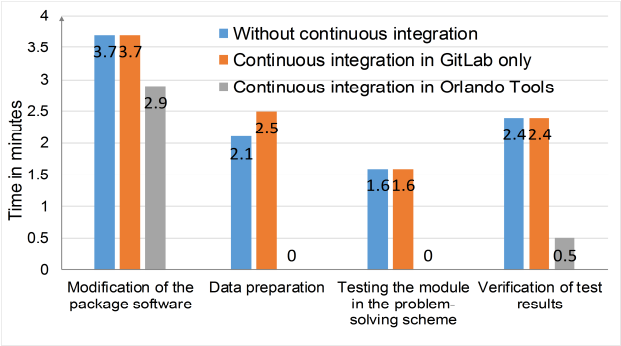

Figure 5. Time spent to the package software modification

point into a local minimum point by the gradient method. *Complete* determines the global minimum. The operations description is provided in [32].

In the package, each of these operations can be implemented by different modules. They depend on the methods of forming the set of initial points in the multi-start algorithm, allocation of resources for problem-solving, distribution of a computational load between resources, and multi-extremal functions used to test modifications of the algorithm.

At the same time, a variety of problem-solving schemes is due to the variety of operations. New problem-solving scheme for some algorithm modification can be created by excluding some operations from the existing scheme and adding other operations of the package. Depending on the algorithm modification, problem-solving schemes include from 3 to 5 operations.

Fig. 4 demonstrates the average time that a developer spent on the modifying one module without continuous integration, using automation of continuous integration in Orlando Tools, and applying the external tools of continuous integration (GitLab only) in the manual use manner. These results were obtained on the base of average operation time evaluations provided by the participants of two developer groups those developing multi-start algorithm versions for the same set of multi-extremal functions in above-listed modes. In a one week, there were 31 and 37 module modifications in the first and second groups correspondingly.

In the first case, we see the large time that developer spends at each stage of the module modification.

In two other cases, we see the significant reduction of developer efforts. However, in comparison with continuous integration in GitLab only, such process in Orlando Tools enables the developer to decrease the time at the stages of the module modification and verification of the results. A developer does not spend significant time at the five stages due to their full automation in the Orlando Tools continuous integration.

When the package software modification is needed (Fig. 5), Orlando Tools demonstrates obvious advantages at all stages in comparison with the other two ways of continuous integration. In Orlando Tools, two stages of continuous integration are fully automated. In Fig. 5, we used average user's evaluations of the operation time for typical processes in the Orlando Tools.

In practice, the development and modification of packages for the heterogeneous distributed computing environment can cause additional labor costs. Especially, it is significant with the manual use of external tools of continuous integration and human factors, for instance, various errors from the developers and end-users. Automation of the technological sequence of continuous integration significantly decreases the probability of errors and reduces the labor costs to correct them.

In the paper, we first time evaluated the effectiveness of the developed prototype system for continuous integration of modules. All experiments are carried out in the environment based on the heterogeneous resources of the Matrosov Institute for System Dynamics and Control Theory of SB RAS and public access computer center "Irkutsk Supercomputer Center of SB RAS" [34].

VI. Conclusion

In the paper, we propose a new approach to the continuous integration of modules for distributed applied software packages. To this end, we develop a special Orlando Tools framework.

A key feature of such packages is a possibility of the change of algorithmic knowledge implemented by modules that can be developed and modified by different developers and end-users.

We propose the scheme of the automation and unification of module assembly processes applying external continuous integration tools unified through the Orlando Tools server.

In this scheme, we unify the external tools into the uniform technological sequence. We use the conceptual model for specifying information and logical relations between the external tools and packages.

Orlando Tools automates the launch of the required external tools and provides data transfer between them. In contrast to the well-known tools of similar purpose, it also supports synthesizing test problem-solving schemes in the automated mode.

We develop the prototype system for continuous integration of modules for distributed applied software packages. The practical experiments show the significant reducing in the time of debugging, testing, and deploying the package modules compared with traditional approaches.

Nevertheless, further study is required. Information elicited from subject data and results of solving problems obtained in scientific experiments are often heterogeneous and subject to frequent changes. In this regard, a flexible, knowledge-based model is needed to set relations between primary information and data structures used in the packages. In addition, we plan to use the test results for predicting module execution time when Orlando Tools allocates these resources. Such a prediction allows increasing the resource utilization and reducing the execution time of problem-solving schemes. These studies will be the subject of future work.

ACKNOWLEDGMENT

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Adapting God Class thresholds for software defect prediction: A case study

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***Abstract*— In software engineering there is an active research field of defect prediction using software metrics. While the research shows that the prediction of defects using software metrics performs well, prediction using metrics alone lacks clear refactoring capabilities. On the other hand, code smells have the ability to describe the code anomalies precisely, and suggest their refactoring. Therefore, code smells can be a much better starting position for software fault prediction.**

In this paper, we present the results of preliminary research on the ability to predict software defects with the code smell God Class. The aim of our research was to test the definition of God Class, as defined by Lanza and Marinescu in 2006, in the ability to predict defects in a case study of the open source projects JDT and PDE within the Eclipse framework. The definition of the God Class was adapted using the grid search technique, with the goal of maximizing the fault prediction ability while keeping the base of the original definition. The results show that adaption of the definition in the specific project resulted in improved fault prediction ability.

I. INTRODUCTION

Deploying a software product with a minimal amount of defects requires the usage of various quality assurance techniques as early as possible in the development life cycle, with software defect prediction being a very important one. Although the prediction approaches based on software metrics was proven to be useful [1], [2], [3], they do not provide guidelines regarding refactoring opportunities of a software entity. Contrarily, the advantage of code smells lies in a clear understanding of the detected anomalies within the entity, resulting in unambiguous directions for refactoring.

Code smells were first introduced by Martin Fowler [4] in 1999. Since then, they have attracted a lot of attention, and, therefore, many different definitions can be found. In general, a code smell indicates structural characteristics resulting from poor design decisions and implementation choices that have a negative impact on the quality of the developed software system [4], [5], [6], [7]. Fowler et al. [4] highlighted 22 bad smells that can be classified into seven groups proposed by Mntyl et al. [8].

Code smells could be detected with the help of predefined rules implemented within different tools [9] aimed for static analysis of the source code. Rules depend on software metrics and chosen threshold values, that could vary in different development environments. In the presented study, we limit work to the God Class code smell, and follow the definition provided by Lanza and Marinescu [10]. The defined rule is implemented within the PMD tool, wherein the applied software metrics and related threshold values are being taken from the same source. The aim of the presented research is to *adjust the default threshold values for the metrics ATFD, WMC and TCC, with the goal of maximizing the fault prediction ability*. The study was done using the grid search technique on the case study of the open source projects JDT and PDE within the Eclipse framework. In this research, we limited our scope only on the God Class code smell, and only on one source code dataset. Our intent was to test if the official definition of a particular code smell can be adjusted to align better with the fault prediction.

The structure of the paper consists of the following parts. The second section introduces the definition of the God Class, and investigates the connection between the God Class and the prediction of faults in the software products. The third section describes the case study on the connection between God Class in the software fault prediction in the case of the Eclipse JDT and PDE source code. The research methodology, the data used and the analysis procedures are presented herein. Following are the sections with the discussion of the results of the case study, and the conclusion that can be made based on the results of the analysis.

II. USING GOD CLASS TO PREDICT THE SOFTWARE FAULTS

A. God Class detection

Different strategies for identifying code smells exist, starting with the manual review, or by using predefined rules. The rules are based on combining different software metrics, since the evaluation of software projects based on just one software metric can offer insufficient results [10]. Lanza and Marinescu [10] defined detection strategies for detecting design flaws affecting classes and methods. As they say, the detection strategy consists of logical conditions that are based on software metrics, and can detect design fragments with specific properties [10]. Rules are defined for six code smells (1) God Class, (2) Feature Envy, (3) Data Class, (4) Brain Method, (5) Brain Class, and (6) Significant Duplication.

The code smell God Class is similar to the code smell Large Class defined by Fowler et al. [4] that fit the group Bloaters, proposed by Mntyl et al. [8]. God Class indicates a software class that tends to centralize the intelligence of the system by performing too much work, and delegating only minor details to other classes while using the data from other classes [10]. With this, the reusability and understandability of a certain class is decreased [10]. Therefore, the detection of God Class is done using three software metrics [10]:

- ATFD (Access To Foreign Data) expressing the number of foreign attributes used by a software class.
- WMC (Weighted Method per Class) is the sum of all statistical complexity of all methods in a software class.
- TCC (Tight Class Cohesion) represents a relative number of method pairs of a class that accesses in common at least one attribute of the measured class.

The God Class is a class that has a high value of metric ATFD, has a very high WMC and a low value of TCC, with respect to the used threshold values. The defined rule is presented graphically in Fig. 1, including the default threshold values [10].

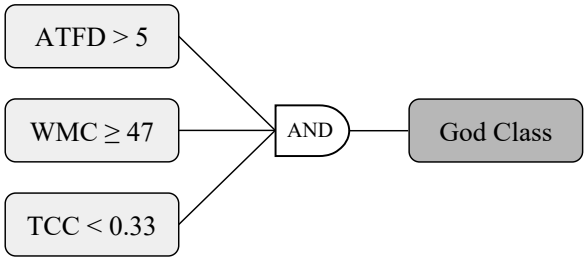

Fig. 1. The God Class detection rule with corresponding threshold values

The God Class code smell is implemented within different rules aimed for identification of code smell or for finding the refactoring opportunities. Among others, the detection of code smells can be done with JSpIRIT [11], JDeodorant [12] and PMD [13]. The latter was used in the implemented study since it follows the rules and thresholds defined by Lanza and Marinescu [10] strictly.

To increase the correctness of identification, it is crucial that reliable threshold values are used for the used software metrics. Although the PMD tool uses predefined threshold values defined by Lanza and Marinescu [10], they can be modified by the user. In the presented study, they were adjusted in order to find the combination of threshold values that had the highest ability to detect software defects.

B. Predicting software faults with God Class

Several studies have addressed the impact of God Class on the frequency of detected defects in studied software components. Despite a number of studies in this research field, the correlation between God Class and the number of detected defects remains discordant and inconclusive.

Regarding the impact of code smells on detected defects, Li and Shatnawi [14] studied the relation between Data Class, Feature Envy, God Method, God Class, Refused Bequest, and Shotgun Surgery on detected defects in three projects of the Eclipse framework, namely Eclipse Platform, Eclipse JDT, and Eclipse PDE. The authors found a positive association between God Class affected classes and the number of detected defects in the studied software.

Olbrich, Cruzes, and Sjoberg [15] conducted research on the impact of the code smells God Class and Brain class on the number of detected defects. The study was carried out on three software products, namely Apache Lucene, Apache Xerces 2 Java, and Log4J, and took into consideration the size of classes containing the code smells. Interestingly, the study results showed, that when normalizing a defect rate with respect to class size, God Class even has a negative correlation with the number of defects.

Along with Brain Class and Feature envy, the researchers Marinescu and Marinescu [16] studied the impact of the God Class code smell on the number of defects detected in three versions of Eclipse IDE (2.0, 2.1, 3.0). The study did not confirm any correlation between God Class and an increased likelihood of defect detection.

Finally, Zazworka et al. [17] observed the impact of the God Class code smell on defect-proneness in the Hadoop software package. The study confirmed a positive correlation with higher defect-proneness in the context of the source code of the Hadoop library.

III. CASE STUDY

A. Research design

The case study performed in this paper is a preliminary analysis aimed to investigate the God Class code smell. It is based on publicly available software defect prediction datasets from the Eclipse Java Development Tools (JDT) open source project.

In order to determine the coverage of the new definitions of God Class over the faulty files, we measured a couple of classification metrics – coverage accuracy and F-score of coverage. The coverage accuracy was calculated as is shown in Equation 1:

$$Accuracy = \frac{Number\ of\ faulty\ God\ class\ files}{Number\ of\ all\ files} \quad (1)$$

As the ratio between the faulty and fault free files in the JDT source is not balanced, the measure of accuracy is not advised [18], [19], as it is biased towards the majority class (in our case, the fault-free files). To tackle this, we also calculated the average F-score, which is a harmonic mean between the precision and the recall for the individual class [20], as is shown in Equation 2 bellow, and the overall F-score is calculated as the weighted average of both F-scores (Equation 3):

$$Fscore = 2 \cdot \frac{precision \cdot recall}{precision + recall} \quad (2)$$

$$Fscore_{overall} = F \cdot Fscore_F + NF \cdot Fscore_{NF} \quad (3)$$

F is the share of faulty files, $Fscore_F$ is the F-score for faulty class, and NF indicates the share of fault free files, while $Fscore_{NF}$ is the F-score for faulty free classes.

B. Datasets

For the purposes of our case study, we prepared two datasets. Both of them are based on java classes from the source code of pieces of software under the study. The first dataset contains data about the faultiness of the observed classes. The classes containing more than one detected defect are marked as faulty in the dataset. The second dataset contains metrics measurements, related to identification of God classes in the projects' source code. Based on these two datasets, we could identify God Classes in the studied software, and build defect prediction models for the observed piece of software.

The defect dataset was generated in our previous work [21] according to the systematic data collection procedure. In accordance with the existing defect dataset, we ran our experiments on the source code of two independent projects within the Eclipse IDE development process of, namely, the Eclipse JDT[1] and Eclipse PDE[2] projects. Both projects are an important component of the open-sourced Eclipse Integrated Development Environment (IDE)[3], a development tool particularly popular among Java developers. We used version 3.2 of both projects, although the selected version is somewhat obsolete from todays perspective, because its source code is still available and can be downloaded freely from the Eclipse code repositories[4].

The dataset of software metric measurements of software metrics is calculated using the PMD tool. The PMD tool [13] is able to identify God Class code smells in source code according to the definition and thresholds proposed by Lanza and Marinescu [10]. Therefore, it can also be used to retrieve all software metrics required for God Class identification. Because PMD is not designed primarily as a metrics measurement tool, some small changes in the source code of the tool downloaded from its GitHub repository[5] were required, in order to to extract the internal values of the desired metric measurements. With the use of a slightly modified PMD tool, we were able to measure values of WMC, ATDF, and TCC metrics in the source code of the observed software. In the metrics' measurement, we included only source files in the source directory of the project. Other source and test files found in the projects were omitted. Compliance of God Class definition with the definition given by Lanza and Marinescu and the availability of its source code was the main reason why we chose the PMD tool, and not one of the alternatives examined by Paiva at al [9].

C. The case study

To find the thresholds of God Class definition for optimal defect detection in the studied software, we implemented the grid search algorithm as a Java-based console application. The console application iterates through all sensible threshold values of the metrics used for God Class definition, identify God Classes in the software, and test how accurately a modified God Class definition can predict defect faulty classes in the studied software. The grid search implemented in the console application followed the brute force approach. Basically, we iterated through all sensible thresholds using three nested loops, one for each of the metrics from the definition. In order to speed up the grid search, the console applications design exploits the multi-core architecture of the CPUs by executing the program code in multiple threads.

For the purpose of our case study, the domain of thresholds used in the grid search was limited up and down by minimal and maximal values of the measured metrics obtained from the software by the PMD tool. As shown in Table I, the minimum threshold value for the WMC metric was set to 0, and the maximal value was set to 1630. Because the value of the WMC metric is an integer number, the threshold values used in the grid search were incremented by the value 1. In the case of the ATFD metric, the minimal value used in the case study was set to 0, and the maximal value to 2886. The thresholds of the ATFD software metric were also incremented by 1 for the same reason as the WMC metric thresholds. Finally, the minimal value of the TCC metric threshold was set to 0, and the maximal to 1. Because the domain of TCC metric measurements is real numbers, the thresholds used in this research were incremented by value 0.02. This value was chosen as a compromise between the accuracy of the results and the acceptability of time complexity of the grid search.

Thresholds Limits			
Metric	MIN	MAX	Increment
ATFD	0	2886	1
TCC	0.0	1.0	0.02
WMC	0	1630	1

TABLE I

TABLE OF USED METRICS AND THEIR THRESHOLDS LIMITS

For each threshold combination used in the grid search, we tested its defect prediction performance. The goal of the experiment was to find a global maximum, i.e. thresholds that lead to the most accurate defect prediction model. After setting the thresholds of the God Class definition, we marked classes in the source code of the observed software pieces either as God Class, or as an ordinary class. With this step, we got two sets of classes, smelly classes, and regular ones. By using these two class sets we tested how accurately God Classes can predict faulty classes in the observed software. Both accuracy and F-score values were calculated using predefined algorithms from the Weka library[6].

On a computer system with Intel i7 - 4790 CPU, 24 GB of RAM, and exploiting all eight available CPU cores, the grid search took less than 30 hours to calculate accuracy and

[1]https://projects.eclipse.org/projects/eclipse.jdt/

[2]https://projects.eclipse.org/projects/eclipse.pde/

[3]https://www.eclipse.org/ide/

[4]https://projects.eclipse.org/

[5]https://github.com/pmd

[6]https://www.cs.waikato.ac.nz/ml/weka/

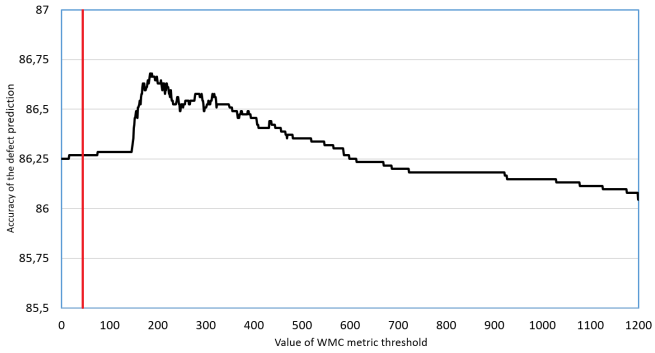

Fig. 2. Accuracy of Studied WMC Metric Thresholds

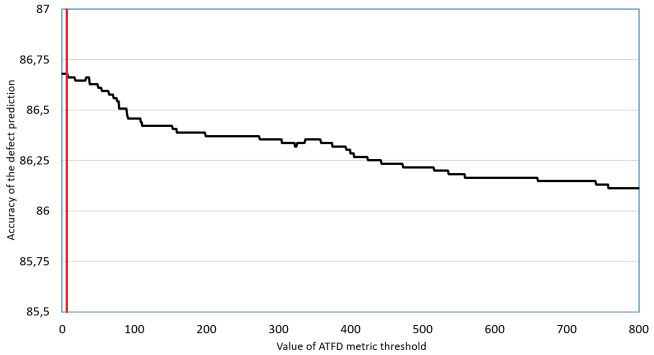

Fig. 3. Accuracy of Studied ATFD Metric Thresholds

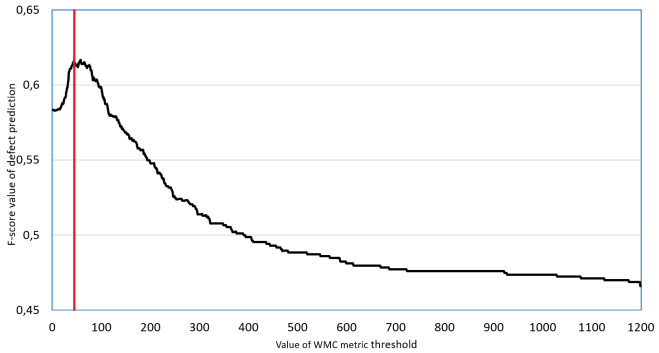

Fig. 5. F-score values of Studied WMC Metric Thresholds

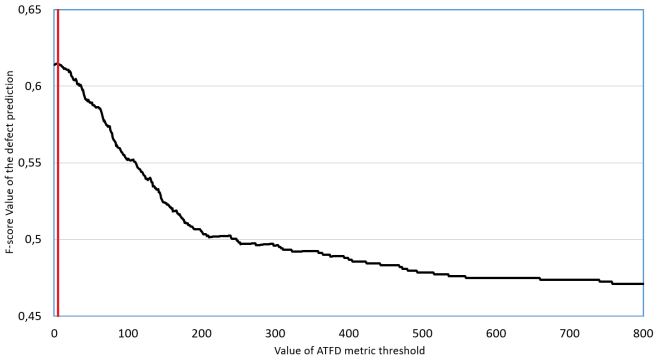

Fig. 6. F-score values of Studied ATFD Metric Thresholds

F-score values for all predicted thresholds of metrics used in the God Class definition.

D. Results of the case study

The results of both, accuracy and overall F-score are shown in the Figs. 2–7.

The output of the grid search algorithm was a dataset of data containing calculated values of accuracy and F-score parameters for each combination of thresholds of software metrics WMC, ATFD, and TCC within their limits, as defined in Table I. Consequently, the algorithm generated a vast amount of data, of which only a part is relevant for further analysis. To support further data analysis, we extracted thresholds of the studied metrics for which the maximum values of accuracy and F-score were reached. Based on the obtained maximum values of accuracy and F-score parameters, we could conclude whether better optimized software metric thresholds of God Class definition exists for purpose of the defect prediction in the projects in the experiment.

For the purpose of a deeper analysis of the behavior of the observed metric thresholds, we also extracted data of optimal accuracy and F-score values for each observed metric on the threshold interval. The analysis was performed for accuracy and F-score values separately by linear transition through the generated dataset. The data obtained in the analysis can be seen in Figs. 2-7. For clearer presentation, the interval of observed threshold interval is shortened, namely to an interval between 0 and 1200 for the WMC metric,

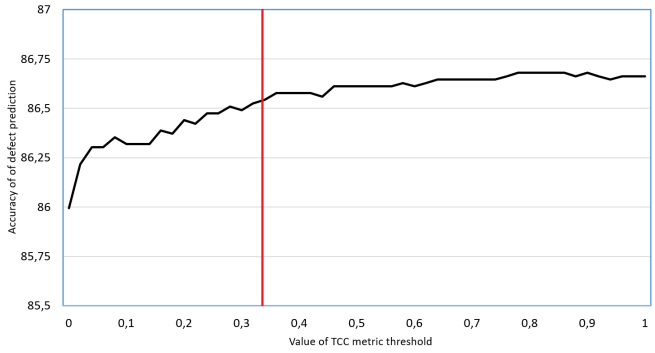

Fig. 4. Accuracy of Studied TCC Metric Thresholds

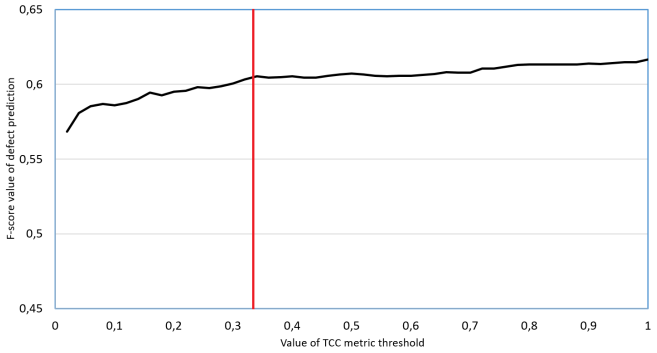

Fig. 7. F-score values of Studied TCC Metric Thresholds

and 0 and 800 for the ATFD metric. The charts in Figs. 5 and 6 for the TCC metric show the whole interval of analyzed threshold values. By shortening the interval, we could visualize important behavior at the beginning of the interval better. After the point of the cut of intervals in the charts, only a slight fall of accuracy and F-score value can be detected. The red line on all of the Figs. shows the default software metric values that are used in the definition of God Class proposed by Lanza and Marinescu.

IV. DISCUSSION

On the basis of the analysis of the data obtained by the grid search, we could answer our initial research question. The data analysis shows that the optimal thresholds of God Class definition metrics are relatively close to the values of metrics' thresholds proposed by Lanza and Marinescu [10]. Nevertheless, in the context of the studied software projects, we were able to find a more suitable metric threshold of God Class definition. With the use of these thresholds, we were able to predict faulty classes based on the identification of God Classes in the source code of the studied Eclipse JDT and Eclipse PDE projects more accurately compared to predictions made by the threshold of God Class definition metrics proposed by Lanza and Marinescu.

A. Global optimum

From the data collected by analyzing the Eclipse JDT and Eclipse PDE projects, we can discern clearly that the optimal metric thresholds of God Class definition used for the defect prediction in the observed projects is 58 for metric WMC, 5 for the ATFD metric, and 1 for the TCC metric. So, for the observed projects, the God Class definition predicts defects optimally by using the stated metrics' threshold values. The measured value of accuracy for optimum thresholds is 82.904, the measured value of F-score using the same optimal thresholds is 0.617. In comparison to the results calculated by the defect prediction using God Class definition with default threshold proposed by Lanza and Marinescu, accuracy and F-score values are slightly lower. Namely, the WMC threshold value was 47, the ATFD threshold value was 5, and the TCC threshold value was 1/3 of the reached value of accuracy, which are 81.256 and F-score 0.601. The maximum and minimum values of calculated accuracy and F-score for observed metrics is depicted in Table II. The defect prediction using the optimal threshold obtained by our grid search implementation is 1.65 pp more accurate compared to the defect prediction that uses the default threshold for God Class definition. The defect prediction performed on the studied projects using the optimal thresholds reaches a better F-score value, namely the value 0.015.

B. Thresholds of software metrics

Analysis of the deviations of the optimal thresholds of God Class definition obtained by grid search in our case study with the metrics threshold proposed by Lanza and Marinescu shows interesting differences in threshold values. The ATFD metric, our threshold matched completely with those in the generally accepted definition of God Class. Similarly, the calculated values of the WMC metric threshold were also quite close to the generally accepted values. On the contrary, in the case of the TCC metric, the optimal threshold deviates more distinctly compared to the recommended value proposed by Lanza and Marinescu.

Software Metric	Accuracy		F-score	
	MIN	MAX	MIN	MAX
ATFD	86.011	86.680	0.464	0.615
TCC	85.994	86.680	0.580	0.617
WMC	86.011	86.680	0.464	0.617

TABLE II
MINIMAL AND MAXIMAL VALUES OF ACCURACY AND F-SCORE VALUES

Figure 5 shows the chart of calculated F-score values for each value of WMC metric on the interval between 0 and 1200. In the analysis, we relied mainly on the F-score value, which represents the effectiveness of the defects' prediction algorithm balanced for both F and NF classes. The chart shows the efficiency of defect prediction of the God Class code smell by a different threshold of the WMC metric. The optimum of F-score value for the WMC metric was reached at value 58, which is relatively close to value 47 (the value is marked with the vertical line in Fig. 5), proposed by Lanza and Marinescu. Both thresholds, the threshold obtained by the grid search in our research and the generally accepted one, lie on the plateau on the interval 32 to 96, on which the defect prediction algorithm is, in the case of the studied software pieces, the most efficient, as it exceeds the F-score value of 0.6. The chart in Fig. 2 shows calculated values of accuracy value for each value of WMC metric on the interval between 0 and 1200. From the chart, it can be seen that the studied prediction algorithm is most effective by the threshold of WMC metrics at value of 200, and, after that, the accuracy is falling slowly and evenly.

The chart in Figure 6 depicts calculated F-score values for each value of the ATFD metric threshold on the interval between 0 and 800. In the chart, the depicted F-score values, which represent the effectiveness of the defects prediction algorithm balanced for both F and NF classes, reached the optimum by the value 5. The optimal value of the F-score parameter calculated by the grid search algorithm in our research completely overlaps with the ATFD metrics threshold proposed by Lanza and Marinescu. In both cases, the metric value 5 is the optimal threshold in the context of use for software fault prediction on studied pieces of software. Analysis of charts for both accuracy (Fig. 3) and F-score (Fig. 6) values of the ATFD metric, shows that software defects based on God Classes are the best predicted at low metric values. After the optimum threshold at value 5, the accuracy is falling slowly and almost evenly, while more and more relevant God Classes are left out due to the threshold of the ATFD metric being set too high.

Analysis of F-score values of the TCC metric thresholds depicted in Fig. 7 shows that the optimal value of the F-score parameter obtained by the grid search is reached at the metric

threshold value 1. The accuracy of software defect prediction of the studied Eclipse JDT and Eclipse PDE, reached the value of 0.6 at the TCC metric value of 0.33, which is in line with the thresholds in the God Class definition proposed by Lanza and Marinescu. After that point, the F-score value for the TCC metric continues to rise continuously until it reaches its optimum at value 1. From the perspective of the studied projects Eclipse JDT and Eclipse PDE, the definition of God Class with values of metric TCC around the value 1 is slightly more accurate when used in software defect prediction. Similar observations can be obtained by observing the behavior of the accuracy parameter for the TCC metric in Fig. 4. The behavior observation of accuracy and F-score values for the TCC metric raise an additional question about the contribution of the TCC metric for defect prediction. Namely, when the thresholds of the TCC metric are rising, fewer classes are marked as a God Class. When the threshold at value 1 is reached, none of the classes in the source code of observed projects is marked as a God Class. This observation demands further investigation.

V. CONCLUSION

Our case study is a preliminary case study, whose goal was to test whether there is any room for optimization of the metric thresholds of God Class definition proposed by Lanza and Marinescu. In our research, we were interested in the optimization of the God Class definition from the perspective of its use in the process of defect prediction. The data analysis shows that the optimal metric thresholds of God Class definition obtained by the grid search predicts software defects in projects under the study slightly better compared to the metric thresholds of God Class definition proposed by Lanza and Marinescu. The predictive performance of the threshold obtained by our approach is better, both from the perspective of accuracy by 1.65 pp, and by 0.0153 from the perspective of the F-score. As this is only a preliminary study, we tested our research question on a limited number of projects, namely Eclipse JDT and Eclipse PDE. The both projects are also based on java technology stack and are developed within the same open source community. Therefore, our project selection can induce potential threats to validity of our research. In order to be able to derive more reliable results, in the future, more projects written in different programming languages should be included in the replication of the case study. Our study opens new possibilities of adjusting and optimizing the process of defect prediction using approaches that are, compared to the used grid search, more time efficient. In the future, we plan to extend our research with one of the Machine Learning approaches. Further, we plan to extend our study to other types of code smells.

ACKNOWLEDGMENT

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Parametric versus direct modeling in manufacturing process management

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***Abstract* - Manufacturing process management (MPM) defines "how" a product is to be produced. It is a summary of inputs, which are helpful within the production. One of these inputs is computer-aided design (CAD). CAD is divided to 2D and 3D modeling. There are many free and paid software applications which can be used by designing a product. 3D CAD applications with ability to create both 3D and 2D designs are widely used among the designers. 3D CAD is divided to parametric and explicit (direct) modeling. But which suits the best for product design? This article gives an overview over several aspects of designing 3D models.**

Keywords – Computer-aided design, 3D CAD, 2D CAD, Parametric modeling, Explicit modeling.

I. INTRODUCTION TO MANUFACTURING PROCESS MANAGEMENT

Nowadays, the biggest milestone of successful product placing on market is time reduction, therefore the production of any product should be very quick. Customers are very impatient and market is overloaded with similar products which differ in quality and design. It is up to manufacturing companies if they choose the way of quality and design attractive product, which leads to higher costs of material and components and at the end to higher cost of final product. Or they choose the way of average quality and design, where the production costs and final price of the product are lower.

Customers consider the usage of product. Some of them are using products daily and in that case they usually pick product of higher quality and price. Those who are using products occasionally will pick product with lower quality and price.

All processes which influence product production are connected to manufacturing process management (MPM). MPM defines "how" a product is to be produced. MPM receives the digital product definition from engineering, considers the capabilities and capacities of internal plants and external suppliers, and delivers the set of manufacturing plans required to produce the product. MPM also entails giving early feedback from manufacturing to engineering based on preliminary versions of the manufacturing processes. Additionally, the MPM process communicates with production systems (ERP/MES), delivering optimized routings, as well as manufacturing bills-of-materials (mBOMs) and work instructions, including all supporting documents needed by production operators to build the product [1].

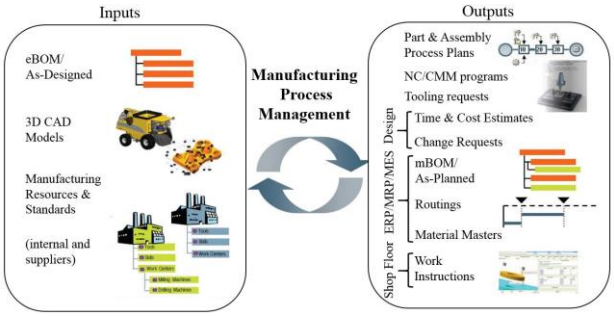

Figure 1. Process of defining and managing the manufacturing processes used to fabricate parts, assemble final products, and perform inspection [8]

II. COMPUTER-AIDED DESIGN

The digital product definition comes from one of the most powerful tools in MPM, which is called computer-aided design (CAD). CAD is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software helps to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. Its output is often in the form of electronic files for print, machining, or other manufacturing operations [2].

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called DCC digital content creation. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry [3].

Invention of CAD is attributed to a French engineer, Pierre Bézier (Arts et Métiers ParisTech,

Renault). After his mathematical work concerning surfaces, he developed UNISURF, between 1966 and 1968, to ease the design of parts and tools for the automotive industry. Then, UNISURF became the working base for the following generations of CAD software. As computers became more affordable, the application areas have gradually expanded. The development of CAD software for personal desktop computers was the impetus for almost universal application in all areas of construction. Key products for 1981 were the solid modeling packages - Romulus (ShapeData) and Uni-Solid (Unigraphics) based on PADL-2 and the release of the surface modeler CATIA (Dassault Systemes). Autodesk was founded 1982 by John Walker, which led to the 2D system AutoCAD. The next milestone was the release of Pro/Engineer (now PTC Creo) in 1987, which heralded greater usage of feature-based modeling methods and parametric linking of the parameters of features. Also of importance to the development of CAD was the development of the B-rep solid modeling kernels (engines for manipulating geometrically and topologically consistent 3D objects) Parasolid (ShapeData) and ACIS (Spatial Technology Inc.) at the end of the 1980s and beginning of the 1990s, both inspired by the work of Ian Braid. This led to the release of mid-range packages such as SolidWorks and TriSpective (later known as IRONCAD) in 1995, Solid Edge (then Intergraph) in 1996 and Autodesk Inventor in 1999. An independent geometric modeling kernel has been evolving in Russia since the 1990s [2]. CAD software can create 2D and 3D designs.

III. 2D CAD

2D CAD is commonly used to design vector-based layouts. For example, architects use CAD software to create overhead views of building floor plans and outdoor landscapes. These layouts, which contain vector graphics, can be scaled to different sizes, which may be used for proposals or blueprints. 2D CAD also includes drawings, such as sketches and mockups, which are common at the beginning of the design process [4].

There are many 2D CAD software applications which can be used for creation of design intent. Some of them are paid, some free. Paid versions mostly provide greater functionality and direct connection to 3D CAD applications. In table 1 are shown some of free and paid 2D software applications. On figure 2 is shown example of 2D design created in 2D application.

TABLE I. EXAMPLES OF FREE AND PAID 2D CAD APPLICATIONS

Examples of 2D applications	
Free	**Paid**
DraftSight	AutoCAD
QCAD	ArchiCAD
LibreCAD	Visual ARQ
Draft IT	PowerCAD

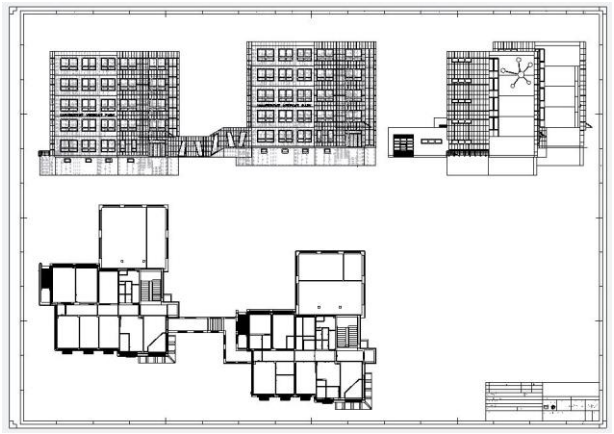

Figure 2. Example of 2D design created in 2D application

IV. 3D CAD

3D CAD models are typically vector-based, but the vectors include three dimensions. This allows designers to create complex 3D shapes that can be moved, rotated, enlarged, and modified. Some 3D models are created exclusively of polygons, while others may include Bézier curves and other rounded surfaces. When creating a 3D model, a CAD designer may first construct the basic shape of the object, or "wireframe." Once the shape is complete, surfaces can be added that may include colors, gradients, or designs that can be applied using a process called texture mapping. Many CAD programs include the ability to adjust lighting, which affects the shadows and reflections of the object. Some programs also include a timeline that can be used to create 3D animations. 3D CAD includes computer-aided manufacturing (CAM), which involves the actual manufacturing of three-dimensional objects [4].

There are many 3D CAD software applications which can be used for creation of design intent. Some of them are paid, some free. Paid versions mostly provide greater functionality as simulations, optimization, mechanism design, sheet metal design, human factor design and more. In table 2 are shown some of free and paid 3D software applications. On figure 3 is shown example of 3D design created in 3D application.

As mentioned before 3D CAD programs provide 3D models. Basically is creation of 3D models called solid modeling. There are 2 types of 3D solid modeling in 3D

TABLE II. EXAMPLES OF FREE AND PAID 3D CAD APPLICATIONS

Examples of 3D applications	
Free	**Paid**
123D Design	3DS Max
Blender	Autodesk Inventor
FreeCAD	CATIA
OpenSCAD	PTC Creo
SketchUp	SolidWorks
TinkerCAD	Rhino



Figure 3. Example of 3D design created in 3D application

CAD applications: parametric modeling and explicit (direct) modeling.

A. Parametric modeling

Parametric modeling is also called feature based modeling. Each entity, such as a boolean primitive, a line or arc in a wireframe, or a filleting operation, has parameters associated with it. These parameters control the various geometric properties of the entity, such as the length, width and height of a rectangular prism, or the radius of a fillet. Mentioned parameters also control the locations of these entities within the model.

These parameters can be changed by the operator as necessary to create the desired part. Parametric modelers use a history-based method to keep a record of how the model was built. When the operator changes parameters in the model and regenerates the part, the program repeats the operations from the history, using the new parameters, to create the new solid. There are many uses for this type of modeling including testing various sizes of parts to determine which is the "best" part by simply adjusting the model parameters and regenerating the part.

Some parametric modelers also allow constraint equations to be added to the models. These can be used to construct relationships between parameters. If several parameters always require the same value, or a certain parameter depends on the values of several others, this is the best way to ensure that these relationships are always correct.

These modelers allow other methods of relating entities as well. Entities can be located, for example, at the origin of curves, at the end of lines or arcs, at vertices, or at the midpoints of lines and faces. These entities can also be located at a distance or at the end of a vector from these points. When the model is regenerated, these relationships are maintained. Some systems will also allow geometric constraints between entities. These can require that entities be, for example, parallel, tangent, or perpendicular.

Parametric modeling is most efficient working with designs which only undergo dimensional changes rather than gross geometric ones such as removal of a feature [5].

On figure 4 is shown 3D assembly with fully accessible history in model tree created in 3D parametric application.

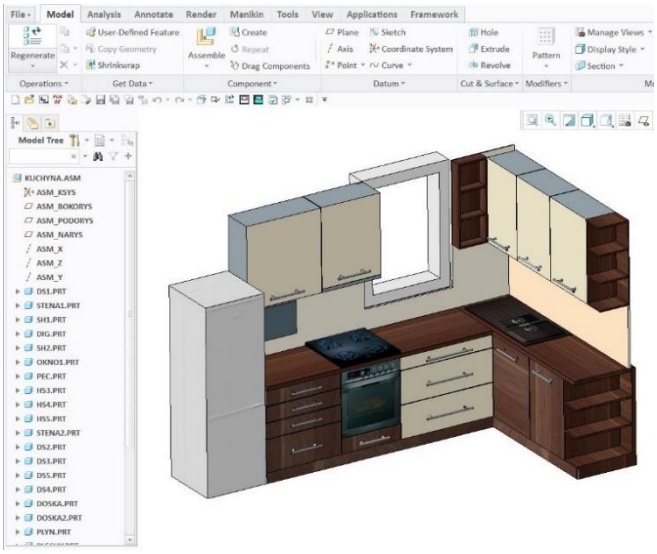

Figure 4. 3D assembly with fully accessible history in model tree created in 3D parametric application

B. Explicit modeling

Explicit (direct, non-parametric) modeling is also called modeling without history. It is a CAD method that allows designers to interact directly with the geometry of the model. This means they can manipulate it by pushing, pulling, or twisting. This can save significant amount of time, because it is easier for designer to change model to desired shape. So, unlike parametric modeling, where a feature's final geometry has to be built into the steps which create the final model, direct modeling allows the features geometry to be modified without having to edit the interim model stages [7].

After creation of 3D volumes like extrude, revolve, hole, chamfer, round or any other geometric shape all history of creation will be lost. The way of back volume reconfiguration is not possible. Explicit applications also miss many features which are available only in parametric modeling, because they cannot create references between entities. On the other hand any 3D model, which was

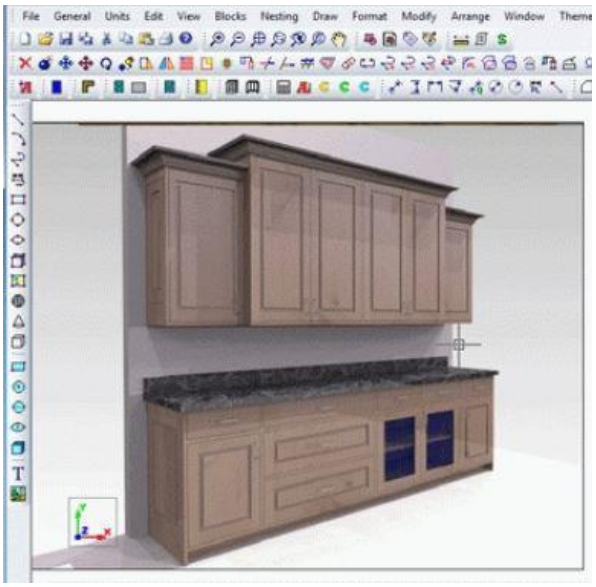

Figure 5. 3D assembly with no history created in 3D explicit application [9]

TABLE III. EXAMPLES OF PARAMETRIC AND EXPLICIT 3D CAD APPLICATIONS

Examples of 3D applications	
Parametric	**Explicit**
FreeCAD	3DS Max
Creo Parametric	Creo Direct
CATIA	123D Design
Rhino	SketchUp
SolidWorks	TinkerCAD
Autodesk Inventor	Blender

successfully loaded to program can be easily and quick edited. A non-parametric model is essentially a "dumb model" which is created when a CAD model is imported from another program. There are tools for copy and paste, remove, reshape, but model does not have the additional constraints and relationships to allow the update to affect other design elements. Explicit modeling is mostly used by engineers which need to make huge design changes in models and do not have in their parametric software the ability of flexible modeling. It is the ideal choice for non CAD experts.

On figure 5 above is shown 3D assembly with fully accessible history in model tree created in 3D parametric application. In table 3 above are mentioned examples of parametric and explicit 3D CAD applications.

C. Best practises

As students, teachers, application engineers and researchers, we worked with many CAD applications: three 2D CAD, four parametric 3D CAD and four explicit 3D CAD. Below are listed some parametric and explicit 3D CAD programs.

Before is made a decision of the right type of suitable CAD software, the designer, architect, engineer has to think about the end design of product. There are many questions. Here are some of them, which can be helpful by accurate decision.

- Is 3D design simple or complex shape?
- Does the software application have a library of materials and colours?
- Is the creation of drawings necessary?
- Are products similar? Is it better to create generic model and then library?
- Does the company have database system for archiving?
- Is product an assembly? Will there be a need to create mechanisms and their analysis?
- Is there a desire to perform design changes later?
- Does the design consist of frameworks? Are tools in software application capable of creation of this kind of geometry?
- Is there a desire to place humans into design and compute ergonomic analysis?



Figure 6. 3D design created in parametric application with freestyle feature

- At the end is there a need to create photorealistic output?

If the answer for most of these questions is yes, then 3D parametric software is right decision. In modeling mode you can create 3D models, specify materials, colours from library, define and create own colours. You can create advanced volume features in which you connect similar or various sketches (sketches have to contain equal number of points) parallel, by angle or by curve. If you need similar models like for example bolts, you can create generic model, choose parameters (dimensions, texts, new features) which will vary, define new values for parameters in table and new models will be virtually created. If you open such a model it will become visualized and you can use it as single model or insert it to assembly. In assembly mode you can make various analyses: mass, surface areas, create mechanisms and collision analyses.

In many parametric applications is now the possibility to work with app called flexible modeling. It contains many features which help quickly change entire model. One of them is feature which is called remove surface. This feature enables to remove surfaces and volumes which are selected. There is also a possibility to replace one surface with another. Another function is to select surfaces, feature or features and move it or them to desired location. This function is similar in explicit programs, so parametric program becomes partially explicit. Another functionality, which gives you “free” modeling is feature called freestyle. It allows to start the design from sphere or other 3D shape and work very quickly on design. Above on figure 6 is an example of 3D design made with freestyle feature in parametric 3F software. This design was made in 1 hour. Without the possibility of freestyle, it would take at least 7 days of feature based modeling and usage of advanced curves and surfaces.

V. CONCLUSION

Most parametric software applications have many extensions, which can help you with various analyses of your model: flexible modeling, design exploration, interactive surface design, piping, cabling, advanced framework, human factors, advanced rendering, reverse engineering, ECAD-MCAD collaboration, statics, dynamics, CAM and manufacturing.

But sometimes there are moments that parametric approach is not so quick for creation of new model designs, which will not need to be huge reconfigured later. (The functionality of freestyle and flexible modeling is paid and your parametric software does not contain it). In those moments is suitable to use explicit software application, best free.

The technology of programming CAD software applications is still progressing and software companies are every year presenting new functionalities and updates in their applications. There are applications which are divided to parametric and explicit parts. They can work fully independently. Since they are programmed on one platform, their huge functionality is that they can collaborate together. When a model is created in explicit application and later imported to parametric all operations that was made in explicit part of application appear in model tree and 3D model becomes parametric, fully accessible and reconfigurable with all dimensions and references. Mostly this functionality is used. Designer creates quick design and later sends it to CAD expert for processing to desired form.

And this is our answer to question what kind of software you should use by your work with 3D models.

If it is possible use software application which enables you to work in one platform with parametric and explicit applications.

If it is not possible, use any parametric software with functionality of flexible modeling and freestyle.

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Graph Database Approach for Data Storing, Presentation and Manipulation

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***Abstract* - An increasing number of IoT systems and a generation of unstructured data make it difficult to choose and apply a suitable database model. Using a NoSQL database on a test data model shows the advantages of storing, manipulating, and presenting the required data. A test data model was created on a relational database and on a graph database to compare the options of manipulating and presenting the same data. A comparison of these two models was made on a small sample, and the results were displayed on the same query as the default for both types of databases. Simpler query syntax and better visualization of data are some of the benefits presented by this model on the graph database.**

Keywords - NoSQL; Graph database, IoT, Neo4j, Cypher query language, MySQL

I. INTRODUCTION

When a database is mentioned today, one commonly refers to a relational database and a data processing system based on a relational data model. The growth of the Internet has brought on new technological challenges in various areas, such as IoT systems. This paper describes a different approach for storing, presenting, and retrieving data stored in the database. The two types of databases, relational and graph databases, have their advantages and disadvantages, and in some situations, some of the databases contribute more successfully to the result of querying data. The dynamics of the IoT system, the constant changes in the structure and the number of data are the motivation for exploring different approaches to storing and accessing data. One of the possible approaches in the dynamic IoT environment is to use the graph database. In comparing the two types of databases, MySQL was used as a relational database and Neo4j as a graph database.

One of the biggest challenges is the amount of data; more specifically, the system's difficulties in accepting and processing a large amount of data in as little time as possible. These challenges created new types of databases in which data is not organized according to the principles of the relational model, but according to a much simpler and freer data model. One of these systems are graph-based systems. Such databases consist of nodes and connections between them, and enable efficient query through nodes following their connections [1]. Graph-based databases belong to the so-called NoSQL databases. NoSQL data storage aims to be very fast and always available because it is represented in the object structure. There is no link between the tables as in a standard RDBMS (relational database management systems) so the requested objects can be accessed directly. If one is using a large system for which quick access to data is preferred, then storing data in a NoSQL database could be exactly what it takes. If one requires a consistent method of storing large amounts of data, without the need for a high response rate, perhaps using a traditional RDBMS database is a better solution [2]. A relational open source database was used for modelling data for the IoT system, as well as an open source graph database. The data model makes possible the presentation of the basic idea and the comparison of these two models on different databases, their visual presentation and the ability to retrieve the requested data. The paper is divided into six chapters. After the introduction, chapter II. describes the characteristics and advantages of the graph database over the relational database. Chapter III. describes the test environment for comparing a typical query with the relational database and the graph database. Chapter IV. describes the structure and data used in both databases. Chapter V. provides a comparison of some queries, results and their presentation. Chapter VI. contains the final considerations and suggested directions for future research.

II. GRAPH DATABASE

A graph database consists of a number of nodes which are interconnected and directed by connections. They are best suited for storing interconnected data, as they also allow for storing information about the links between the entities [3].

Most applications for IoT have to work with dynamic and fast-changing systems: new devices and applications regularly use the communication network, and must smoothly use said network. This requires a data model that can be developed without unnecessary reintegration of the database and the applications, and without affecting the availability of applications. Connections between devices and other entities can be changed faster than the data they describe. It is necessary to have a system that can easily and without stopping any part add and delete relations between entities, and graphs are the natural way of showing links between entities. Real-time response is an important factor in the Internet of Things. The graph database solves this request in a natural way,

without requiring large hardware requests [4]. The graph database that was used to retrieve data is the Neo4j database, a graph platform which is specifically optimized for mapping, analyzing, storing, and retrieving network-related data to reveal invisible contexts and hidden relationships. By intuitively mapping data points and connections between them, it enables intelligent real-time applications that address today's toughest challenges including:

- Artificial intelligence and machine learning
- The Internet of Things (IoT)
- Real-time recommendations and personalization
- Detecting fraud
- Network and IT activities
- Identity management and access [5].

Graph databases are effective when used for discovering and giving meaning to complex interdependencies and relationships between entities. They are designed for easy modeling and data navigation, with extremely high performance, which makes them very popular for use on social networks. Now they are being increasingly embraced by companies that want to extract the maximum value from the Internet of Things [6]. The interconnection of devices and data focused on a scalable solution for processing requests from IoT devices has shown that the graph database is a viable solution for modeling such systems. There are many operations in IoT systems that run in real-time and require tools that can display interconnections very quickly; they use similar queries that would otherwise require JOIN operators in a relational database [7]. Modeling data in the form of a graph is simple and natural, and has the advantage of being simple to understand for common data users. The relational model is more prevalent, but when it comes to billions of devices connected to the Internet, the graph database has certain advantages in view of the complexity of the system. When the choice of a database must be applied to smaller amounts of data and a response very close to real-time reactions, then the graph database can be very useful in the IoT system [8]. The main challenge with rapidly growing amounts of data is its discrepancy. This problem has lead to a greater use of nonrelational databases that are very scalable and efficient, and can store large amounts of unstructured data. Although relational databases are able to use all three data types (structured, semi-structured and unstructured), more work and compromises are needed to achieve effective storage of unstructured and semi-structured data. Relational databases store structured data because they are already in an acceptable form, but the storage of semi-structured data involves increased complexity. Semi-structured data should first be converted into the appropriate data form for relational databases before storage. In the case of unstructured data, it is stored as a blob object and not directly [9].

III. DATA MODEL ENVIRONMENT ARCHITECTURE

The data model is the set of data arranged in multiple tables in the RDBMS database, and the same pattern of data is used to create nodes and relationships in the graph database. The testing environment is a setup of software support and a virtual server. The testing environment relies on multiple physical servers in a cluster that uses the hypervisor on which a virtual server with the desktop operation system was created. The application and the database for the graph database were installed on the virtual server: Neo4j and the associated graph database. The application itself contains software support for data manipulation via the Cypher scripting language and is accessible via an Internet browser. The Internet browser connects to the application of the graph database via ports 7687 (Bolt), 7474 (HTTP), or 7473 (HTTPS). On the same virtual server, the RDBMS database was installed through the XAMMP application. XAMPP is a completely free, open source Apache distribution that contains MariaDB, PHP and the Perl scripting language [10]. The Phpmyadmin application, which connects via an Internet browser to the MySQL (MariaDB) database through port 3306, was used to access the database. The functional diagram of the server and the software support for the test environment is shown in Figure 1.

IV. DATA MODEL

Unlike classic RDBMS data models that use tables and table data display, the graph database uses a data model with a structure consisting of nodes, tags, node connections, and node properties which have the following characteristics:

A. *Nodes*

- main data elements
- connected to other nodes through connections
- can have one or more properties (attributes stored as a pair of keys / values)
- have one or more tags describing its role on the graph

B. *Connections*

- connect two nodes

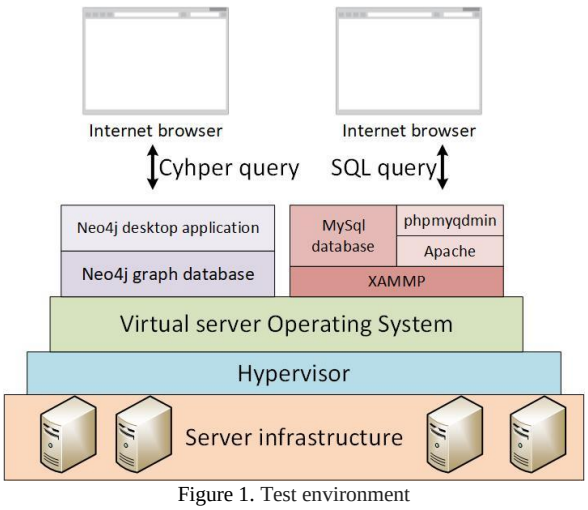

Figure 1. Test environment

• focused

• nodes can have multiple connections and can even be recursive

• can have one or more properties (attributes stored as a pair of keys / values)

C. *Properties*

• named values where the name (or key) is a string of characters

• can be indexed and restricted

D. *Tags*

• used to group nodes into sets

• a node can have multiple labels

• indexed to accelerate the finding of nodes in the graph

For the purposes of use comparison and data retrieval in the data model, an identical data model was created in the classical RDBMS database (MySQL) and in the graph database (Neo4j). The data that forms the database in the MySQL database is shown in the tables in Figure 2. The "device" table contains the device names and locations to which the device belongs (10 records), the "location" table contains the names of the locations and the region in which the location is located (13 records), and the "region" table contains the names of the regions (4 records). The "measurement" table contains the measurements obtained from the device, the date of measurement, and the type of measurement (11 records), and the "measurement_type" table contains the name of the measurement type (2 records). The data in individual tables is linked as follows: the sequence number of a record from one table is associated with the values from the second table using a foreign key. The data model in the graph database is shown in Figure 3. The data structure in the graph database followed the data structure in the relational database where five types of nodes were made: type of measurement (2 nodes, green), measurements (11 nodes, red), devices (10 nodes, yellow),

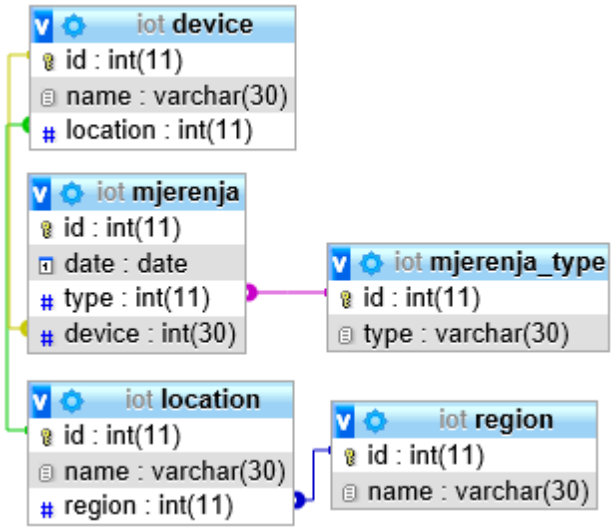

Figure 2. Model of data tables in the MySql database

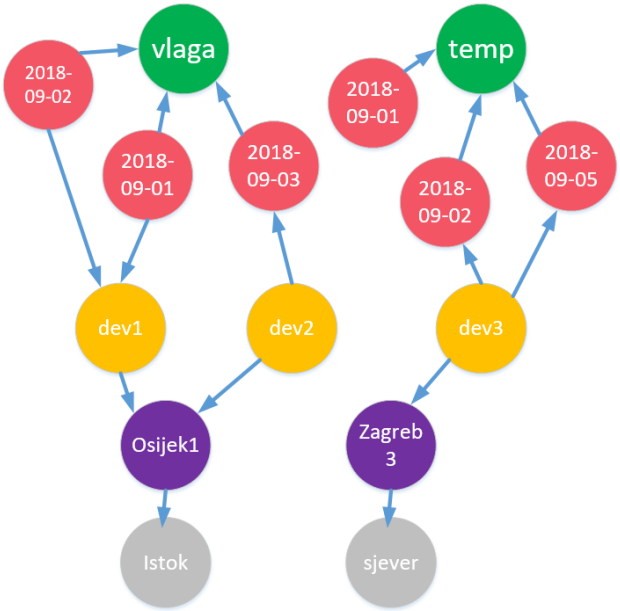

Figure 3. Segment of data model in graph database

locations (13 nodes, purple), regions (4 nodes, gray). All nodes are connected by connections, each node with a specific connection to the neighbor node. Figure 4. shows one of the relationships that is obtained by searching according to the given criteria. The image shows which types of nodes are associated with their neighboring nodes and the names of their connections (Type of measurement, Measured, Below).

Already by comparing the data display itself, it is clear that the graph displays the data more intuitively, and certain data connections can already be determined from a visual inspection. Thus, one can in a simple manner, for example, determine which devices belong to which region, which device did not deliver a measurement, during which days there had been no moisture measurement at all, and so on. As long as the set of data is small enough for a simple graph, we can take advantage of the visual data view. For large data sets, the graph display does not provide the previously mentioned visual advantage, but queries and manipulations of data are

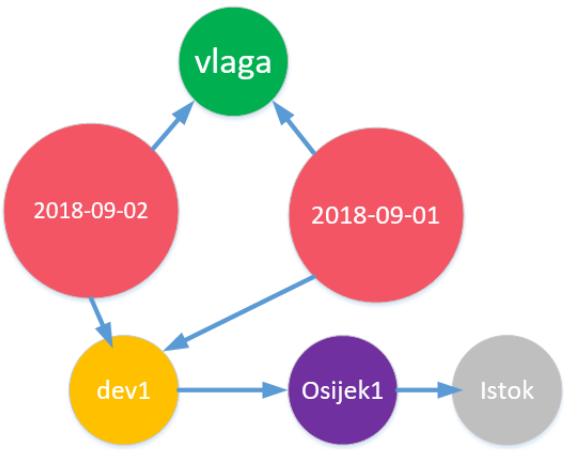

Figure 4. Result of Cypher query in the graph database

required, as in relational databases. The next chapter will show that a query of the graph database is much easier than a query of the relational database, as well as provide a visual display that can be easily interpreted.

V. DATA QUERYING

Retrieving data in the relational database was done using SQL queries. SQL (Structured Query Language) is a structured, standard language for accessing and manipulating databases [11]. In the data model for this paper, for example, the data that corresponds with the question "show all the moisture measurements of device dev1 in the region east" is to be found. A Standard SQL query by relational database for such parameters would be:

SELECT metrics.id, measurements.date, device.name, dimensions_type.type, region.name

FROM device, location, region, measurements, measurements_type

WHERE device.location = location.id and location.region = region.id and measurement.device = device.id and metering.type = measurements_type.id and region.name = 'east' and measurements_type.type = 'humidity' and device .name = 'dev1'

The result of this long query is a simple table containing the requested data and is shown in Table I.

TABLE I. RESULT OF SQL QUERY OF RELATIONAL DATABASE

id	***date***	***name***	***type***	***name***
1	1.9.2018	dev1	vlaga	istok
2	2.9.2018	dev1	vlaga	istok

In order to obtain the result of the query, it was necessary to read the related data of five tables which will be displayed in a single table for the sake of convenience.

The Cypher syntax is used for the same query in the graph database. Like SQL, Cypher is a declarative query language that allows users to specify which actions they want to perform (such as matching, inserting, updating or deleting) on graph data. Cypher is a platform-independent open code used on a variety of graph ecosystems. The syntax is in the ASCII format, which provides a well-known, legible way to collapse patterns of nodes and relationships within graph data sets [12].

Using the same question as on the test data model, "show all moisture measurement of device dev1 in the east region", a Cypher query was used on the data in the graph database:

MATCH
*p = (d: Device) - [*] -> () - [] -> (t: Type), w = (d: Device) - [: Below * 2]*

WHERE
d.name = "dev1" AND t.name = "moisture"

RETURN p, w

One can note that the Cypher syntax is much shorter than the SQL query, and is more understandable. As a result, we get the graph showing the required data shown in Figure 4. The figure immediately shows the relationship of data (nodes) and their values.

In the above example, the structure of the graph database followed the standard structure of the relational database where the data was divided into several tables and connected with foreign keys. If the data structure was adapted to the graph database then the requested query based on the graph database would be even simpler. When all the data is added to the nodes representing all the devices and all the measurements, they are mutually linked, as shown in Figure 5, where yellow nodes represent devices, and red-labeled nodes represent measurements. Device nodes have these defined properties: name, location, region; while measurement nodes have the following defined properties: date, value, type of measurement. In this case, another measurement feature has been added – the value of the measurement that was not used in the previous model. This is another advantage of the graph database, where certain nodes can add different, often unrelated properties that may need to be used in future analyses. Adding new properties to relational databases would require much more action than creating new tables and linking them to specific data from other tables.

With such a small data model it is very easy to visually notice the extremes – in this case, devices that have not made any measurements are clearly visible. Each node is defined with properties that can be displayed by clicking on a particular node shown in Figure 6. or in tabular view of the properties of a particular node.

For the same query used in the previous model, "show all moisture measurements of device dev1 in the east region", Cypher query was used according to the graph database:

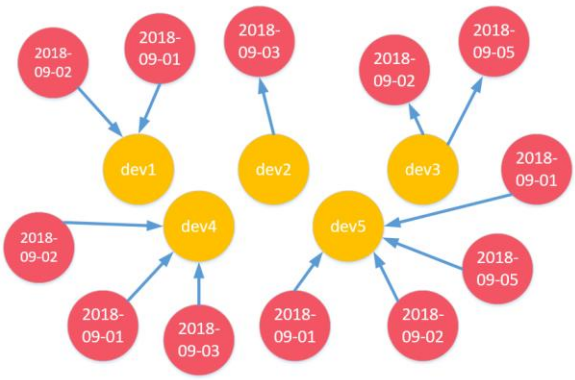

Figure 5. Graph Data model with two types of nodes

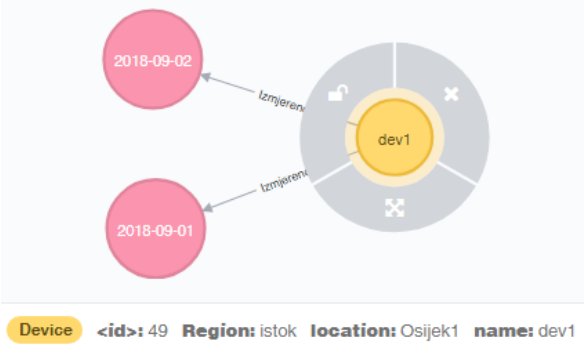

Figure 6. Result of cypher query used in a new data model

MATCH
p = (d: Device) - [*] -> (m: Measurements)

WHERE
d.name = "dev1" AND m.type = "moisture" AND d.Region = "east"

RETURN p

This shorter Cypher query gets the identical result as in the previous model shown in Figure 4. described in previous chapter IV.

For this data model, a shorter and more transparent Cypher query is required in relation to the SQL query based on the relational database. All data is read from a graphical view or can be read as shown in Table II.

TABLE II. TABULAR DISPLAY OF THE VALUE AND PROPERTIES OF THE REQUESTED CYPHER QUERY

"p"
[{"name":"dev1","Region":"istok", "location":"Osijek1"},{},{"date":"2018-09-01", "type":"vlaga","value":"100"}]
[{"name":"dev1","Region":"istok", "location":"Osijek1"},{},{"date":"2018-09-02", "type":"vlaga","value":"20"}]

VI. CONLUSION

Due to an increasing tendency of connecting devices through the communication network and the increasing number of generated data that needs to be stored and processed for future use and data analyses, the question of choosing a suitable database is raised. Data is still stored in relational databases because they are already in a structured form and can be easily stored, manipulated and analyzed in relational databases. By increasing the IoT devices, connecting devices of different characteristics, and obtaining different unstructured data that needs to be stored, a solution is proposed in the form of non-relational databases. This paper compares the use of a relational database (MySQL) with a non-relational database (Neo4j) on the test data model. Data manipulation compares data retrieval requirements in the form of SQL queries for the relational database and Cypher queries for the graph database. The query result was identical, but the Cypher query was better and more simply structured than the SQL queries. It is also possible to achieve a visual representation of the results from the query result layout which is graphically displayed in the form of nodes and interconnections in the graph database..The relational database displays the data in the form of a table, while, in the graph database, the result can be displayed both in the form of a table and in the form of a graph. According to the studied and available literature [12], [13] it can be concluded that the manipulation of unstructured, abundant data is simpler in the graph database environment. Although the test data model was well-structured and did not contain large amounts of data, one can note the advantage of using of a graph database for IoT systems that will, in the future, have more and more unstructured data that will need to be analyzed and processed as quickly and efficiently as possible.

In future work it would be useful to examine how easily large amounts of data can be manipulated and presented. For this purpose, the single programming approach of both databases should be used and the cases in which it is better to use a relational or non-relational database ought to be examined in a measurable way.

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Design and development of an automated web crawler used for building image databases

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***Abstract* – Every day people worldwide upload millions of images to social networks, personal blogs, community forums and other web-based applications. To increase impact and public popularity however all these images should be indexed by search engines. Building an efficient non-textual search engine is far from a trivial task. It should employ modern information retrieval and image processing techniques to extract, index and store proper metadata from images that allows fast subsequent processing and searching.**

Before any image processing to apply, the search engine should be able to find and process the large amount of data being constantly added to the Internet. The WWW represents an enormous directed weightless cyclic graph by nature. Blind crawling of such a structure is a pointless waste of time and may never end. To achieve any efficiency, the crawler itself should be able to determine if the current crawling direction is perspective and lead to desired resources or not. Thus calculating weights of graph components (vertices and edges) is absolutely necessary to allow the automated crawling tool to navigate through the web.

This paper suggests various ways of calculating weights and proposes architecture of a web crawler designed for building image databases. Choosing the most appropriate search strategy seems to be the key point in building an efficient special purpose web crawler.

Keywords – web crawling; image databases; search engines; graph traversing (key words)

I. INTRODUCTION

The development in IT and modern computer systems in both hardware and software aspects allows them to be used in all areas where information can be given as a digital representation. They are also capable of storing and organizing huge amounts of different types of information which has led to the development of databases and information systems. In turn this has driven service improvement offered to customers using the information. Due to this development, these days databases are not only capable of dealing with written information but also images, audio and video formats. Naturally, the problem of combining, organizing and structuring all of this information emerges. The information needs to be useful for all users and the subjective factor when structuring and organizing all the data has to be avoided as much as possible. Thus, the aim is to automate the process of organizing and accessing the information. The solution to this problem with the current amount of information on the internet and the daily update of that information is the use of web crawlers or spiders for specific data type.

II. THEORETICAL ASPECTS

Web crawlers are applications or programs that use the graph structure of the Web space to crawl through it by page-by-page. This type of programs are also known as spiders, travelers, worms, robots and other similar concepts that have come from the essence of their features and functions. Web robots arise in order to organize and search for web pages content based on any of their representations stored in local databases of the web search engines [18]. Subsequently, these databases can be used for the needs of different applications.

If the web space was a static set of sites, it would significantly simplify the concepts and tasks of these searching robots, because once they have crawled through all the pages and created the database with the relevant information, it would not be necessary to crawl and search again. Web space, however, is too dynamic, which complicates the web robot's functions in order to maintain the integrity and up-to-date of the information in the relevant databases [1]. The result of the aim of this program to maintain the absolute integrity results in all areas is a very cumbersome application. To avoid this, web robots should be implemented to employ a certain selectivity with respect to the pages they crawl or the information they are looking for. These are the so-called heuristic robots that use thematic or focused crawl and search [2, 3, 4, 5]. Most often they are used as a combination of search engines for different types of information.

The main problem with the automated crawling of the Internet is the creation of an adequate strategy to ensure a high efficiency of crawling. The speed of new resources being published on the Internet is so quick that achieving high quality and quantifiable results for minimal time is critical to any spider.

III. RELATED WORK

The issues that web crawlers generally face are the large volume and the rate of change of information in the web since every day there is a large number of pages added, edited or removed. An additional problem is the fact that current processing speeds and storage capacities have improved significantly more compared to network speed. To deal with the large volume of data the web crawler has to prioritize its tasks as it is unable to download all information within a given time. Hence, due to the high rate of change, the last pages to be downloaded

might have been edited by the time the crawler has reached them [6, 7].

Matthew Gray, who studied physics in Massachusetts Institute of Technology (MIT) implemented ***World Wide Web Wanderer*** [8] in 1993. It was a standalone application written in Perl and the main purpose was to research the size of the World Wide Web for academic purposes and the Web was still relatively small. A single machine was used to develop and run ***Lycos Crawler*** [9]. Lycos used Perl's associative arrays to maintain the set of URLs to crawl. When the application went public on July 20, 1994 it had a catalog of 54,000 documents. It provided ranked relevance retrieval, prefix matching and word proximity bonuses. Lycos' capability of indexing tens of millions of pages was its main difference but unfortunately the design of this crawler remains undocumented. The first published Web crawler was *RBSE* [10] and it was based on two programs – spider and mite. The former was a program that creates and manipulates an Oracle database of the Web graph, traversing links having patterns of "*.html" or "http:*/ ". Mite, when given a URL as a command line argument, retrieves the document into a local file and prints any URLs found in the document on standard output. Spider spawns mite, reads the list of URLs and stores URL source–target pairs in the primary database table. ***WebCrawler*** [11] was the first comprehensive full-text search engine for the World-Wide Web and it is still working on the web. A full text index and a graph representation of the Web form the database of the WebCrawler, which is stored on disk. The database is updated as new documents are added and to protect it from system crashes these updates are made under the scope of transaction that are committed every few hundred documents. ***Google Crawler*** [12] was implemented in C++ and Python at Stanford. Only the early version of its architecture is described in some detail - the original crawler consisted of five functional modules running in different processes. Google's fast distributed crawling system could scale to hundreds of millions of Web pages. A single URL server serves lists of URLs to a number of crawlers (typically about 3). Roughly 300 connections are kept open at once by each crawler. This is necessary to retrieve Web pages at a fast enough pace. Using four crawlers the system could crawl over 100 Web pages per second at peak speeds. Written in Java, ***Ubicrawler*** [13] is a distributed crawler that has no central process. It is composed of several identical "agents" that ensure no page is crawled twice unless one of the agent crashes causing another agent to re-crawl the pages from the failed agent. The assignment function is calculated using consistent hashing of the host names. UbiCrawler offered platform independence, full distribution of every task, tolerance to failures and scalability as essential features..

IV. WORKING ALGORITHM AND ARCHITECTURE

The World Wide Web (www) is a cyclic oriented weightless graph by nature that could have finite but enormous number of vertices. Blind crawling of such structure is meaningless as it cannot finish in a reasonable amount of time. So crawling should be navigated somehow in order to reach high efficiency in retrieving useful resources only. To achieve that, evaluation criteria should be introduced that measure if and how perspective the selected crawling direction is. The overall numerical representation of these criteria could be directly used as a weight of vertices or edges. That converts www from weightless to a weighted graph. And this transformation is mandatory in order to allow the crawling algorithm to navigate itself, i.e. to decide by itself which vertex (web site) to continue with. Then any of the well-known heuristic algorithms for informed (guided) graph search could be used as a crawling algorithm. The most challenging task in web spider development is defining the way weights are calculated. Their accuracy and precision directly impact decision making and crawling efficiency.

There are three ways of calculation vertices weight is general:

- the spider calculates weights by itself based on some heuristics or evaluation criteria;
- the weight of a vertex is calculated as a sum of the weight of all edges pointing to it (similar to PageRank algorithm);
- combination from the previous two.

In the early years of www, search engines calculated the page ranks based on the second way - as a sum of weights of the vertices/edges pointing to them. At that time however search engines designers had not think of sophisticated ways of calculating weights of edges. So the weight of a vertex depended entirely on the number of edges pointing to it. In other words the position of the web site within the search results depended primary on the number of hyperlinks pointing to it. Having that in mind, many ambitious entrepreneurs created large networks of similar interconnected websites (for example online shops) that points to each other. Or SEO experts posted plenty of comments in discussion forums, while adding a hyperlink to their website at the end of each post. That tricks worked well for some time, moving highly interconnected websites higher in the search results.

However this way of calculating page ranks started to decline over time and gave place to some more adequate methods allowing the spider to calculate weights (page ranks) by itself based on proper criteria – not only the number of pages pointing to a website, but also the importance/significance of the referrer, its weight, number of visitors, rate of update and others. Furthermore in case of a domain-specific search the spider can also assess how much the crawling resource is related to the specified subject domain and if it satisfies other pre-defined requirements.

Every spider maintains its own data structure containing the URLs of the non-crawled vertices (or those already crawled but should be re-indexed). For simplicity, this structure will be called a list, but in practice it could be of a more complex type. The goal of the crawling strategy algorithm is to calculate the weight of all vertices in the most accurate way. The rest is just sorting the list of URLs by their importance (i.e. weight) in descending order. The weight of a newly discovered url (hyperlink) could be calculated as follows:

$$w(l_i) = h^* + w(p) + Sim(uSC, l_i) \quad (1)$$

Where:

$w(l_i)$ – weight of the *i*-th hyperlink, found in currently-processed page *p*.

h^* – optional parameter. If present, could be 1 if the link belongs to the same web domain and 0 if the url points to an external domain. The presence of this parameter partly converts the best-first search strategy to breadth-first "best-second" search and allows crawling an entire domain before going to the next one.

$w(p)$ – weight of the page *p*. If the page is highly related to the user's search criteria then its hyperlinks should have higher weight.

$Sim(uSC, l_i)$ – semantic similarity between the user-defined search criteria (keywords used to focus the search) and the text describing the hyperlink l_i. Could be calculated by any existing similarity measure or method known from the Information Retrieval – *vector space model*, *latent semantic analysis* and others.

A text describing a hyperlink could be available on multiple places within or around the link itself. If such is present on more than one place, then just one of them is taken into account, determined in the following order (priority):

- The "title" attribute of the HTML <a> tag. If present, it is supposed to contain the most precise description of the page the link points to.
- The text immediately before or after the <a>… tag. If there is no title attribute in the hyperlink's <a> tag then we can look the text around it. It usually states what the user could find in the target page.
- The text between opening <a> and closing .

Focused crawling is achieved by applying user-defined search criteria (denoted as *uSC*), usually typed in the form of keywords. The similarity between them and the links description could be calculated by implementing some basic text analysis methods, for example the Vector Space Model. In this case *Sim*(*uSC*, l_i) could be calculated as the cosine similarity between the vectors of the query and the link's l_i description (2).

$$Sim(uSC, l_i) = \frac{\sum_{j=1}^{n} w_{qj} w_{ij}}{\sqrt{\sum_{j=1}^{n} (w_{qj})^2 \sum_{j=1}^{n} (w_{ij})^2}} \quad (2)$$

Where:

w_{qj} – weight of the *j*-th term in the query (the j-th keyword of the user-defined search criteria).

w_{ij} – weight of the *j*-th term, describing the *i*-th discovered hyperlink. The *i*-th link is the one currently being processed.

n – number of terms within the entire document (hyperlink) collection built so far.

When implementing vector space model, IR experts (Grossman and Frieder [14]; and Salton and Buckley [15]) suggest to use lnc.ltc weighing scheme to calculate the weight of query and document terms. However using inverse document frequency (*idf*) is a bit tricky in crawling and could lead to potentially bad results. In general, *idf* is employed to lower the weight of a term if it appears in many documents. Its high frequency of appearance is assumed to mean it is low informative. And this is true in general, but it is not the case in focused crawling guided by user-defined keywords. Let's assume we are searching for airplanes and that is the keyword provided by the user. Then the frequent appearance of "airplane" within the descriptions of many hyperlinks does not mean it is insignificant keyword. It means there are many URLs that satisfies user's search criterion. On the other hand inverse document frequency reliably detects and excludes words which we can assume uninformative related to users' search - prepositions, conjunctions and etc. Therefore, if no *idf* is applied then a list of stop words [17] should be used to remove semantically insignificant words. Additionally words could be stemmed by using Porter's algorithm [16] before computing their weights.

If no *idf* is used, then the weight of terms of both the query and the hyperlinks could be calculated as their frequencies or their logarithmic scale down (3).

$$w_{ij}, w_{qj} = 1 + \log(tf_j) \quad (3)$$

Where tf_j is the number of times the term *j* appears in the query or in the hyperlink description.

If crawler designer decide to use *idf*, then the term weighs of hyperlinks could be calculated by the traditional ltc scheme.

$$w_{ij} = \left(1 + \log\left(tf_{ij}\right)\right) * \log\frac{N}{n_t} \quad (4)$$

Where *N* is the number of all discovered hyperlinks and n_t is the number of hyperlinks that contain the term *t* in their description.

It should be noted here that in context of crawling we do not have an entire document collection in advance, but it is constantly growing as crawling progresses. So *N*, n_t and the inverse document frequency of a term *t* are constantly changing as well.

The weight of a page w(*p*) could be determined as the similarity between the user-defined criteria (keywords) and the page content. So it could be calculated in the same way like the one between the keywords and the hyperlink descriptions. Additionally the place of appearance of a term inside the page content could also be taken into account when computing its weight. We can assume that words inside titles and headings (h1, h2 and h3 html tags) are actually more informative than the words within the body of the text. So they can get higher weight.

Figure 1 presents a generalized algorithm of a web crawler, used to automatically extract, process and store image URLs. It should be mentioned here that not all image urls are stored but just those of images that meet the pre-defined requirements for data format and size – JPEG or PNG images with aspect ratio > 9:21 and < 21:9, and width higher than 350 pixels. All the other images are considered to be advertising banners, menu buttons and etc.

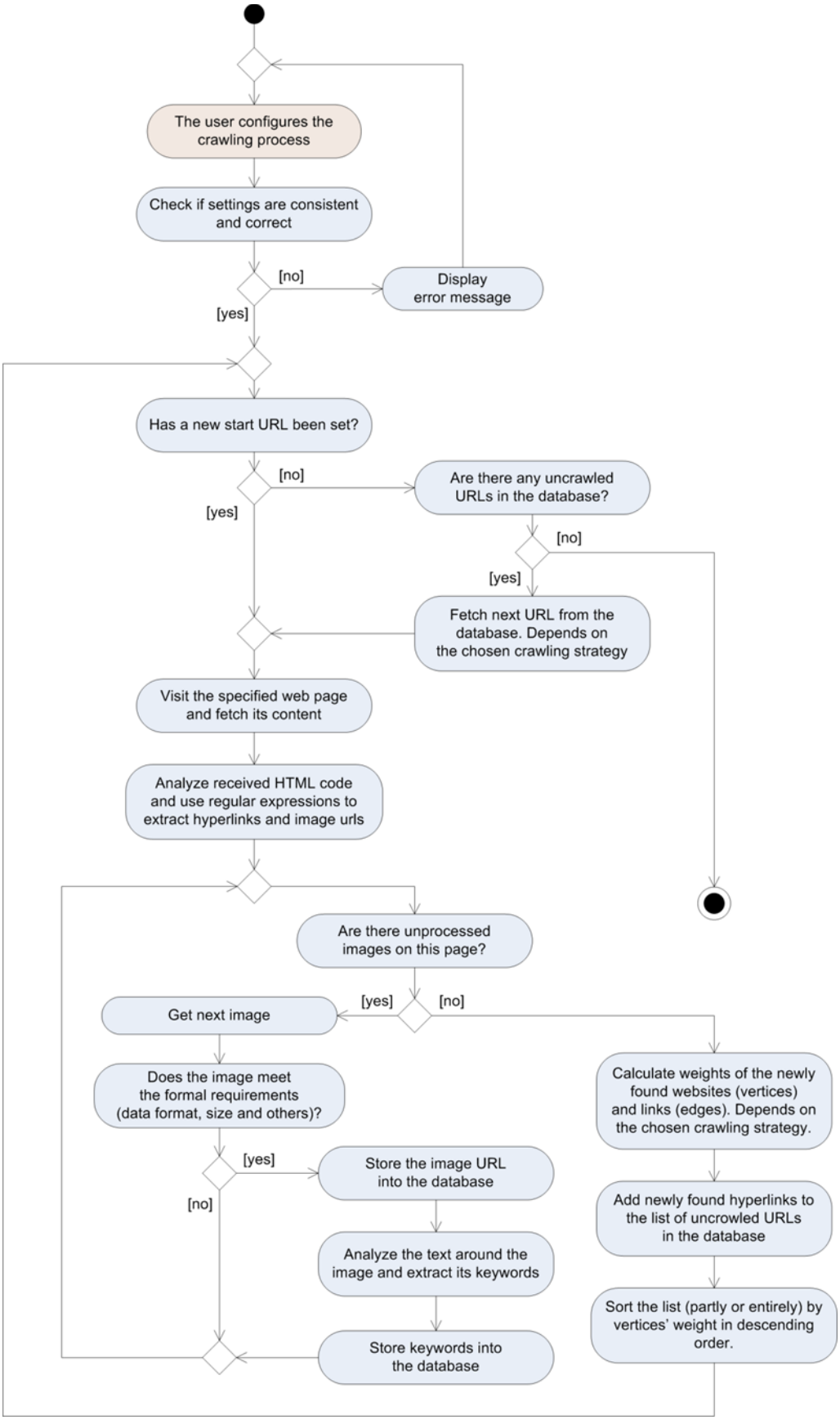

Figure 1. Generalized working algorithm of a web crawler

At the beginning the list of URLs is empty and the user should set up a new starting address. The crawler connects to it and fetches its content including its HTML code. All hyperlinks are located and extracted from the html code, and temporarily stored in the operating memory. The same is done for image URLs as well. Then the crawler gets each image by its URL and analyzes its size and format. If the image meets the requirements, its url is kept within the operating memory until the crawler retrieves its metadata. The latter is done as follows: The HTML code is removed from the page so that just the text left. Then the text is processed by one or more semantic analysis methods (such as latent semantic indexing, vector space analysis employing proper tf-idf schemes and etc.) in order to obtain its keywords. A word could be classified as a keyword based on its meaning, grammatical (lexical and syntax) significance, frequency of appearance in the text, user-specified importance and others. The extracted keywords are actually used as image metadata.

Once keywords are retrieved, they, along with the URLs of the images that meet the requirements, are stored into the crawler's database. Needless to say, keywords and their relevance to the chosen subject domain are also used in calculating the weight of the respective vertex (website). That is why weights are calculated right after the text analysis. Then extracted hyperlinks together with the calculated weights are added to the list of non-crawled vertices/URLs. Finally the list is sorted (partly or entirely) by vertex/website weight in descending order and the crawler continues with the first URL positioned at the beginning of the already sorted list. The first element on the list represents the most perspective website that should be crawled next. Although text analysis and keyword extraction from it are quite time–consuming operations, they are mandatory in order to perform an automatic image classification and categorization. Otherwise there will be complete chaos. The crawler may have downloaded a large amount of images but they are useless if there is no way to automatically determine their content and semantics.

Figure 2 presents an architecture of a web-based crawler used for retrieving images that meet certain requirements for format, size and semantics. As most of the web applications, the crawler implements a 3-tier architecture where user interface, business logic, and data are separated into three functionally-independent non-overlapping layers. That provides easier data replication and portability; higher reliability and flexibility; and allows fast and easy personalization or complete change of the user interface.

The crawler's core functionality is implemented by the following modules:

- ***Web Crawler and Content Analysis*** – responsible for accessing pages on the Internet, fetching and analyzing their content.
- ***Crawling Strategy Planner*** – calculates weights of the graph vertices and edges based on the data provided by the content analysis and image analysis modules.
- ***Image Analysis and Processing*** – checks whether the newly discovered images meet the formal requirements and if so stores them into the local database. Optionally this module can extract and index additional image features such as color content and its spatial distribution.
- ***Crawling Statistics*** – maintains and provides real-time statistics about the crawling process and its progress.
- ***Settings*** – Allows administrative users to manage the entire crawling process in details.

Once the user sets up the crawling and the indexing processes, and provides a starting URL, the spider starts working. It visits every web page, analyzes its HTML code and extracts hyperlinks, image URLs and keywords from it. Image URLs are passed to the "Image Analysis and Processing" module that checks their format and size, and decides if they meet the requirements and should be stored into the local database. Similarly, hyperlinks and keywords are sent to the "Crawling Strategy Planner" that calculates the weights of the current and the newly discovered vertices (web pages) of the graph. Then again the Crawling Strategy Planner adds the newly extracted URLs to the list of unvisited ones and sorts the list by vertices weight in descending order. Sorting could be done partially or entirely based on user settings and the chosen crawling strategy. After processing the current vertex (web page), the "Web Crawler and Content Analysis" module deletes it from the list of non-crawled URLs and continues with the next one. As the list is sorted by weight in descending order the next vertex represents the page evaluated as most perspective by the "Crawling Strategy Planner". All these activities are cyclically repeated until the user stops the crawler or the list of unvisited URLs gets empty.

V. CONLUSION

Millions of images are uploaded to the Internet every day by people all over the world. To be useful however these images should be easily discoverable and accessible, i.e. they need to be organized and indexed in a way that will allow fast subsequent search among them.

The World Wide Web represents an enormous directed cyclic weightless graph that features an extremely high rate of change. Blind (brute force) crawling of such structure is literally impossible and it cannot finish in a reasonable amount of time. Thus searching should be navigated by proper heuristics in order to reach efficiency in retrieving useful resources. To achieve that the graph should be converted from weightless to weighted one by introducing vertices weights. We propose that in focus crawling, the weight of a vertex (newly discovered hyperlink) should depend on: the semantic similarity between its description and the user-defined search criteria (keywords); and the importance of its referrer. Additionally the importance of the referrer can also include its number of visitors and rate of change.

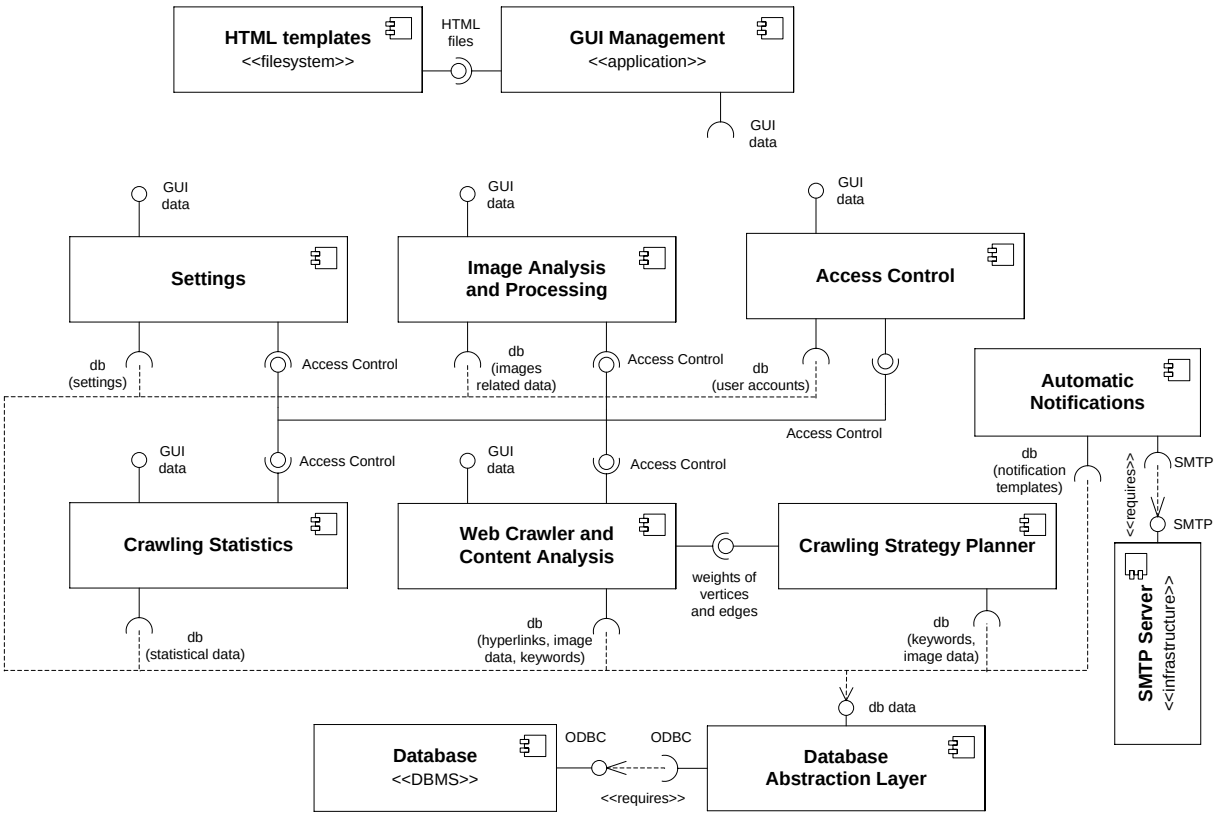

Figure 2. Architecture of a web-based web crawler

We have implemented a web crawler that we use to build and maintain our own image database (imdb). Its primary objective is to provide us with a large enough dataset for testing various content-based image retrieval (CBIR) techniques, methods and algorithms. However our crawler implements a breadth-first search strategy that is an exhausted search crawling rather than focused one. We will soon modify it according to our suggestions presented in this paper. Then we will perform a comprehensive experimental evaluation to determine the most suitable term-weighting schemes. Results will be presented in another paper that will be entirely devoted to experimental evaluation of the proposed focused web crawler.

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Spatial data integration in heterogeneous information systems' environment

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Abstract **- Development of a spatial decision support system requires integration of various spatial data sets coming from different information systems of possibly more than one organization. The spatial decision support system development for spatial planning and environmental protection is discussed and spatial data integration is described. The heterogeneity of information systems from which spatial data come is reflected through their purpose. Utility and real estate cadaster systems imply services to citizens as part of spatial data infrastructure in the Federation of Bosnia and Herzegovina. The spatial planning information system is intended for registration of environmental changes and spatial decision making. Utility cadaster information system development is described along with important aspects on how to satisfy both functional cadastral services and spatial planning experts needs to analyze information related to land use and network supply systems. Particular attention is given to spatial data transformation for utility cadaster database development in accordance with a prescribed data model.**

Keywords - Spatial Data Integration, Data Transformation, Utility Cadaster, Real Estate Cadaster, Spatial Planning, Spatial Decision Support Systems

I. INTRODUCTION

Recent trends related to the widespread availability of geoinformation have a direct impact on the quality of work of all organizations, especially on administration and those involved in providing public services. The current availability of digital geospatial data in Bosnia and Herzegovina (BiH) is a result of several successful projects over the past decade: digitization of geodetic cadastral plans and land registry data, land registry and real estate cadastre, implementation of a unique software for maintaining a real estate cadastre database (RECDB) "katastar.ba" and land register "e-grunt", development of reference GNSS stations network - BIHPOS, preparation of a map data for population census 2013, development of spatial plans at entity, cantonal and municipality levels, implementation of photogrammetric and LiDAR data collection covering large areas, IT equipment for local government and strengthening of their administrative responsibility, Local Development Improvement, and various activities related to the INSPIRE EU Directive. There is also a growing need for access to available geoinformation by civil servants, centralization of data, better interaction between officials using information exchange (messages and tasks), and use of uniform methodology and geoinformation technology in all administrative organizations [1]. In order to use available geoinformation (digital cadastral data, spatial planning documentation, digital orthophotos) and meet operational needs, it is necessary to support business processes through the development of centralized spatial information systems [2][3]. BiH has specific administrative and political organization. It consists of two entities, Federation of Bosnia and Herzegovina (FBiH) and Republika Srpska (RS), and one district – Brcko District. Furthermore, FBiH is divided into cantons, and each canton consists of municipalities and cities. The Federal Administration for Geodetic and Property Legal Affairs (Federal Geodetic Administration – FGA) has jurisdiction over the FBiH territory. It carries out tasks related to establishing and updating of real estate cadastre (REC) and utility cadastre (UC), as well as development and maintenance of accompanying information systems. FGA has established several data models that are available to a wider user community in the following form: Topographic Data Model (TM): UML Application Schema and Catalogue of Objects; Data Model of FBiH Real Estate Cadastre Database (RECDB): UML Application Scheme, Catalogue of Objects [4] and GML Schemes, and FBiH Utility Cadastre Data Model: UML Application Schema and Catalogue of Objects [5][6].

According to the Law on Cadastre of Utilities [7], Utility Cadastre is a comprehensive technical record of - surface and underground communal installations. Communal installations are networks of water supply, sewerage, telecommunication, power supply, remote heating, gas pipeline, traffic power supply, and other special networks (liquid fuels, salt water transport etc.) with associated facilities, tunnels, warehouses, pedestrian passes, underground garages, cellars etc. According to the Rule book on the Development and Maintenance of Cadastre of Utilities [8], the development and maintenance of utility cadastre is under the authority of a local government, while supervision of development and maintenance is performed by the Federal Geodetic Administration. There is a clear trend of increasing local government interest in establishing this cadastre, especially after the creation and adaptation of a data model for its development. The Ministry of Spatial Planning and Environment Protection of the Tuzla Canton (MSPEP) carries out tasks related to spatial planning, environmental protection, issuance of urban-technical documentation, as well as support for land survey and

maintenance real estate and utility cadastre within its jurisdiction. With the FGA technical assistance, the Ministry has initiated the project to develop a utility cadastre unified software solution in 13 municipalities.

The aim of the project was to provide up-to-date information on communal installations in order to carry out further spatial analysis, planning and environmental protection. Main tasks were development and implementation of solution including application and database for UC according to the data model prescribed by FGA, and in accordance with the Law on cadastre of utilities. Also, it included tasks like migration of existing digital data into the UC information system, including all received utility survey elaborates in municipalities; integration of UC with RECDB in all locations (13 municipalities and MSPEP); training municipal cadastre and Ministry staff; and upgrading the existing information system in the Ministry with the WebGIS component. This paper partially describes the implementation with a special emphasis on spatial data transformation for the purpose of the utility cadastre database development in accordance with the prescribed data model.

II. SPATIAL DECISION SUPPORT SYSTEM FOR SPATIAL PLANNING

Space is a resource subject to many influences and changes. Changes need to be continuously monitored and both timely and efficiently addressed by appropriate measures and activities. Spatial planning, as part of such measures and activities, is complex process based on the principles of scientific achievements in the field of urbanism, spatial planning, geospatial analysis, ecology and other disciplines, as well as on the standards of development and legal regulation. Contemporary spatial planning is characterized by the application of geographic information systems (GIS) in planning, spatial analysis, decision making, maintenance and monitoring.

Spatial decision support system (SDSS) are in a nutshell integrated computer system that support decision makers in an interactive and iterative way with functionality for handling spatial and nonspatial databases, analytical modelling capabilities, decision support and information presentation utilities. The SDSS solution is often developed with easy-to-use graphical user interface and functionality for spatial database management and analysis, scenario evaluation, modelling, visualization through maps, graphs, tables, and report generation. According to this, we can recognize four main components of the system: database management system, analysis procedures, display and report generator, and user interface [9]. The SDSS application in spatial planning includes development of transportation and traffic models, population models, determining service and commercial premises locations, energy and water consumption, water production, etc. There are three specific areas of interaction between information technology and spatial (urban) planning: the structure of computer systems used for urban planning, the modelling of urban planning data using GIS, and the models as the major components of spatial decision support system [10]. Spatial database design is very important to the development of planning support systems, since a GIS system should be built on standard components. The components rely on a spatial database as a foundation for editing, analysis, simulation, and visualization functionality [11].

A. *Information system for spatial planning and environmental protection of Tuzla Canton*

Experience in applying the Geographic Information System (GIS) as a tool for spatial planning and decision making in the Tuzla Canton has been gained during the past two decades or since the development of the first spatial plan of the canton. Due to this, the Ministry has a certain level of IT infrastructure that includes: ICT infrastructure (servers, network equipment), GIS (MapInfo Professional, Oracle Spatial) and spatial data sets (orthophotos, spatial plans, urban data). Spatial plans are in MapInfo (.tab) and DBMS (Oracle Spatial), and attachments in Word (.doc) or in Acrobat (.pdf) formats.

Spatial database is administrated with MapInfo Pro, which through Oracle Call Interface (OCI) directly communicates with the Oracle database and accesses data without middleware and enables conversion to and use of BiH national coordinate system, use of the GML format prescribed by FGA for RECDB and other local formats, and use of the temporal schema in the database. The Land Use and Planning Information System (LUPIS) represents a unique information system in spatial planning, land use and environment protection for all administration levels. It is a website with the unified entry and reporting formats according to the "Regulation on Content and Carriers of the Unified Information System, Methodology for Collecting and Processing Data, and Unique Forms for Records" prescribed by the FBiH Government [12].

B. *Development of the WebGIS component for spatial decision-making support*

Development of the information system for spatial planning includes development of a WebGIS component that should provide the review of data from the UC and the existing LUPIS for the Tuzla Canton area. This component should be in the form of an online interactive map showing land use data from the RECDB, network supply systems from the UC, orthophotos and spatial plans. As a solution for spatial planning data presentation and decision making WebGIS portal (Figure 1) is used. It provides an overview of vector and raster map data, thematic (text, tables, diagrams) data and related documents, enabling the data search, selection, distribution (review and download), publishing, administration and information feedback from users.

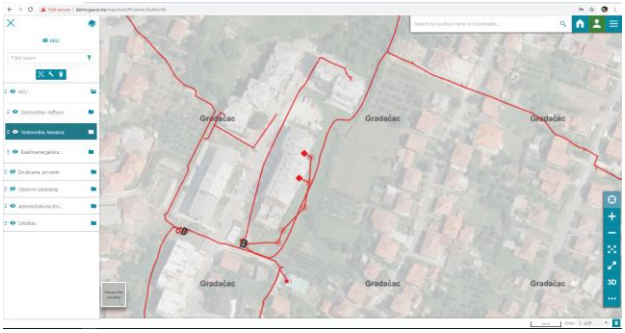

Figure 1. WebGIS portal with network system

III. CADASTER INFORMATION SYSTEMS AND SPATIAL DATA INTEGRATION

As shown in Figure 2, up-to-date land use and official orthophoto data should come from the real estate cadastre managed by FGA, utility data from municipal cadastral services, and spatial and urban plans from the spatial database of the Ministry. In terms of data integration, these are three heterogeneous information systems communicating with each other at various administrative levels (entity, canton, municipality), which are managed by various administrative organizations (FGA, the cantonal ministry, municipalities). Their architecture is scalable and ranges from classical distributed IS architecture with central database and desktop applications user interfaces to service-oriented architecture with Web services.

A. Real Estate Cadastre Information System in FBiH

In mid-2013, the Federal Geodetic Administration implemented and released unified software for the real estate cadastre of the FBiH "Katastar.ba" enabling real estate data for the Federation of Bosnia and Herzegovina to be available over the Internet. The software solution has standardized maintaining of digital cadastre plans, as well as providing data through a unified application at the Federation level. The basis for the successful implementation of the unified software for the cadastre of the FBiH was the realization of the project for development of the Real Estate Cadastre Data Model in 2012, and design of the Topographic and Utility Cadastre Data Model.

The "Katastar.ba" is used daily by municipal cadastre employees and is maintained by the FGU in both technical and functional sense. FGA has decentralized organizational structure, meaning that municipal cadastres are primarily responsible for the maintenance and distribution of cadastral data. The cadastral IS has a homogeneous distributed system architecture where data is replicated to a central location in FGA (Federal and Local Community Levels in Figure 2). Oracle 11g DBMS is used on all levels, and the system consists of desktop applications for graphic processing and web application for process management.

B. Utility Cadastre Information System Development

As the solution for updating utility cadastral data, the project has developed the application with tools for entering, maintaining and exporting data in accordance with the data model (Figure 3). The solution supports functions like CAD / GIS drawing tools and Data Import / Export Tool in standard CAD / GIS formats (AutoCAD, MicroStation, MapInfo, Esri, ...). All data is stored in central database (DBMS) with data replication to databases in FGA and Ministry; and it is possible entering data individually or importing data groups (bulk import of the entire surveying elaborat). Also, there are functions for protocol management; and report generation using selection from the database by drawing a line or polygon. User can review data from other information systems (municipal cadastre and spatial planning department), and integration of utility data with other databases or web services (orthophoto, BPKN, official maps) (Figure 4).

System implementation included modelling and reengineering of business processes, functional and non-functional system specification, system design (system and software architecture, data model), application development, software installation, spatial data collection, ETL existing data, metadata input, user / system administrator training, and maintenance. The project uses OSS technology for application and database development, due to its good performances and low initial costs.

C. Spatial data integration

A special challenge during the project implementation was the conversion and transfer of existing spatial data into the central database, and the transformation of the utility cadastre data from various formats into the prescribed data model. This was also the case with elaborates of utility cadastre for 13 municipalities of Tuzla Canton. The spatial data integration required development of both the concept and the detailed ETL migration and validation plan for existing digital data in the utility cadastre system. It also required designing a solution for accessing data from other information systems.

Spatial data integration is a process that involves collecting data from different sources at different collection modes and unifying them in the database to provide a unified environment for processing, modelling, and visualization [13]. Integrating different data sources into a single database is a database-level integration, which involves converting data from different formats, projections, or reference systems, and adapting them to a data model. Accessing data in an application environment without their permanent and physical placement in a database according to a data model, is integration at the application level, which is most effectively solved by

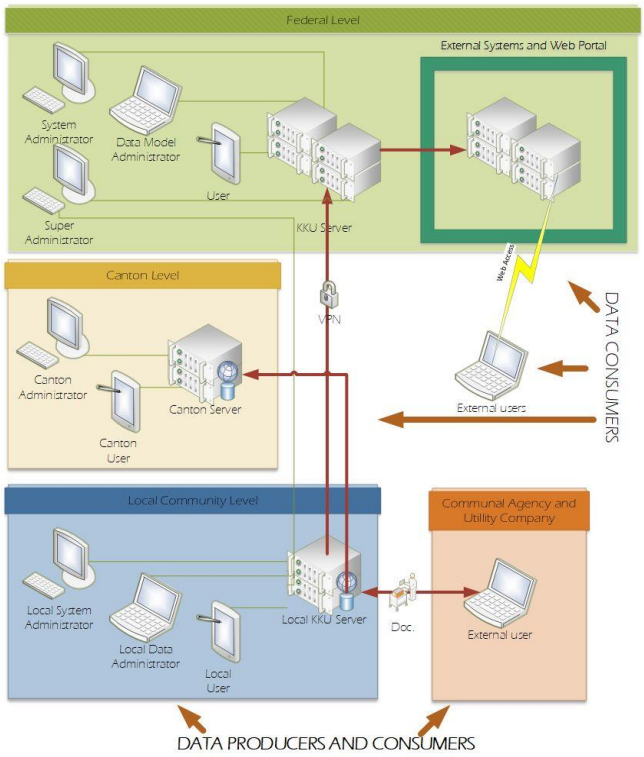

Figure 2. Heterogeneous information systems' environment with three administration levels

accessing the data via the Web services. In this project the data integration considers both integration levels.

Storing data in a single database according to a given model requires considering a number of issues related to the data besides the heterogeneity of formats, projections, and reference systems, related to the data syntax. Addressing these issues requires experience in working with the data and familiarity with their context. Semantics data problems related to data integration and exchange are much more difficult than data syntax problems that are more technical in nature. These problems are related to the particular use, language, perception, representation and many other differences that are typical for application of spatial information in a given environment. Overcoming these problems requires the use of more expressive geoinformation concepts and better standards [14].

Further, regardless of a format used, data users are not always sure of the accuracy and precision of the information they receive. Data from a variety of sources, which can easily be combined and integrated, may be incompatible in terms of different quality. Differences in geometric and topological quality may be due to the use of different collecting methods, accuracy, resolution or standards [15]. Data should often be harmonized so that they are uniform at the geometric and classification quality level. The consequence of data harmonization standards development is the use of metadata. The information about a source, collection method, resolution, model and data type is mandatory and stored into the database. This makes it easier for users to estimate whether the data provided is suitable and reliable for their needs [16].

Throughout this project it was necessary to ensure that spatial planning experts have access to spatial data sets and tools for a visualization at the application level, including spatial plans, administrative boundaries, demographics (from own database), official maps and orthophotos, cadastre real estate (from the FGA database) and utility cadastre (from municipal database). Municipal officers from the cadastre department, in addition to accessing official maps, orthophotos and real estate cadastre data at the application level (from the FGA database) should also have appropriate tools to maintain the utility cadastre supporting previously mentioned functions. Figure 2 shows the links between the information systems at all three administrative levels, data flow enabled with WebGIS application (Figure 1) and application for utility cadastre (Figure 3) developed throughout this project.

IV. DISCUSSION

The project included tasks like making the inventory of available data in municipal cadastres; analysing the data model and proposing data transformation procedures; recognizing the external data sources and offering options for access to this data; and proposing the design for web solution and utility cadastre application, including access to data sources. Table 1 provides an overview of installations by type of network and municipalities / town of Tuzla Canton, with total values shown in kilometres. A total of 1585 elaborates is processed for 9 different types

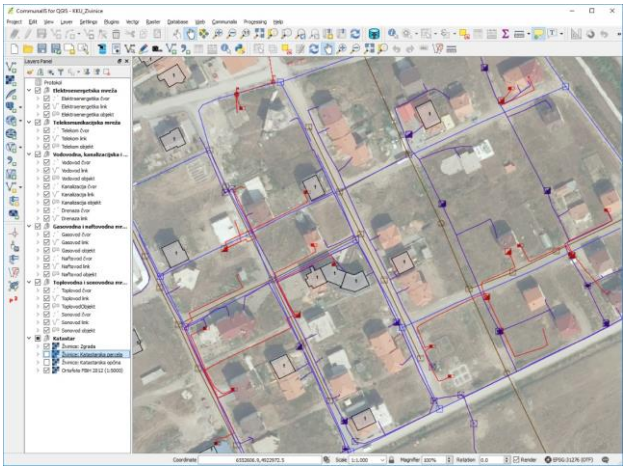

Figure 3. Application for updating utility cadaster data

of utility networks. Original data was topologically unordered, mainly in CAD (.dwg) format (about 97%), while only a few elaborates were in the GIS (.shp) format. The owners of the installations (utility companies) engaged geodetic companies for geometry surveying and preparation of elaborates, which were delivered to the municipal cadastral services, and the Federal Geodetic Administration has supervised the execution of these tasks. Geodetic companies provided data structured in a variety of ways, so there were over 30 different dataset structures. In some cases, the same company had several different ways to structure these data, depending on individual operators.

Pursuant to Article 38 of the Law on Cadastre of Utilities (Official Gazette of SR BiH, No. 21/77) [7], in 1978, the Republic Geodetic Administration of the Republic of BiH drafted the Rule book on the establishing and maintenance of Cadastre of Utilities [8]. As previously mentioned, this cadastre should be established by the individual municipalities, however, due to the efficiency of its implementation, the Federal Geodetic Administration adopted unique data model in 2013. The object catalogue is designed according to the ISO 19110:2005 (Geographic Information – Methodology for feature cataloguing) and meets class of compliance for Attributes and associations. The names of the feature types and the attributes are specified in the natural

TABLE I. OVERVIEW OF UTILITY NETWORKS IN TUZLA CANTON AREA BY MUNICIPALITY AND BY TYPE

Municipality	Power Supply [km]	Telco [km]	Water Supply [km]	Others [km]	Total [km]
Banovici	28.8	50.0	2.6	2,3	83.7
Celic	13.2	60.0	5.5	10,4	89.1
Doboj Istok	4.7	8.1	0.0	0,0	12.8
Gracanica	17.3	119.5	127.9	53,6	318.4
Gradacac	21.4	131.0	131.0	148,0	431.3
Kalesija	0.0	0.0	192.7	0,0	192.7
Kladanj	6.2	13.4	0.0	0,8	20.4
Lukavac	57.2	232.5	37.1	38,2	364.9
Sapna	10.9	45.2	0.0	0,5	56.6
Srebrenik	34.5	271.8	1.7	3,4	311.3
Teocak	1.5	23.8	16.3	0,0	41.6
Tuzla	50.5	193.2	23.7	53,6	321.0
Zivinice	65.5	78.0	7.2	24,0	174.9
Total	311.8	1226.4	545.7	34.1	2418.6

language and are followed by the data type - domain of attribute values. Other standards used for the development of the catalogue of objects are: ISO/TS 19103: 20005, Geographic Information – Conceptual schema language, ISO 19107: 2003, Geographic Information – Spatial schema, ISO 19109: 20005, Geographic Information – Rules for application schema, ISO 19115:2003, Geographic Information – Metadata, INSPIRE Generic Conceptual Model and INSPIRE Generic Network Model [6]. The application scheme of utility cadastre formally describes the structure and content of data to be met by all utility cadastre applications in FBiH (Figure 5), ensuring the unambiguity and consistency of the representation of data model for development of cadastral applications [5].

During the implementation of the project, special attention was given to the transformation of spatial data for the development of utility cadastre database in accordance with the prescribed model. All the aforementioned elaborates' spatial data are converted into a convenient form for entering into the database. Also, maps had to be scanned, georeferenced and then vectorized. There was a rather small amount of data in digital format that only required model compliance verification and minimal correction.

Data transformation procedure implemented several additional steps while migrating data into the database. First, clearing downloaded .dwg files to keep only the content of the utility cadastre elements. Then, editing the contents of the drawing (e.g. getting centroids for complex graphic objects with blocks). Then, polygonising the objects presented by a line content with created hatch. After conversion goes deleting duplicate content and identification of the network characteristics (type of network, pipes, cables, materials, diameters etc.) and input of attribute data. Important step is processing information about the elaborate and the contractor associated with the line content, as well as other metadata about data quality. This information may be useful later in the case when it is necessary to determine author of report. At the end is detailed control of the entire converted content.

As mentioned above, web services have been used to access data at the application level. The developed WebGIS solution (Figure 6) as a component of a spatial planning decision support system represents geoportal that provides the entry point for access to all data required by

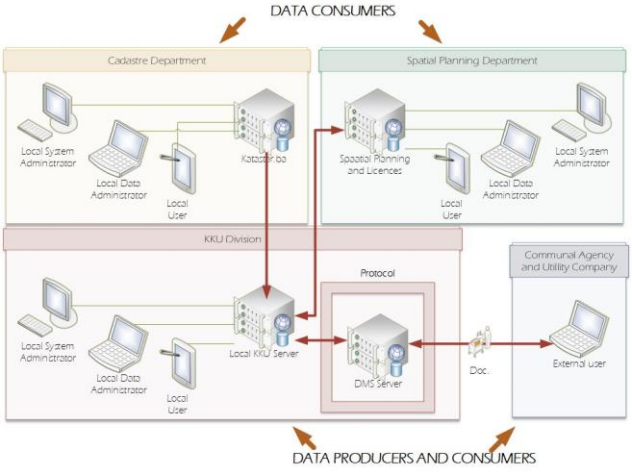

Figure 4. Data flow between different ISs at municipal level

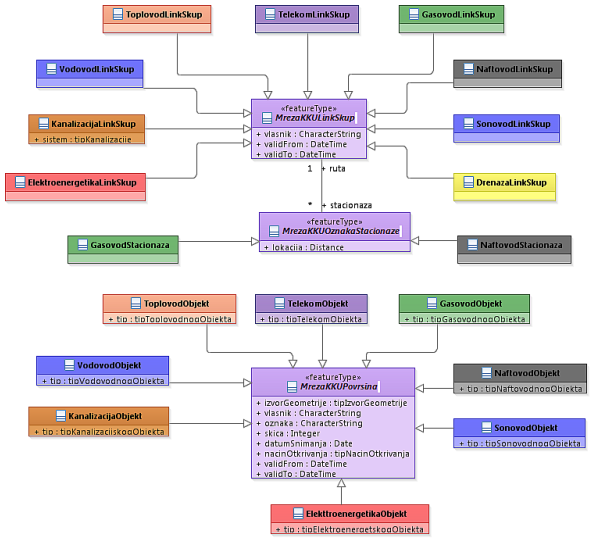

Figure 5. Utility Cadastre Data Model (UML Application Scheme)

spatial planning experts. Its upgrading and further development at three levels of functionality is proposed: as web services platform, as enterprise geoportal, and as spatial data warehouse [17]. Currently there are established Viewing services (Web Map Service WMS and Web Coverage Service WCS) and Download service (Web Feature Service WFS), which are significant for municipal spatial planning departments. At the federal level, WMS, WCS and WFS web services are available and provide access to real estate cadastre, official maps, administrative boundaries and orthophotos to all users at the local and cantonal level. They are accessed through the developed Web and Desktop GIS applications. Table 2 shows the ways of accessing spatial data achieved through their integration.

TABLE II. SPATIAL DATA ACCESS

Users	Spatial Data Set	Administration Level	Way of Data Access
Cantonal spatial planners and decision makers	Spatial plans, demography, statistics data, urban data	Cantonal	Own database
	Official maps, orthophotos, administrative boundaries, real estate cadastre	Federal	WFS, WCS, WMS
	Utility cadastre	Local community	WFS
Real estate and Utility cadastre municipal officials	Official maps, orthophotos, administrative boundaries,	Federal	WFS, WCS, WMS
	Real estate cadastre, Utility cadastre	Local community	Own database
Municipal spatial planners, Communal and utility companies' staff	Official maps, orthophotos, administrative boundaries, real estate cadastre	Federal	WFS, WCS, WMS
	Spatial plan, urban data	Cantonal	WFS
	Utility cadastre	Local community	WFS
FGA officials	Utility cadastre	Local community	WFS

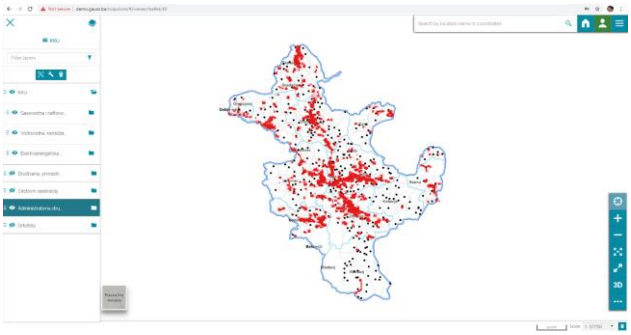

Figure 6. WebGIS portal: View of utility cadastre data of all municipalities in the canton

The architecture proposed for the realization of the GIS platform has been created using a fully-open geospatial software stack for publishing data on the web including the following software components: PostGIS (as robust spatial database system), GeoServer (as map and geospatial data server), GeoExplorer (as browser-based tool commonly used to view, navigate, and manage data, either locally or remote. It is built upon OpenLayers and GeoExt, two JavaScript libraries for building geospatial applications), GeoWebCache (as server that accelerates the delivery of map images by pre-drawing and caching) and QGIS (as desktop-based tool for viewing and interacting with geospatial data and maps). User interface is intuitive and simple to learn, as shown in Figure 6.

V. CONCLUSIONS

This paper describes the upgrade of the cantonal spatial planning information system with the spatial decision support component. One of the tasks of the project was the development of a uniform application for updating cadastre of utilities including database development according to the prescribed data model. A particular challenge was the integration of spatial data gathered from different sources: existing information system of real estate cadastre and poorly structured cadastral records on utilities from municipal cadastral offices. The heterogeneity of information systems, from which spatial data originate, can be observed through their communication at various administrative levels (entity, canton, municipalities), and through different administration responsibility (Federal Geodetic Administration, Cantonal Ministry of Spatial Planning and Environment Protection, Municipal Cadastre Offices), and also their scalable architecture ranging from distributed system with desktop applications to service-oriented one with Web services. This has resulted in two different integration approaches related to access data: integration at the application level and integration at the database level.

In addition to solving the heterogeneity of formats, projection and reference system, which is a matter of data syntax, migrating data to a single database required answering questions related to the presentation of the data, their accuracy and precision, and other characteristics of their geometric and topological quality. This resulted in a specific handling of data transformation that was carried out while migrating the data to the database. Considering this, there is still a strong need for the development of new concepts and geoinformatics standards for the harmonization of data, as well as promoting existing standards and their wider application. By adopting and applying the unified data model of utility cadastre, developers have freedom to choose approaches, tools and technologies for the development of application solutions and information systems with a focus on their efficiency, affordability and quality of maintenance. Additionally, upgrading and improvement of the WebGIS application at the levels of web services platform, enterprise geoportal, and spatial data warehouse is proposed, enabling wider application of Web services as a highly efficient way of accessing data.

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Version control features for versioning-required documents within relational databases

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***Abstract* – Version control systems, such as Git, successfully manage tracing changes within files. Advantages of the Git system are cryptographic authentication of history, branching capabilities, distributed development, etc. Even though those systems are sophisticated considering the file versioning they are limited regarding the support for other data structures. Often we are faced with the challenge of versioning relational data structures since the file structure is not always adequate storing structure. Database management systems do not offer explicit versioning of target data structures. Some aspects of version control might be used implicitly. In this paper, we will explore the possibilities of supporting version control features for versioning-required document files within with relational databases.**

I. Introduction

The majority of creative people start a project without having a back-up strategy [1]. Since digital data is fleeting and can be easily lost, the loss of important data without having a backup solution can be painful and in some cases financially burdening. Furthermore, for certain types of data, it is important for the user to have access to versions of data before certain changes. Version control, also known as source control or revision control is the process of managing multiple versions of a piece of information [2].

Many people perform version control by hand: they save every modification of a file under a new name that contains a number, each one higher than the number of the preceding version [2]. The use of a manual approach can be time consuming and is much less error-tolerant, as users can often mistakenly rename a file using a wrong name or delete it. Various tools have been created for the automation of this task aiming to reach more efficient version management.

Versioning tools mostly work within the file system, taking into account the hierarchical structure of directories and files. However, data or files that we work with and their versions we want to store are often not just independent units, but are linked in a relational data structure. Relational databases, which are traditionally used in the case of relational data structures, have limited support for data versioning. In this paper, we will consider the options of integrating version control systems with relational databases in order to take advantage of the best features of both.

The structure of the paper is as follows. In Subsection II-A, version control systems are presented. Different solutions for versioning within relational databases is detailed in Subsection II-B. The main contribution of the paper is presented in Section III with the proposed solution detailed. Section IV provides a final remarks and future research directions.

II. Related works

A. Version control

We can define a version control system as a system that tracks incremental versions (or revisions) of files and, in some cases, directories over time [3]. It must provide three important capabilities: *reversibility*, *concurrency*, and *annotation* [4]. Beside tracking incremental versions of files, many version control systems offer support for branching (see Figure 1). Branching can be defined as tracking parallel changes to the same codebase (file) [5].

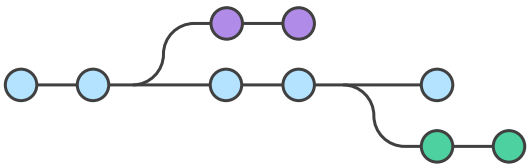

Fig. 1. Git branches [6]

We can divide the history of version control into three generations (see Table I). From the first generation, where concurrency was handled only with locks, version control has progressed to separation of merges and commits [7].

TABLE I
Three Generations of Version control [7]

Generation	Networking	Operations	Concurrency	Examples
First	None	One file at a time	Locks	RCS, SCCS
Second	Centralized	Multi-file	Merge before commit	CVS, SourceSafe, Subversion
Third	Distributed	Changesets	Commit before merge	Bazaar, Git, Mercurial

One of the oldest version control systems is Concurrent Versions System (CVS) [8], developed by Dick Grune in 1986 [1], [9]. Its primary focus was on solving concurrency problems in projects with multiple people working together

on a set of files. It is based, as well as most of the later solutions, on the concept of abstract data types – repositories. CVS was developed in the form of UNIX shell scripts and uses RCS programs as version control primitives. Despite the fact that CVS is the oldest, many newer systems are compared to it [9].

Subversion (SVN), introduced around 2001, has quickly gained popularity. The most significant differences in comparison with CVS were atomically committed changes [1] and better support for branches.

One of the most widely used version control tool today is Git, invented by Linus Torvalds to support the development of the Linux Kernel [1].

B. Versioning in relational databases

There are several views on the versioning challenge within relational databases and approaches to address them. Most approaches are based on a specific method of modeling a database rather than technical changes to the database management system itself.

In data warehousing *Slowly Changing Dimensions* (SCD) are not changed on regular basis but change slowly and unpredictably, while some changes can cause referential integrity problems [10], [11]. Kimball *et al.* [12] define set of methods to manage SCD which are known as *Kimball Types*. If we take into account the similarity between the SCD problem and the data versioning problem, we can conclude that Kimball's Types could also be used for versioning in relational databases.

When using Kimball's Type 1 (*Overwrite the Value*) we merely overwrite the old attribute value in the dimension row, replacing it with the current value (see Table II). Despite relatively simple implementation, it is obvious that the major issue of using such a data storage method does not support preservation of previous versions of individual data.

TABLE II
SCD TYPE 1

ID	Department_name	FK_supervisor
14	Human Resources	255

ID	Department_name	FK_supervisor
14	Human Resources	367

Kimball's Type 2 (*Add a Dimension Row*) approach creates additional row for each change (see Table III). By using Type 2, all versions of data remain preserved and unchanged. Nevertheless, there is an issue in grouping all versions of a particular data, since each version has its own key, and the versions are not related to each other. In addition, the temporal dimension of each version of the data is missing.

TABLE III
SCD TYPE 2

ID	Department_name	FK_supervisor
14	Human Resources	255
18	Human Resources	367

Type 3 (*Add a Dimension Column*) adds an additional column to the table, which contains the previous value of the specified data (see Table IV). Similar to Type 2, all versions of data remain preserved, however, the temporal dimension is missing.

TABLE IV
SCD TYPE 3

ID	Department_ name	FK_ supervisor_ prior	FK_ supervisor
14	Human Resources	NULL	255
18	Human Resources	255	367

In addition to three basic types, Kimball *et al.* [12] define also Types 4, 5, 6 and 7. Type 4 adds an additional history table, where the original table keeps the current data, the history table contains all changes with the changes timestamped. The remaining types combine previous ones with addition of start and end dates as well as boolean flags which mark current and previous versions.

Change data capture (CDC) design patterns [13] use similar approach while adding timestamps or version numbers to table rows.

A related solution can also be found in the use of bitemporal databases [14] which distinguish between two dimensions of query tuples: *validity time* and *transaction time*. Bitemporal databases offer easier integration since such system already acts as one component, however, bitemporal data tends to increase in size as various versions of data accumulate over time.

Also, some DBMS offer the database snapshots functionality which captures the current state of the entire database and saves it to a separate location. This paper focuses on a specific case of versioning the document files that are simultaneously associated with the relational data structure.

III. PROPOSED SOLUTION

In larger systems, we often need to track versions only of some data, usually documents. At the same time, that data is part of a larger, usually relational, structure. Using version control system for entire data structure is not always possible since the majority of those systems work with the hierarchical structure of directories and files.

One option is to use Kimball Types, which can practically provide a solution to the versioning problem. The problem that may arise is mainly reflected in duplication of rows (when using Types > 1) and the active intervention in the database structure (when using Types > 2).

Duplication of rows is problematic mainly considering a querying process, since using Type 2 [12] do not provide a reliable attribute that would define information which row is current and which is "historical". If we assume that the primary key is a strictly auto-increment, we can claim that the current line is the one that has the highest value of the primary key (see Figure 2).

In tables containing rows from different categories despite a guaranteed auto-increment of the primary key, we can

```
SELECT FK\_supervisor
FROM Department
WHERE ID = (SELECT MAX(ID) FROM
    ↪ Department);
```

Fig. 2. SQL Query: trying to select newest row

not know which is the most recent value of an individual attribute in a particular category. We can only provide this if there is an unchangeable attribute (a [foreign] key) by which categories can be grouped. If we intend to group by an attribute that does not have the properties of a key, it may result in our query becoming irrelevant when the value of that attribute changes (in our example, *Department_name*).

Using Type 3 [12] adds a certain advantage in terms of identifying the newest row, compared to Type 2 [12], although this query becomes more complex to a certain extent. The easier task is to find out which row is the oldest – the one that has the *prior* attribute value set to `NULL`. Finding the newest row is a bit more complicated, since we have to find to which row none of the other rows are linked by using the *prior* attribute – in this problem, we can quickly see recursion, which is definitely wasteful from the optimizational point of view. The grouping problem remains unchanged, only the possibility of grouping into "chains" appears by using the current and *prior* keys.

Using history table in Type 4 [12] solves most of the aforementioned problems: the complexity of queries is slightly reduced and there are no more problems finding the current row. The new issue that arises is increased complexity of inserting new rows – next to normal data entry it is required to properly handle the previous data. This can be solved either programmatically, either by using a trigger in the database.

Higher types use start timestamps, end timestamps and *current* flags, which to some extent simplify queries since we can eliminate recursion. However, the problem of adapting the structure of the database remains, as we lose the "clean" database model.

Given that relational databases well resolve the problem of storing data with relational data structure, but they were not designed for versioning document data (for which the Kimball's Types can provide a sufficient rather than the ideal solution), and on the other hand, the version control systems are good solution for the problem of data versioning, but are not able to effectively store data with a relational data structure, for the specific problem of storing document data that are part of a relational data structure, we can propose the following solution.

Assume that we have a diversified data model that does not require versioning for most of its tables, but there is a table that has an attribute in which we store (structured or non-structured) document material. To store document material, we use a version control system, Git in our example, and one attribute for file referencing in our corresponding table within relational database.

The table in relational database (see example provided in Table V) retains its original structure, the only supplement thereto is a column that contains a reference to versioned file in version control system.

TABLE V
TABLE WITH REFERENCE TO GIT REPOSITORY

ID	Department_ name	FK_ supervisor	Manifesto
14	Human Resources	255	m/hr.xml
19	Finances	345	m/f.xml

In the version control system, we prepare a system of directories and files (which need to be versioned) that structurally corresponds as closely as possible to the tables in the relational database or it is logically organized in any other form allowing easy access (see Figure III).

```
m/
– hr.xml
– f.xml
– ...
d/
– ...
⋮
```

Fig. 3. File and folder structure in Git repository

Using the file path (we can make a HTTP request: `GET /projects/:id/repository/files/:file_path`) allows us access to all metadata about the file including size, encoding, reference to previous commit, etc. We can access the content itself by adding `/raw` to the file path.

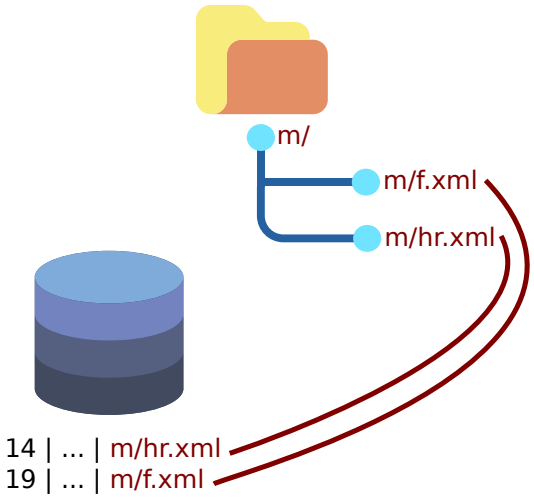

Fig. 4. Using file paths in database for referencing associated files in Git repository

The usage of this method of storing data is possible without any additional software, but can quickly lead to inconsistent maintenance of links between the relational database and Git repository. For this reason, it is advisable

to develop and deploy special software that would take care of the synchronization between the two storage systems mentioned above.

IV. Conclusion

The problem of data versioning is not rare. Moreover, it is often present within file systems. Therefore, in most cases, developers are the most common users of version control systems. Nevertheless, developers are not the only users of version control systems. In use cases we can find examples, where it is necessary to control versions of data or documents which form a part of a larger, in most cases relational, data structure.

Versioning such data without the use of a relational database is nearly impossible, as storing relational data inside file structure would be very difficult to implement. It is difficult to avoid using relational databases and at the same time the versioning method should be implemented wisely. We have reviewed some of the most common methods of introducing data versioning to a relational database. All these methods, to a certain extent, solve the data versioning problem, while at the same time they contain some shortcomings, such as intervention with the original database structure, increased complexity of queries and in the case of large documents, load to the entire database.

For this reason, we proposed an approach in which we would maintain the use of a relational database, while at the same time the data or documents that we want to version would be excluded from the database and linked to it by a location reference. It is important to emphasize that the proposed solution is intended for a specific scenario for versioning the document files that are simultaneously associated with the relational data structure. In case of using the proposed approach, final query is divided into two parts: the SQL query in its original form and the file query that uses the file path from the SQL query result. Therefore, we distribute the responsibility between the database and the versioning system, since each one performs the work for which it was originally intended. Further research options include an overview of implementation possibilities of the aforementioned software solutions and study the effectiveness of the proposed approach. The aspect of scalability and performance can be crucial in many systems, therefore we can considered it as an independent subject of future research.

V. Acknowledgments

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Design and Implementation of Smart Contract: A use case for geo-spatial data sharing

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***Abstract* - In this paper, we propose to use the blockchain technology as a mechanism to store and share geospatial projects. Blockchain helps to improve efficiency and security. Smart contracts provide a secure, distributed and shared decentralized ledger of all assets and transactions. We will discuss a way to implement a platform on which scientists can share their studies. We propose a design methodology for the mentioned smart contracts, which enables the development of different use cases using blockchain technology. A detailed design of the smart contracts, functions and processes is presented. We will provide an outline of advantages and limitations of blockchain in general, and for the proposed platform.**

Keywords - Blockchain; Ethereum; Smart contract; distrubuted data sharing

I. INTRODUCTION

Lately blockchain technologies have received considerable attention form many researchers and government institutions. In this paper, we propose to add blockchains as a mechanism to design and implement a smart contract application to share geo-spatial data. Blockchain technology [1,2] enables the creation of a decentralized environment, where the cryptographically validated transactions and data are not under the control of any third-party organization [3]. Any transaction ever completed is recorded in an immutable ledger in a verifiable, secure, transparent and permanent way, with a timestamp and other details. Each blockchain employs a consensus mechanism to resolve different states, or "forks" in the network and the choice of mechanism varies among networks. [4] details a variety of consensus mechanisms.

We have chosen Ethereum [5] as the blockchain in our research. Ethereum provides a decentralized Turing-complete platform [6] called Ethereum virtual machines to run application codes called smart contracts. Ethereum also provides a currency called ether, that is used to implement value exchange between nodes in the platform. Smart contracts are codes that reside within the Ethereum blockchain environment that executes when specific conditions are met. Smart contract can store and control ether. The functionality to control ether can be used to build applications that require deposit and payout of ethers such as games, Identity managements systems [7,8]. In the Ethereum blockchain platform, each computational step has a cost associated with it [9] called gas.

In this paper we propose a design methodology for smart contract to implement a project called 'D-GIS' [10], which enables geologists and engineers to share geospatial data and studies in the most efficient manner possible. In [11] we have discussed a way to implement a platform on which scientists can share their work/study in a secure and efficient manner using blockchain technology and artificial intelligence [12]. We use the blockchain to prevent two of the major flaws in scientific research as well as data sharing and collection: ownership-rights, and based on the model described here, equal rights and a democratic eco-system for publishing your data, the last is completely automated; by doing so we also remove the need for a third-party, thus removing bureaucratic short-comings, i.e. corruption and inefficiency [11]. Based on this, we also introduce a model detailing how such platform can be programmed to mimic an economic market in order to also produce competition between authors, leading to better studies. Artificial intelligence is used in order to support this model by examining similarities between projects, therefore detecting potential plagiarism or unauthorized redistribution.

We aim to build a ranking system based on points (tokens) won by contributing to the community, the bigger the contribute, the bigger the reputation the user has in the community. When someone votes, his vote is equivalent to his power inside the network. But also, the voter has a small penalization when he votes. This acts as a friction mechanism which limits the amount of votes a user can submit. In order to generate a median-like variable to check the ratio of a specific user's tokens with respect to the total amount of tokens in the network.

D-GIS is a decentralized application, meaning that no one owns it and everybody can benefit from it. Due to this fact, no one can manipulate the will of the community on a certain decision it makes.

Although 'D-GIS' makes use of two technologies: Deep Learning [13] for categorization and Blockchain for distribution, at this paper, we're going to focus only on the distribution part, more specifically the on-chain part. Focusing mainly on some coding approaches related to Smart Contracts, taking a look at advantages and disadvantages for each of them. Our main goal is to

identify specific methodologies used in DApp, which allow us to grab onto the strongest pillars of Ethereum and in turn develop a safer experience for the end-user.

The paper is organized as follows. In Section II is presented a background of blockchain, smart contracts and different approaches used to implement smart contract and related works. Section III presents system details, on-chain and off-chain elements. The On-chain elements of our implementation are described at section IV and the off-chain ones at section V. Smart contract design methodology, and some aspects of security are described in section VI. The remain sections discuss conclusions and future work.

II. BACKGROUND AND RELATED WORK

Many people and researchers believe that blockchain applications in different vertical industries could lead to three generations of the Blockchain, namely Blockchain 1.0, Blockchain 2.0 and Blockchain 3.0 [14,15,16,17].

Analyzing the papers, we found that some of the platforms that use the concept of smart contract are: Bitcoin [18], Ethereum, Codius [19], Lisk [20], Counterparty [21], Monax [22], Stellar [23], Rootstock [24]. Two of most prominent platforms that use concept of smart contracts were Ethereum and Bitcoin.

To implement smart contract, exists three approaches [25,26,27]: (1) *Centralized*: The smart contract is deployed on a Trusted Third Party. This approach is also known as off-blockchain implementation since there is no blockchain involved; (2) *Decentralized*: The Smart contract is deployed on a blockchain platform such as Ethereum. This approach is also known as on-blockchain; (3) *Hybrid*: The contract is split and deployed partly off and partly on-blockchain. Some clauses are enforced off blockchain; others are enforced on-blockchain. The partition is based on several criteria including blockchain cost, performance, consensus latency, smart contract languages and privacy.

The paper [28] discusses the implementation of smart contracts on hybrid architectures. On-blockchain platforms suffer from scalability, performance, transaction costs and other limitations. Off-blockchain platforms are afflicted by drawbacks due to their dependence on single trusted third parties. They showed how a smart contract can be split and executed partially and an off-blockchain contract compliance checker and partially on the Rinkeby [29] Ethereum network. They argument that in several applications areas, hybrid platforms composed from the integration of off- and on- blockchain platforms are better than either alone [28].

While implementing smart contracts, it is important to take into consideration security aspect. Unfortunately, it is a challenge to create smart contracts that are free of security bugs. We can mention some cases where critical vulnerabilities in smart contracts have led to losses reaching millions of USD [30,31,32,33].

An important implementation of a geospatially-enabled blockchain is FOAM [34]. It uses a crypto-spatial coordinate (CSC) system. A FOAM blockchain does not just record an entry's specific time, but also requires and validates its associated proof of location, giving an immutable spatial context that regular blockchains lack, and allowing the accurate mapping of physical world events in a temporal sequence [35, 36, 37].

In [38], authors think that citizen engagement in the crowdsourcing of geo-tagged data can be combined with augmented reality and blockchain technology in powerful new crisis mapping and recovery scenarios, e.g., in the production and real-time updating of an augmented crisis map for navigating a disaster-stricken area.

III. SYSTEM DETAILS

For the design and deployment of Blockchain implementation we must consider the following selection criteria [39,40]: (1) Type of consensus mechanism [41]; (2) Programing language; (3) Type of cryptocurrency [42] used for mining; (4) Authorized participant in Blockchain network.

A high-level programming language called Solidity [44], is used to write smart contracts and decentralized applications (DApps). In our study we focus on smart contracts written in Solidity [43, 44] programming language, because it is adopted by the largest blockchain network that supports smart contracts.

A Decentralized Application (DApp) is an application that uses smart contracts providing a friendly user interface to smart contract [45]. The steps that are required to follow for the development of the DApp are [45]: (1) design and implementation of smart contract in high-level language; (2) Compile the contract to generate a binary file; (3) Deploy the contract on Ethereum Blockchain network using Ethereum clients; (4) Build a Web application (front-end) that interact with the smart contracts.

The basic setup of our D-GIS project consists of two components. The on-chain components which mainly consist of Ethereum Smart contracts for access control, generating and storing projects, and the off-chain modules which consist of client application module that interfaces with the smart contracts.

IV. ON-CHAIN ELEMENTS

A. Local Storage

A local storage (LS) is used to represent a work done by a user and then uploaded on the blockchain. Physically speaking it represents a study on a specific zone (inside a specific region). These elements have an ownership, rating and other details used to describe the work done. Figure 1 represents a Local Storage in its structure.

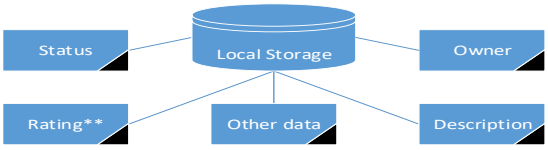

Figure 1. Local Storage

*OWNER** - This represents the owner of the storage, in Solidity this is implemented via a variable type named,

address. It points to an *Individual Account* on the network. This value is set in the initial deployment of the contract and cannot be changed later on. We assign an owner for each storage in order to avoid double-copies and to grant special *Read/Write* access to the contract. This assures that nobody else, except the author of the work will be able to access sensitive information inside the storage (i.e. status, description or if it's for sale, price).

*Rating*** - This is the reputation of the work stored in this storage across the Global Storage in which it is saved. Using of "Rating" will serve as a way to categorize any (geo) scientific based on their peer-reviews as well as an incentive for users to upload a better work. Ratings are manipulated via *user votes* and a specific *"Filtering Algorithm"* used to restrict or grant specific access on a work based on its reviews.

Description - This is a generalized description of the work or study done in that area. It is used not only for users to recognize and create a general idea on what the material uploaded consists of but also for indexing and finding data uploaded in a certain region.

Status - This parameter indicated whether this storage is available anymore. It can be either set to *true* (if available) or *false* (otherwise).

Other data - In this field we can add additional information regarding the material uploaded. On the 'DGIS' platform we use this space in order to assign a value (of Ether) which must be submitted in order to access the material.

We need to take into consideration that the material itself is not uploaded on the chain; instead we upload only its metadata. This allows us to take control over the work itself and edit it if need be.

B. *Individual Accounts*

Every user is registered to the network as a "Streamer", in this structure we store information regarding the user's work uploaded as well as his reputation across the chain. At Figure 2, we present the structure of an Individual Account (Streamer).

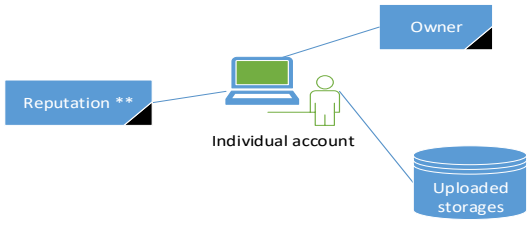

Figure 2. Individual Account

*OWNER** - In this case this address points to a wallet public address. It serves the same purpose of the field inside the LS element.

*Reputation*** - This represents the user reputation across the network, set automatically by the Filtering Algorithm based on reviews of his/her studies.

Uploaded Storages - This is used to index every LS owned by this user. It is not publicly accessible (although it might as well be), LSs can be found via a Global Storage.

The idea behind this, is that material uploaded by a single user is connected altogether and also used to create a general "image" of the user in the chain. This image represents the reputation and privileges of the user across the Global Storage. Thus, not only linking work-done to its author but also detailing and filtering any invalid or out-of-date study. Users with a negative reputation are restricted from selling (if selling is implemented) as well as publishing additional work on the network.

Global Storages (GS) are used to identify, index and store global data regarding works published on the network. These are used in order to classify materials based on their Geographical location, as such each Country (or another specific zone) will have its own GS representation on the network. Additionally, GS are used to grant access to individuals wishing to contribute with their own work done in that specific region. Thus, allowing users to register into this storage and have a limited writing access on it. Global Storages are designed in the following way as presented at figure 3:

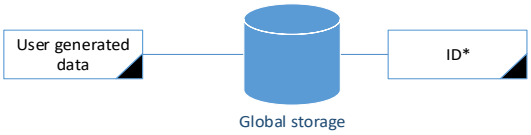

Figure 3. Global Storages

*ID** - This is used to identify each Global from one another. Information regarding its public key (address) and name (i.e. Texas, USA) is stored in the off-chain part. There's a check on the off-chain part to determine if the given ID has been taken or not so there are no GS with the same ID. However, users can freely initiate 'Globals' of their own, in which case there's no particular check to whether the given ID is already in use, this is of no concern whatsoever as we use IDs only to index 'Globals' on the off-chain source so users can search through them, but the actual connection is done by using the address of each GS. So, if user A initiates a new Global (which is not indexed and cannot be found via an implemented search engine), user B can still access it as long as A gives B the GS address.

User-generated Data - This is a collection of ratings and accounts registered on the Global in order to generate enough information to be used within the filtering algorithm, creating by us at [11]. Such data consist of a list of registered accounts (Streamers), a list of Local Storages uploaded by the user and so forth.

Each GS has its own data, therefore its own set of rules which either grants or restricts certain privileges for users. Therefore, in a hypothetical situation we have: User A, Global G, Global S.

User A can publish material on G, but cannot do it on S, as it doesn't meet the necessary requirements to do so (user-generated data on S is different, therefore leading to different rules). Although, this is not always the case it is of a certain importance to mention it, so you can create a better understanding of how every element has its own

attributes and is free from a centralized controller. Special cases can arise in which A can publish in both G and S.

Before moving on to the off-chain elements it is of vital importance that you are able to realize the similarities that this system and an economic market has. We allow users to upload content wherever they want as long as they're capable of meeting the specific requirements that "market" has. By taking into account that some of these studies or works can be sold, each GS is regulated by the Filtering Algorithm which prevents monopoles and sets competitive statuses for everyone joining it.

Following this logic, if User A wants to gain revenue from a study then it must ensure that the work being uploaded is valid and correct, therefore it will be cut out of the network and his/hers privileges on that Global will lower. Moreover, if User A's reputation is being decreased this will affect his capability to interact with other 'Globals', thus cutting down A's personal "market share". So, at this moment we have a networking made out of three-on chain elements like as they are presented at Figure 4:

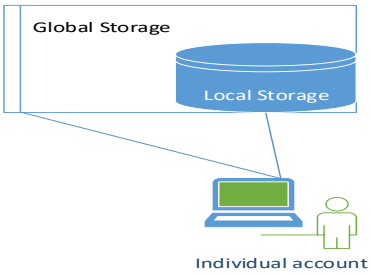

Figure 4. Global Storages

At this point the Streamer has access to each Local Storage inside the Global Storage, however it cannot edit or access sensitive data as long as it does not have ownership of that Local Storage.

V. Off-chain Elements

A. Ethereum Client-Server Service

We're going to name this element as "GoServer", since our work so far has been done on Geth and Go-Ethereum [46] (both Go implementations of the Ethereum protocol). GoServer is an application-layer which allows users to connect to the Ethereum blockchain (or even a private blockchain) thus interacting with storages and accounts there. In our implementation we've chosen to use a client-server approach, allowing multiple users to access the network from multiple sources. An example of this would be User A accessing the network from both its PC or from its Smartphone to check for pending requests.

Such architectures not only favor a more complex yet strangely elegant approach to access the network but it also reduces the weight of each user's application on its device. Another way to see this is like a proxy service, where users send requests to a single instance which in turns runs as a proxy connecting both users and the blockchain yet still remaining in the middle of the action. At figure 5, we illustrated the whole client-server implementation:

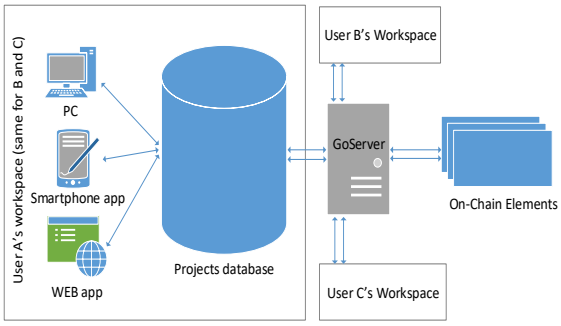

Figure 5. Client-Server Implementation.

As you can see from the diagram multiple users are able to send requests to the network via the GoServer at once. Each request is processed and queued for sending. In order to enable a safer experience for users, the GoServer registers each user's device and allows only known devices to operate. For instance, if a user wants to use his/her PC to edit and submit studies said user must "register" on the GoServer in order to do so. Registrations are either manual or automatic, it can be configured once on the server startup. An example of this would be the following scenario:

User A wants to register its smartphone as a device in order to access the network. Whether *User A* has any other devices registered (like a PC or a WebApp) is of no concern. Assuming that the server has been configured in order to accessible by everyone (aka automatic registration) and *User A* has been already registered on the server, *User A* has to follow these steps in order to add its smartphone:

1. Send a *NEW_DEVICE* request to the server from the unknown device.
2. Server checks whether this user is registered and the device is not listed on its database.
3. Server adds the newly registered device to its database and links it to the personal virtual database of that user.
4. Server sends a unique key to the user in order to for the user to access the server.

Since the GoServer is responsible for connecting the user to the network, it also passes on request from other sources to the user, such as material reviews, requests and so on. Then the server stores that information in a personal database for each user registered on it, allowing users to access their history but also avoiding data loss if a sudden server breakdown occurs. However, if the user is not registered on the server there are two more scenarios to cover: (1) The server has been configured in order to accept automatic registrations; (2) The server has been configured not to accept automatic registrations.

In the second case the server owner must register the user manually from the machine running the server, then the user can proceed to register its devices. Otherwise, automatic registrations follow these steps: (1) User sends a registration request to the server, including any info regarding itself (username, password and so on); (2) Server checks whether a user with the same name has

been registered; (3) Server registers the user and sends back its ID.

VI. Methodology Implementation

In this section we aim to present a model, or methodology to use while creating a DApp. D-GIS is a decentralized data sharing platform built on top of Ethereum's blockchain. Smart contracts are public, hosted on a huge decentralized network, therefore accessible by millions of users, so we must write our code keeping in mind that we shall inspect any kind of security worm-hole. Another thing to take in consideration is code efficiency, in order to reduce gas fees [47, 48]. These fees are based on what users are willing to pay in order to keep the network up as well as how much miners are willing to invest in the forward-propagation of the blockchain. Thus, every time you deploy a smart contract, call a specific function or change its state you have to pay a specific fee in order for your transactions to be pushed on top of the latest block being mined. Fees are known to lower once the Ether price rises, however this is not in a 1:1 ratio.

Last but not least, we must remember that once a contract is deployed its code cannot be changed anymore. So, once we reach production stage, we have to be sure that our code is completely "bug free". However, this is very impractical and, in most cases not really possible. Additionally, if we want to implement new features, we must re-deploy the whole network of smart contracts, and this is a real trouble. To get around this, we present a work-around idea, which adds a bit more of work but it might save some time during the future releases.

A. Security

Contracts ownership is now a standard, but here we have to make sure that the caller which wants to access a published data, or even change its rating, must be of the right type. More specifically we allow only *TxtStreamers* to vote on a storage reputation. To do this, we first register each streamer's address as a "friendly address". And to take it one step further, we also check during this registration that the address we're marking as friendly represents a *TxtStreamer*. For this we use the soon-to-be implemented opcode, EXTCODEHASH [49] and check its hash code with that of a *"dummy" TxtStreamer* deployed by the Global storage during its initialization. The following code can be found inside the Global's constructor:

```
TxtStreamer mDummy_streamer = new
TxtStreamer(address(this));
address m_addr = address(mDummy_streamer);
assembly{
       dummy_streamer := extcodehash(m_addr)
}
```

dummy_streamer is of type bytes32, which is a bytes representation of a Keccak256 hash code [50] derived from the deployed dummy's byte-code. From this we use mappings to assign contracts as friendly.

```
function IsStreamer(address addr) public view
returns(bool o_streamer){
bytes32 o_data;
        assembly{
            o_data := extcodehash(addr)
        }
        o_streamer = (o_data == dummy_streamer);
    }
    function RegisterStreamer() public {
        require(IsStreamer(msg.sender), "Invalid
source calling function RegisterStreamer().");
        require(!IsAccountPresent(msg.sender),
"Streamer already registered.");
        accounts_present[msg.sender] = true;
    }
```

accounts_present is a boolean type of mapping address, and if *accounts_present[X] == false* (that's what *IsAccountPresent(<address>) checks)*, then the calling contract *(which address is X)* is not "friendly", therefore it cannot vote on storages reputation. However, hash-checks consume gas on their own, that is one of the reasons we consider using mappings to query "friendly" addresses instead of checking the hash of each storage on every call they perform inside a Global.

B. Proxy contracts

When you deploy a contract, its address cannot be modified, therefore if you want to roll out updates you have to re-deploy every other contract. Sometimes this is not a problem, however there are times when users are not able to switch to the new contracts unless they migrate all their data there, which is impractical.

We prefer to call a form of work around for this, a proxy contract. Just like a real proxy this type of contract will be used as a bridge to connect users to the source they want to call. *Contract 1* can call a specific function inside *Contract 2*, by simply knowing the address of *Contract 2*. However, if we push an update, the newly deployed contract will have a different address, so *Contract 1* cannot access it anymore. A proxy contract works by storing the address of the currently updated contract and simply passing it to the caller. Moreover, the proxy contract can also store previous versions of the source contract, and let the caller decide which version they want to use. At figure 6, presented below, we can see the structure of a proxy contract.

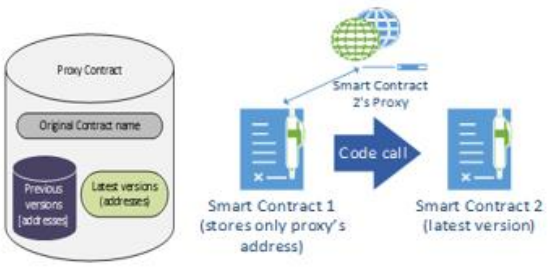

Figure 6. Structure of proxy contract.

So, a caller contract can simply store the address of the proxy and request the newly released version to be sent, or otherwise if possible, a previous working version.

VII. Conclusion

Even though Ethereum is still in its infancy, it shows all the signs of a successful future. Developers looking to invest their time and resources in this new technology must always be prudent while deploying their projects.

Analyzing D-GIS as a use case we try to highlight some of the advantages and possibilities that can be derived through the blockchain. On this paper, we mainly focused on some coding approach relating smart contracts. Our main goal was to identify specific methodologies used in DApp, which allow us to grab onto the strongest pillars of Ethereum and in turn develop a safer experience for end-user.

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INVITED PAPER

Knowledge Engineering Paradigms for Smart Education and Learning Systems

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***Abstract* -Recently, artificial intelligence (AI) receive increasing attention within the field of developing smart digital education. Researchers have been used the computational intelligence (CI) and machine learning techniques methodologies to develop a smart tutoring systems (STSs). On the other side, the convergence of AI, data science and Internet of Things (IoT) is enabling the creation of a new generation of web-based smart systems for all educational and learning tasks. This paper discusses the CI and knowledge engineering paradigms for developing the smart educational and learning systems. In this study the two popular CI paradigms; case-based reasoning and ontological engineering are discussed and analyzed namely. The main objective of this study is to determine and exploration the benefits and advantages of such intelligent paradigms to increase the effectiveness and enhancing the efficiency of the smart tutoring systems. Moreover, the paper addresses the challenges faced by the application developers and knowledge engineers in developing and deploying such systems.**

Keywords - Knowledge engineering and management, Artificial intelligence in education, Smart tutoring systems, Computational intelligence, Machine learning.

I. INTRODUCTION

Currently, the large-scale digitalization of all spheres of economic activity is manifested not only in the mass introduction of information and communication technologies (ICT) in a variety of spheres of human activity, but also in the convergence, integration of the digital and physical world through the use of smart digital solutions. The digital economy contains a significant reserve for an improvement in the lives of the population of various countries around the world. Nevertheless, the use of the potential of smart technologies of digital economy is possible on condition of existence of enough the people having competences for development and application of such technologies. This puts forward new requirements for the education system, first, in terms of the development of new areas of training in universities in order to prepare highly qualified personnel for the ICT sector, and secondly, in terms of the integration of ICT competencies in all areas of training to expand the skills of application of smart technologies in all areas of economic activity, and thirdly, in terms of creating new educational models that are adequate to the requirements of the digital economy. In this case, it is important to speak about establishment of Smart education.

Smart education (SE) represents a collection of e-services that employ digital media and ICT for supporting educational processes. SE is interdisciplinary area, encompassing many aspects of the educational technologies that cover instruction, training, teaching, learning, pedagogy, communication and collaboration. Moreover, the field of artificial intelligence in education has become the most challenging area in the last several years [3, 4, 13, 14]. The goal of the field is to deliver knowledge-based software which can be used in real teaching, learning and training situations.

Theoretical research in the subject field and the development of the concept of Smart education are associated with the convergence of three interrelated areas: the design of new smart technologies (engineering paradigm), the development of digital economy (technological paradigm) and the transformation of the education system, university models, and labor market (innovative, economic, organizational and management paradigms). In this case, we are talking simultaneously about the transformation of educational models and processes and the modernization of technologies and teaching methods [1, 2, 3, 4, 5]. Various attempts to determine the research framework of smart education have been made in recent years in a number of scientific papers [6,7].The researches cover an engineering perspective [8] and organizational and management issues related to the educational process [9,10].At the same time, there is clearly an insufficient number of works considering these two sides of the formation of the system of smart education.

II. SMART TUTORING SYSTEMS (STSS) CHARACTERISTICS

Using AI concepts, computational intelligence techniques, and knowledge engineering paradigms, new forms of smart educational software can be created that

allow the computer to act as a smart tutor. Such AI-based smart tutoring system (STS) can adjust its tutorial to the student's knowledge, experience, strengths, and weaknesses. It may even be able to carry on a natural language dialogue. In addition, automatic generation of exercises and tests is an important feature of STS.

STS is knowledge based software that act as an intelligent tutor used in real teaching. STS is also used in learning, and training situations. The main characteristics of such systems are the ability of reasoning, inference and based on static and heuristic knowledge. From the technical point of view, STS is composed of the following software components: (a) expert model, (b) student mode, (c) instructional module, (d) interface and (e) knowledge acquisition module. STS components are complex to build and complex to maintain. For more technical information, see [11,14].

III. KNOWLEDGE ENGINEERING METHODOLOGYFOR DEVELOPING SMART TUTORING SYSTEMS

A. *Constructing the knowledge-base Process*

This process includes knowledge collection, acquisition, compilation and representation. In this respect, there are many knowledge representation and management techniques, e.g.; lists, trees, semantic networks, frames, scripts, production rules, cases, and ontologies[1,3]. The key to the success of such systems is the selection of the appropriate technique that best fits the domain knowledge and the problem to be solved. That choice depends on the experience of the knowledge engineer.

B. *Selecting the reasoning and inference methodology*

In this process, there are many methodologies and approaches of reasoning, e.g.: automated reasoning, case-based reasoning, commonsense reasoning, fuzzy reasoning, geometric reasoning, non-monotonic reasoning, model-based reasoning, probabilistic reasoning, causal reasoning, qualitative reasoning, spatial reasoning and temporal reasoning [12]. In fact these methodologies receive increasing attention within the community of AI-based smart tutoring systems industry [8, 13, 14].

C. *Selection of Intelligent Authoring Shells*

Intelligent authoring shells allow a course instructor to easily enter domain and other knowledge without requiring computer programming skills. The authoring shell automatically generates an ITS/IeLS focusing on the specified knowledge. It also facilitates the entry of examples/exercises, including problem descriptions, solutions steps, and explanations. The examples may be in the form of scenarios or simulations. It allows organized entry of the course principles and the integration of multi-media courseware (developed with well-known authoring tools) which includes descriptions of the principles or motivational passages. In addition to course knowledge, the instructor specifies pedagogical knowledge (how best to teach a particular student), and student modeling knowledge (how to assess actions and determine mastery). The most common authoring shells are DIAG, RIDES-VIVIDS, XAIDA, REDEEM, EON, INTELLIGENT TUTOR, D3 TRAINER, CALAT, INTERBOOK, and PERSUADE [11].

From the above discussion, one can concludes that, the main difficulty and challenge in developing of STS for specific task is the knowledge-acquisition process. So, efficiency of STS is based on the selection and determination of the appropriate knowledge representation technique, reasoning methodology and the choosing of the suitable authoring shell. Therefore and from the technical point of view, STS systems are complex to build and complex to maintain.

IV. CASE-BASED REASONING (CBR) FOR DEVELOPINGSTS

A. *CBR Approach*

From knowledge engineering point of view, the "case" is a list of features that lead to a particular outcome. (e.g. The information on a patient history and the associated diagnosis). CBR is an analogical reasoning method provides both a methodology for problem solving and a cognitive model of people [15]. CBR means reasoning from experiences or "old cases" in an effort to solve problems, critique solutions, and explain anomalous situations. It is consistent with much that psychologist have observed in the natural problem solving that people do. People tend to be comfortable using CBR methodology for decision making, in dynamically changing situations and other situations were much is unknown and when solutions are not clear.

Determining the appropriate case features is the main knowledge engineering task in developing case-based IeLS. This task involves defining the terminology of the domain and gathering representative cases of problem solving by the experts. Representation of cases can be in any of several forms (predicate, frames, scribes).From the computational point of view, CBR refers to a number of algorithms and techniques that can be used to record and index cases and then search them to identify the ones that might be useful in solving new cases when they are presented. In addition, there are techniques that can be used to modify earlier cases to better match new cases and other techniques to synthesize new cases when they are needed. CBR has already been applied in a number of different applications in many domains, e.g., medicine, industry, law, banking [15,16,17].

In smart case-based e-learning systems, the case can include: (a) A multi-media description of the problem, (b)A description of the correct actions to take including optimal and alternative steps, (c) A multi-media explanation of why these steps are correct, and (d) A list of methods to determine whether students correctly executed the steps. Determining the appropriate case features is the main knowledge engineering task in case-based AI software. This task involves defining the terminology of the domain and gathering representative

cases of problem solving by the expert Representation of cased can be in any of several forms (*predicate, frames, scribes*).

B. Benefits of CBR to STSs

The idea of CBR is becoming popular in developing intelligent eLearning/tutoring systems because it automates applications that are based on precedent or that contain incomplete causal models. Research reveals that students learn best when they are presented with examples of problem-solving knowledge and are then required applying the knowledge to real situations. The case-memory of examples and exercises capture realistic problem-solving situations and presents them to the students as virtual simulations.

On the other hand, there are several benefits where students/learners should be able to perform better using CBR methodology, e.g.,

- With more cases available, students will be able to recognize more situations and the solutions that go with these cases include failure cases, students will be able to benefit from the failures of others.
- Retrieval cases will allow students to better recognize what is important in a new situation. Cases indexed by experts would recall and will show the student ways of looking at a problem that he might not have the expertise for without the system.
- Student will have access to obscure cases that they otherwise would not able to make use of. These obscure cases can help with any of the tasks previously listed.
- During a training period CBR system provides the student with a model of the way decision making ought to be done, for example, what things ought to be considered and provides them with concrete examples on which to hang their more abstract knowledge.
- For tasks where there is much to remember, CBR systems can augment the memories of even educators. Also, both educators and students tend to focus on too few possibilities when reasoning analogically or to focus on the wrong cases.

V. ONTOLOGICAL ENGINEERING (OE) PARADIGM FOR DEVELOPING STS

A. OE approach

The term "ontology" is inherited from philosophy, in which it is a branch of metaphysics concerned with the nature of being. The main objective of using ontologies is to share knowledge between computers or computers and human. Computers are capable to transmit and present the information stored in files with different formats, but they are not yet compatible to interpret them. To facilitate communication and intelligent processing of information, it is necessary that all actors of the digital space (computers and humans) have the same vocabulary. Ontologies are the foundation of cooperation and the semantical understanding between computers (running a lot of non-homogenous software programs) and of the cooperation between computers and humans.

Most of the usages of ontologies in the field of computer science are related to knowledge based systems and intelligent systems. These types of ontologies include a small number of concepts and their main objective is to facilitate reasoning. For example, in multi-agent systems, the knowledge representation is accomplished through a basic ontology, private ontologies and a knowledge base. Private ontologies of the agents are derived from the basic ontology. The names of the concepts used in private ontologies of the agents are unknown, but their definitions use terms from the basic ontology. During the last decade, increasing attention has been focused on ontologies [18]. At present, there are applications of ontologies with commercial, industrial, medical, academicals and research focuses [19,20,21,22].

B.Benefits of Ontology Paradigm to STSs

Ontologies' usage in educational systems may be approached from various points of view: as a common vocabulary for multi-agent system, as a chain between heterogeneous educational systems, ontologies for pedagogical resources sharing or for sharing data and ontologies used to mediate the search of the learning materials on the internet[23].

The abstract specification of a system is composed of functional interconnected elements. These elements communicate using an interface and a common vocabulary. The online instructional process can be implemented successfully using artificial Intelligence techniques. Sophistical software programs with the following features give the intelligence of the machine: adaptability, flexibility. Learning capacity, reactive capacity, autonomy, and collaboration and understanding capacity. This approach enables to solve the complexity and the incertitude of the instructional systems. An intelligent learning system based on a multi-agent approach consists in a set of intelligent agents, which have to communicate. They collaborate through messages. Software agents can understand and interpret the messages due to a common ontology or the interoperability of the private ontologies.

VI. TRANSFORMATION OF EDUCATIONAL SYSTEM: SMART DIGITALIZATION

The successful development of the digital economy requires the transformation of the educational system and the establishment of smart education using all enumerated smart educational technologies in three main interrelated areas.

First of all, it is important to strengthen and expand engineering areas of training at universities to increase the number of specialists capable of creating new smart solutions to meet the needs of the digital economy. Secondly, the mass introduction, penetration and

dissemination of smart educational technologies in all areas of training is required, which allow, on the one hand, improve the quality of the educational process and the level of competency of graduates, on the other hand, provide students with the skills to use smart ICT in real practice. Thirdly, it is important to consider the question of the establishment of educational institutions of the new formation. Smart technologies make it possible to transform both the content of education and the management of the university.

VII. CONCLUSIONS AND FUTURE WORK

In this concluding part, we identify some of the major open problems that must be addressed to ensure the success of developing robust intelligent e-learning systems. In summary, the development of intelligent e-Learning/educational systems is a very difficult and complex process that raises a lot of technological and research challenges that have to be addressed in an interdisciplinary way. Today's the fusion of computational intelligence and machine learning techniques with the knowledge acquisition techniques solves many of the technical problems and difficulties in designing new generation of intelligent e-Learning/educational systems. Further research however is needed to convergence the knowledge engineering, artificial intelligence, machine learning, and educational technology with the recent trends of Internet of Things (IoT) technology. Such convergence will create a new generation of web-based intelligent e-learning and tutoring systems. The web based of such systems can enhance the online education/ learning/training processes through the web. So, the integration of these approaches and educational technologies is beneficial for designing efficient, robust and smart e-learning systems. In addition, ensuring the success of such systems to the cloud is an important challenge.

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PAPERS

Comparing Software Complexity of Monadic Error Handling and Using Exceptions

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***Abstract* - Exception handling has been the definitive way to handle errors of any kind and exceptional circumstances in modern software. Using exceptions ease comprehension of single-threaded software by reducing complexity, but concurrency and asynchronous programming models require other approaches as the stack at the state of an error may not hold semantically important information. A way to handle such cases has been introduced to standard libraries, for example in Scala, the Try and – to some extent – Option constructs help programmers. Since these display monadic behavior, they provide improved composability compared to exception-based methods.**

Measuring software complexity can be done using software metrics. There are several well-known definitions: lines of code, cyclomatic complexity or McCabe-metrics, Halstead complexity measures and A-V.

In this paper, we use definitions of widely-known metrics that have been extended for the case of exception handling and compare complexity of monadic error handling with standard exception handling techniques.

Keywords - exceptions, software metrics, monadic error handling

I. INTRODUCTION

A. Motivation

Handling exceptional code paths is an essential part of all software. These cases can be numerous, starting from validating user input, managing messages from outside sources to handling computational errors. We would intuitively believe that covering all possible errors have a negative effect on the complexity of software. Many possible solutions have emerged since the first days of programming as these techniques had to evolve in parallel with the programming models we apply to solve problems.

In this paper, we analyze how one of the newer methods of error handling – using monads – affects complexity by leveraging software metrics for rigorous and scientific analysis. Our assumption is that monadic error handling does not make the code more complex in nay cases, but helps reducing complexity when applied to functional programming constructs and concurrent code.

B. Software Metrics

Software metrics are used to measure a given property of a piece of software with an absolute numeric value. Applying metrics to software can lead to better expression of the properties of the code; they can ease planning the lifecycle, time and resources required for creating and maintaining the software product [1]. Based on their definition, the properties they measure can range from simply length to how complex it is to test or understand the given piece of code.

Software metrics is a thoroughly investigated research area [2], since they provide a scientific methodology to express various traits of software systems. The mathematical definition of metrics doesn't necessarily hold for these measures – or if they do, the complying definition may not display useful information. For this reason, Weyuker [3] defined nine axioms that every software metric should satisfy instead of relying on the mathematical definition. These axioms can be considered basic sanity checks that would rule out trivially wrong approaches. Although it provided a solid theoretical foundation to the field, the axioms themselves still did not provide practical hints for either the usefulness or the categorization of metrics [4].

It seems obvious that software metrics can be grouped in categories based on the analyzed property or properties of the software. A helpful categorization was described in [5] where the authors defined a simple mathematically sound framework for the theory in which software parts are described by nodes, connections by directed edges and sets were used as abstract containers for the system's modules.

In our paper we use the extended definition of the A-V metrics [6] [7], to analyze the complexity of code. Both the original and the extended versions will be defined later.

C. Monads

Monad is a design pattern in the functional programming world [8] that is usually used to express a chain of computations. Its origins come from the category theory definition as it behaves similarly to mathematical monads [9]. Any functioning monad needs three essential parts:

- A type constructor: for any type `T` it returns `Monad[T]`
- A unit function: for any object `x` of type `T` it returns `Monad(x)` that is of type `Monad[T]`
- A bind function: for any types `A` and `B` and the monad `Monad[A]` it transforms `Monad[A]` into `Monad[B]`

The following code could be used as the backbone of monads in Scala [10]:

```
trait Monad[A] {
  def flatMap[B](f: A => Monad[B]): Monad[B]
}
object Monad {
  def apply[A](x: A): Monad[A]
}
```

Here, the trait itself is the type constructor, `flatMap` serves the bind, and `apply` as the unit function.

More intuitively, monads can express chains of computations, wrapping modifications to the computation's state. One major usage pattern in pure functional languages is handling I/O [11]. The I/O monad's state is passed between the instances that apply modifications to the underlying resource, be it a file or the console output of the program.

The aforementioned operations are essential to create and use a monad, but on top of them, they need to also satisfy the monadic laws, as described in the HaskellWiki [12]:

1. Left identity: `Monad[A](x).flatMap(f)` equals to `f(x)`.
2. Right identity: `Monad[A](x).flatMap(Monad[A](_))` equals to `Monad[A](x)`
3. Associativity: `Monad[A](x).flatMap(f).flatMap(g)` equals to `Monad[A](x).flatMap(f(_).flatMap(g))`

These three laws guarantee that using a class providing these functions naturally behaves as expected from a monad.

II. Extending Metrics for Exception Handling

There are numerous metrics that measure the complexity of software programs [13] [14] [6]; even the simplest measure, lines of code can be categorized as a complexity metric. Apart from the non-trivial cases, these metrics do lack clear and specific definitions as to how exception handling code should be incorporated into the complexity numbers. For the A-V complexity measure, the author left this open for a later interpretation.

A. The A-V complexity metrics

The A-V metrics was defined in 2002 [6], building on the foundations defined by McCabe [13]. The reason for taking a new look at how we measure complexity is obvious considering how much programming had changed between the two papers [15]. A-V provides a way to express comprehensibility much better than cyclomatic complexity for object-oriented and multiparadigm programming languages. The control flow graph is a suitable way of analyzing code execution, which can be used to define the following model. The fundamental concept is Nested Deepness (ND) [16], which represents how many predicates are in scope for any given point in the code (the formal definition can be found in the original paper). They reason that understanding the state that would lead to evaluating a statement highly correlates with code complexity [17], as the programmer needs to keep track of and comprehend these branches, predicates and loops.

On top of statements and execution flow, with the advent of object oriented programming, the way we use data in our programs had gained emphasis. In OOP, core thoughts revolve around objects: how they are represented and what operations can be applied to them. These factors led to the necessity of considering how data is handled when one argues about software complexity. This is why A-V extends the control flow graph with data access nodes: when a variable is either read or written, an edge will be added, pointing from or to the variable. The weight of these edges will be defined by the nested deepness hold by the variable's point in the code. These considerations lead us to the following definitions for functions:

$$\sum_{s \in \{Statements\ of\ f\}} ND(s) + \sum_{v \in \{Variable\ accesses\ of\ f\}} ND(v)$$

and classes:

$$\sum_{f \in \{Methods\ of\ C\}} AV(f) + |\{v : V\ is\ a\ member\ of\ C\}|$$

These formulae provide a more in-depth measure of complexity of modern software.

B. Extending A-V for the case of exceptions

Exception handling introduced various non-trivial concepts to help programmers including special constructs. Furthermore, there is a procedure called stack unwinding to help handling exceptional cases. These specialties drive the need to add proper extension to complexity metrics so that they can give us a better understanding of this error handling construct.

The definitions introduced for A-V [7] follow the fundamental paradigms of the original measure. Most programming languages represent exceptions with a typed object, hence these statements are noted as a simple data access, considering the nested deepness of the point where they happen.

As exception handling provides non-structured control sequences, the focus is more on these. Since the stack is unwound between the throw and its catch, understanding their relation can be a complex task: there can be multiple predicates the programmer needs to apprehend. This is the reason why we define the complexity of an exception by the difference between its throw and catch statements:

$$\Delta ND(e) = ND\big(throw(e)\big) - ND\big(catch(e)\big)$$

We also need to consider uncaught exceptions in the given function, as they describe special cases the programmer needs to understand leading us to the definition of the complexity of function *f*:

$$AV(f) + \sum_{e \in \{Thrown\ exceptions\ of\ f\}} ND(e) + \sum_{e \in \{Exceptions\ of\ f\}} \Delta ND(e) + \sum_{e \in \{Uncaught\ exceptions\ of\ f\}} ND(e)$$

Using these definitions we have previously shown that exception handling does reduce complexity of software when compared to other error handling methodologies, such as `ERRNO`, using return values or storing errors as global state [7].

III. Error handling with monads

While error handling has been made straightforward for structured programs by the concept of exceptions [18], their usage inherently depends on having one execution stack. This has been the case for the majority of software code in the past, but with the advent of multi-core systems and the need to leverage concurrent programming models, this has drastically changed. Furthermore, the headway of functional and multiparadigm languages has opened the way for easier asynchronous and reactive programming [19]. These improvements either require additional code to make exceptions work or we need to use a completely different model. This is where monads come into the picture. As we have discussed, monads naturally serve as building blocks for a chain of computations. A link in these chains can be one that handles errors. Since monads have no reliance on how they are executed, they can reduce the reliance on the stack.

There are several monads in the Scala standard library that we could potentially use for error handling (e.g. `Option[+A]`, `Either[+A, +B]` or `Try[+A]`), but we will focus on `Try[+A]`, as that is the designated monad to handle errors in computations.

A. scala.util.Try[+A]

The `Try` type represents a computation that may either result in an exception, or return a successfully computed value. It is similar to, but semantically different from the `scala.util.Either` type [20]. It has two final subtypes, `Success[T]` and `Failure[T]` and users can only create instances of the subtypes. Based on the API documentation cited above, one can see that `Try` has the necessary methods with the right signatures to be used as a monad:

- `def apply[T](r: ⇒ T): Try[T]` on the companion object serves the purpose of the unit function
- `def flatMap[U](f: (T) ⇒ Try[U]): Try[U]` is the bind function
- Finally, as we have discussed earlier, we don't need anything special for the purpose of the type constructor in Scala

It is easy to see that the monadic laws are satisfied by `Try`, we only mention two technicalities one needs to keep in mind while working through the proof:

- It is important to use the same exception instance while proving left identity and associativity hold, as Java doesn't define well-formulated equality between throwables (it relies on reference-based equality); even though we would intuitively expect value-based equality.
- One needs to use `Try` itself instead of `Success` when proving left identity as there is a difference between how these two types handle uncaught exceptions: while `Success` will bubble it up as a regular exception, `Try` will convert it to `Failure` – and this is the correct approach needed for the proof.

IV. Compare error handling with exceptions vs monadic methods

In this chapter we will examine how regular exception-handling code compares to using the `Try` monad for error handling by computing the A-V complexity metrics. To circumvent any reliance on an inherent property of A-V we will also calculate the difficulty and volume metrics defined by Halstead [21]. These examples are meant to cover idiomatic use cases of various real-world problems.

A. Simple throw-catch

Let us consider the following functions providing some functionality:

```
def f1_e(a: T): T = {
  if(test(a)) a
  else throw new IllegalArgumentException
}

def f1_t[T](a: T): Try[T] = {
  if(test(a)) Success(a)
  else Failure(new IllegalArgumentException)
}
```

and the following client code:

```
val res: Int = try {
  f1_e(1)
} catch {
  case exception: Throwable =>
    println(exception)
    default
}

val res: Int = f1_t(1).recoverWith {
  case exception => println(exception)
  default
}.get
```

If we compute the A-V metric for the code using exception handling, we get 3, as returning the value or throwing an exception are both under the scope of a condition (1+1) and the difference between the nested deepness of the throw and catch is again, 1. The Halstead difficulty metric is 8.125 while the volume is 102.19.

By using `Try`, we end up with a slightly more complex code, as we need to wrap either the result or the exception in the monad, but the client code gets simpler, as there are

no conditions there. The A-V value here is 4. For the Halstead values we get 8.125 and 81.75 for difficulty and volume, respectively.

B. Higher-order functions

In the following example, we test multiple inputs with the previous test methods:

```
val res: Seq[Boolean] = Seq(1, 2, 3).map { x =>
  try {
    f1_e(x)
    true
  } catch {
    case _: Exception => false
  }
}

val res: Seq[Boolean] = Seq(1, 2, 3).map {
  f1_t(_).isSuccess
}
```

Since the test methods remained the same, we will focus only on the complexity difference of the client code. Using exception handling, we get complexity of 1 for the caller, as return false has 1, while by using `Try`, we can keep the complexity at 0, since we haven't introduced any conditions. The difficulty metrics values are 9.5 and 5.5 and volume metrics values are 174.23 and 87.57.
The next example mimics a function that can throw multiple errors (we re-use the exception instances):

```
def test_t(a: Int): Try[Boolean] =
  if(a % 2 == 0) Failure(iae)
  else if(a % 3 == 0) Failure(ae)
  else if(a % 5 == 0) Failure(re)
  else if(a % 7 == 0) Failure(nse)
  else if(a % 8 == 0) Failure(npe)
  else Success(true)

def test_e(a: Int): Boolean =
  if(a % 2 == 0) throw iae
  else if(a % 3 == 0) throw ae
  else if(a % 5 == 0) throw re
  else if(a % 7 == 0) throw nse
  else if(a % 8 == 0) throw npe
  else true
```

and the client code will try to group some inputs to possible outcomes:

```
val range = 1 to 20
val g_t = range.groupBy(test_t)
val g_e = range.groupBy{ x => try {
  test_e(x)
} catch {
    case e: ArithmeticException => e
    case e: IllegalArgumentException => e
    case e: RuntimeException => e
    case e: NoSuchElementException => e
    case e: NullPointerException => e
  }
}
```

As previously, the tester method has the same complexity in both cases, but the client codes differ significantly: while the `Try`-case remains at 0, all possible cases of the exceptions need to be manually handled, resulting in a complexity of 5. Here we can calculate 8.125 and 3 as difficulty and 213.97 and 19.65 for volume as per Halstead.
The purpose of this example is to show how multiple types of errors affect the code, increasing the difficulty of comprehension. Furthermore, it demonstrates that treating errors as data instead of instructions can be hugely advantageous.

C. Chaining computations

Often we have data transformation defined as discrete steps that rely on the outputs of previous transformations. In this section we will examine such a case. Let's consider the following transformation steps:

```
def f0: T1
def f1(x: T1): T2
def f2(x: T2): T3
def f3(x: T3): T4
```

Each of these methods have their own way of handling invalid input or other erroneous state and they use exceptions to communicate these to the outside world. Using them can be done in a single try-block:

```
val res: Either[Throwable, T4] = try {
  val s1 = f0
  val s2 = f1(s1)
  val s3 = f2(s2)
  Right(f3(s3))
} catch {
    case e: Exception => Left(e)
}
```

To let the caller know of the success or the failure of the whole transformation flow, we need some holder object – we have used `Either` here for the sake of simplicity, but we won't use any of its monadic features. This example can be written with `Try` in a very similar fashion:

```
val res: Try[T4] = for {
  s1 <- f0
  s2 <- f1(s1)
  s3 <- f2(s2)
} yield f3(s3)
```

This latter version has lesser complexity by one, as we don't need to manually wrap the failure case. If we were to implement the holder class in the first example as well, the difference would grow further. These code snippets yield 15.75 and 5 for difficulty and 199.7 and 78.14 for volume.
The code gets more involved if we want to provide default values in each step. Using exceptions, we don't have much of a choice other than catching each error and manually returning the default value:

```
val v1 = try { f0 } catch { case e: Exception =>
  T1Def }
val v2 = try { f1(v1) } catch { case e:
  Exception => T2Def }
val v3 = try { f2(v2) } catch { case e:
  Exception => T3Def }
val v4 = try { f3(v3) } catch { case e:
  Exception => T4Def }
```

We have several possibilities when using monads though:

```
f0_t.orElse(Try(T1Def))
  .transform(f1_t, _ => Try(T2Def))
  .transform(f2_t, _ => Try(T3Def))
  .transform(f3_t, _ => Try(T4Def))
```

or

```
f3_t(
  f2_t(
    f1_t(
     f0_t.getOrElse(T1o))
     .getOrElse(T2o))
  .getOrElse(T3o))
.getOrElse(T4o)
```

As previously, the difference in complexity grows by the number of the cases that we need to cover. In this example, `Try` has a complexity advantage of 4. In these examples the calculated difficulty is 21.54 compared to 7.5 while volume is 382.37 against 132.

If we use chained computations, monads have significant advantages by providing simple and well-defined interfaces to easily wrap different outcomes of these computations. These advantages grow as the number of combinations we need to cover increases.

D. Asynchronous code

As we have discussed earlier, the exception handling infrastructure hugely depends on the presence of the execution stack, but running asynchronous code results in not having one unified, contiguous stack. For this reason, we need to introduce code that resolves this issue if we use exception handling. Consider the following example, reusing methods from subsection A:

```
val res = try {
  ec.submit(new Callable[Int] {
    override def call(): Int = f1_e()}).get()
  } catch {
    case e: Throwable => handleError(e)
  }
handleValue(res)
```

We submit a task to an `ExecutorService` which will return a `Future` holding the value. In case the method throws an exception, the `get()` call on the `Future` object will re-throw it, thus we wrap that call in a try-catch and handle this case. The same functionality using monads seems simpler even at a first glance:

```
Future {
  f1_e(1)
}.andThen{
  case Success(value) => handleValue(value)
  case Failure(e) => handleError(e)
}
```

Considering only the error handling bits in both cases, the first example has 2 as its complexity, while the monadic version has 1. Calculating difficulty results in 20 and 9.167; volume is 175.93 and 87.6.

Here we have seen that composing monads (`Future` with `Try` in this case) can be very powerful and has the potential of greatly reducing the effort needed for human comprehension.

V. RELATED WORKS

It is easy to see that the imperative way of handling exceptions by throwing and catching them is not pure. While throwing an exception does only depend on the parameter values and the definition of the function, catching an exception can be non-referentially transparent.

Moggi had defined the exception monad [22] based on category theory. His work also provides denotational semantics for evaluating monads. He introduces two operations for such monads, *raise* and *handle* that behave very similarly to what we would expect. He also argues that the exception monad is the most "well-behaved" compared to other side-effect monads.

Schroder and Mossakowski had extended Moggi's work by defining and implementing an equational definition for the Java monad [23]. This work shows how abnormal termination can be transformed then handled by using monads. They also provide formal proof through Hoare calculus which leads to the possibility to extend these calculi to missing computational features.

Simon Marlow et al. had defined asynchronous exception handling for their extended version of Haskell [24]. In their work they define scoped combinators for synchronous and asynchronous interrupts. The main concept is throwTo that can be used to throw an exception to a given thread. Its implementation is non-trivial as the receiving thread can be blocked. The solution to their problem is applying the blocked and unblocked combinators. Furthermore, they define operational semantics to formally proof the correctness of their approach.

VI. CONCLUSION

In this paper we have investigated the effects of different error handling methods on code complexity, namely exception handling and using monadic structures. We have seen that there is an initial increase in complexity since both normal and error-handling code paths need to create the monad – this is not present when using exceptions. On the other hand, outside of the most trivial cases we can see the advantage of monads: when using in higher-order functions, their nature of wrapping a computation pays off, especially as the number of error cases increases. We have also shown that using monadic structures to handle errors results in simpler code when we need to create a chain of computations. This is only partly due to the possibility of combining monads; with try-catch blocks, we need to add a lot of boilerplate code to handle various cases. Lastly, we have given an example of a simple asynchronous computation, where the fact that monads abstract away their runtime environment, again results in reduced complexity.

As our verification test, we have also computed a widely-accepted complexity measure: the difficulty and volume metrics by Halstead. These numbers also support our claim that monadic error handling does reduce code complexity and are in line with the intuitive assumption.

As future work, we can look into two different higher-scale software systems that provide similar functionalities, but use the two different error handling approaches we have discussed. This way we can show if monads do reduce complexity in real-world applications as well.

ACKNOWLEDGEMENT

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Delivering comprehension features into source code editors through LSP

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***Abstract*—The maintenance of large, legacy software often results in higher development time and cost due to increasing size and complexity of the codebase and its documentation, their continuously eroding quality and fluctuation among developers. Code comprehension tools are designed to tackle this issue by providing various textual information, visualization views and source code metrics on multiple abstraction levels. These tools usually process not only the codebase, but also the build information, the version control repository and other available information sources. Meanwhile source code editors and integrated development environments (IDEs) are not performing well in the field of code comprehension as they are optimized for writing new code, not for effective browsing. This can easily result in frequent switching between environments during development, hindering effective programming and raising development cost. Language Server Protocol (LSP) is an open-source protocol to connect source code editors with servers that provide language-specific features. In this research we analyze how LSP can be utilized to improve the code comprehension experience inside code editors by integrating the features of such tools through remote procedure calls. As a prototype solution we showcase the integration of two open-source applications: Visual Studio Code and the CodeCompass code comprehension tool.**

***Index Terms*—code comprehension, software maintenance, language server protocol, source code editor**

I. Introduction

The lifetime of large legacy software systems can often span over a decade, resulting in several maintenance difficulties. Due to the generally high fluctuation among developers in the software industry, not only the size of the software increases, but a large number (i.e. hundreds) of programmers get involved in the project. During the extended development time, original specifications and design intentions can get lost, the documentation can get unreliable and the code quality can deteriorate. Thus methods and tools to support newcomer programmers to comprehend the existing codebase (or at least the relevant modules) and to reduce the required timespan until they can effectively join the workforce became a substantial aspect of the software development industry.

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Source code editors in general are intended to help the creation of new code with such features like syntax highlighting, code completion, code navigation, code generation, syntactical and semantic error checking and refactoring. Integrated development environments (IDEs) further improves the development experience by integrating the compiler, debugger, tester, version control and other tools used in the development cycle to form a single environment capable to deal with multiple or even all tasks of software development.

While some code editors and IDEs are equipped with advanced code comprehension features [1], most of them are not prepared to help developers navigate in larger codebases. Experience shows that joining into the development of a long-running project is much more common than starting to write a new software from scratch. This means that developers would usually need extended comprehension features of their preferred editor while trying to understand the codebase they are about to modify or broaden.

Extending IDEs with their lacking code comprehension features (e.g. through plugins) means that code of the same purpose had to be written for different platforms which results in redundancy and maintenance difficulties. Code comprehension tools and code editors also lack a common protocol for communication with each other. While some research on IDE independent approaches have also been evaluated by injecting comprehension information into the source code itself as comments [2], missing proper visualization degrades the developer experience. Our research therefore focuses on the integration of existing code comprehension tools into IDEs through the LSP standard.

II. Code comprehension and code editors

This section covers the comparison of a couple of well known editors to determine what features are generally missing or present in them regarding code comprehension.

A. Abilities and deficiencies of editors

Source code editors often include a set of simpler features designed for code comprehension. Tab. I shows a set of

TABLE I
THE ABILITIES AND DEFICIENCIES OF WIDELY USED IDES

IDE	Go to definition	Find all references	Dependency graphs	UML diagrams	Symbol search	Code completion
Visual Studio Code	✓	✓	✓	P	✓	✓
JetBrains IDEs	✓	✓	✓	✓	✓	✓
Eclipse	✓	✓	P	✓	✓	✓
Qt Creator	✓	✓	P	✓	✓	✓
Atom	✓	✓	X	P	X	✓
Emacs	✓	✓	X	P	✓	✓
Sublime Text	✓	✓	P	P	✓	✓
vim	✓	✓	X	P	✓	✓

IDEs and their capabilities and deficiencies regarding code comprehension tools[1].

Go to definition It's one of the most common code comprehension supporting features. Developers usually need to take a look at a function's, attribute's etc. original definition, e.g. to obtain knowledge of field or formal parameter types or method signatures. The feature can be found in almost all modern editors.

Find all references Its frequency is similar to that of *Go to definition* as it is also a very basic tool of code comprehension. This feature is extremely useful when one tries to understand a component of a software since developers usually need to know where each and every field is used in the code.

Dependency graphs A very useful tool when a programmer tries to understand the structure of a legacy project. The larger the software, the more helpful this feature becomes as it depicts the connection between different files and entities of the software in a simple, transparent form. It's a less common feature in IDEs.

UML diagrams The diagrams that describe classes, packages, use cases or even individual objects and the connections between them are used by developers to understand complex software architectures. They are also used in reverse engineering when developers try to decrypt the structure of a software without knowing the code itself. It is worth noticing that IDEs might support the generation and the manual creation of UML diagrams as well.

Search Useful for both writing and understanding code. The broader the search options, the more help it provides. Searching might cover one or more chosen files, may be filtered to e.g. only comments or actual code and search parameters might be set to target the full given text or subtexts. Symbol searching is useful in exploring code with semantic meaning.

Intelligent code completion Although first and foremost useful in writing code, this feature is also helpful in understanding the smallest bits of code. By hovering above an identifier, its usages and possible corresponding methods and attributes are shown, thus helping the developer work out the structure of the codebase.

[1] ✓ symbolizes has a built-in version of the feature in the column, X means that the given feature is missing from the IDE, and P symbolizes that the IDE has the feature in form of a plugin.

B. Code comprehension tools

While common code comprehension features described in Section II-A provide the expected code navigation and understanding support during development, the comprehension of large legacy software for a newcomer developer without detailed preliminary knowledge of the system requires the aid of enhanced code comprehension tools.

Advanced search Code comprehension tasks often start with a fast feature location with the aim to narrow down the code segments where the features to be worked on are implemented. Beside the traditional text search, multiple features can improve this functionality, like: extending the search phrase with regular expressions and logical operators, symbolic search of a specific programming language, file name or path filtering based on a search pattern or fuzzy search – e.g. for log or error message search, where an exact match cannot be expected.

Enhanced code browsing During code comprehension, ad-hoc browsing the code should be made as straightforward and fast as possible. This can be supported by a browsing history view which shows the direction of navigation in a tree structure instead of a linear one, so the user may easily jump back and forth between the traversed locations of dependencies, e.g. function calls. Some tools also provide interactive views with multiple code displaying windows open with their traversed connections (function calls, variable definitions, etc.) visualized as connections – see *CodeBites* in CodeCompass.

System architecture views One of the main task of code comprehension software tools is to provide navigation and visualization views for the reusable elements of the source code, because humans are better at deducing information from graphical images [3]. By analyzing all the build information at compile time beside the source code we can differentiate between the types of relationships between the source, header and binary files. An implementation file *uses* a header file if it uses a symbol declared in the header, but it can also *provide*

it, when defines the names declared in the header. There can be *containment* relation between binaries and source files: a binary may contain several source files if those are linked together in the build phase. Similar views are of great interest also on a higher, module (directory) level. Through visualizing these relations of system architecture (e.g. like on Fig. 1), the complex connections of a software are more easily perceived [4].

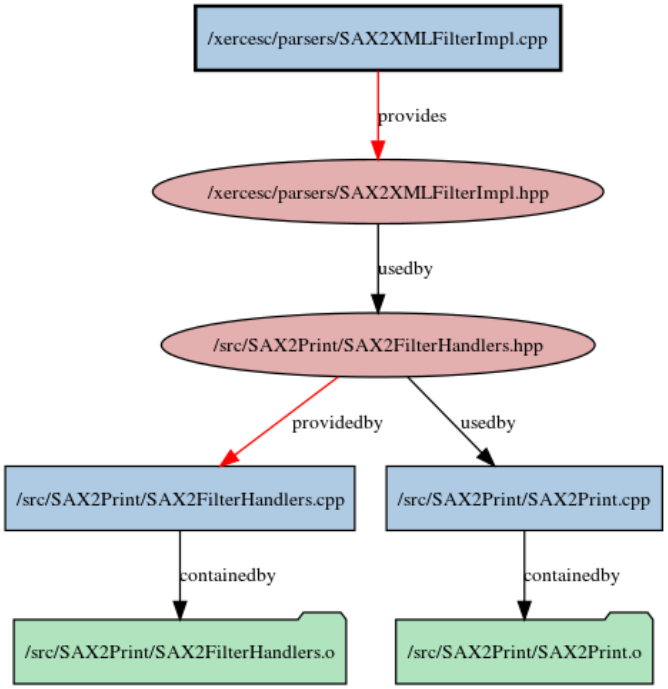

Fig. 1. User components of `SAX2XMLFilterImpl.cpp` in *Xerces-C++*.

Revision control navigation A main resources of knowledge about the a projects' source code is hidden in version control commit messages. Therefore alongside the commit messages for a file, presenting the author for each line of code and visualizing how old a code segment is (e.g. through color coding) can also aid code comprehension.

III. Language Server Protocol

Language Server Protocol is a joint project of Microsoft and others to standardizes the communication between language tooling and code editor. In other words, LSP comes as a new layer between IDEs and language tooling. This enables LSP compliant tooling services and IDEs to communicate in a standard way, thus making them independent of each other and providing the following advantages: language tooling services can be implemented in any language making it possible to adapt to special needs and/or optimize the performance of these utilities. At the same time, since code editors are also independent of the tooling environment, language tooling can be assigned to multiple IDEs and also an IDE can make use of several LSP compliant language tooling utility [5].

The Language Server Protocol is a very useful approach that supports the development of tools that help to make source codes more understandable. However it lacks certain functions that could enable it to get to the next level.

LSP is based on client-server mechanism, where the client can send requests to the server, and it can display the responses of the server in the development environment (IDE). Responses can be classified into 3 groups:

- returning position or position list: e.g. response for a *Goto Definition* request is the position of the definition, or response for a *Find all References* request results in a list of reference positions
- returning information as text: information inserted in the document or information displayed as a tooltip
- executing (a) command(s): for certain predefined request types a command that calculates or displays something – can be set to be executed

Typically LSP returns responses containing texts (position, short texts, or perhaps a name of a command), which can be freely used by the integrating code editor to display the information, either in a textual or visual way [6]. Still there is demand for more complex structures/types as response content. Imagine a scenario where clicking on the name of a class the server would return the UML diagram of the class in picture format. An even more advanced feature could be a response containing an interactive UML diagram, where clicking on certain parts of the picture would trigger events to which event handler methods could be assigned.

While the *executive command support* feature is useful, providing an option for the user to be able to pick an executable command themselves would further improve usability. Implementing a response type that returned a list of commands depending on the position in the file that could be executed on that position (e.g. diagnostic tasks or displaying specific diagrams), would further enhance the customizability of the protocol. These could be displayed in a context menu of the IDE and upon choosing one would execute the corresponding command.

Currently it is not supported (or at least it is not easily implemented) that the server and the client run on a different machine. This could prove useful in such cases where processing of requests is quite demanding as it requires significant amounts of resources, therefore it is not fortunate to let the client deal with it.

IV. Integration into CodeCompass

To demonstrate the capabilities of LSP, we implemented its methods into the backend of CodeCompass [7]. CodeCompass is an open source code comprehension supporting software developed by Ericsson Ltd. in cooperation with Eötvös Loránd

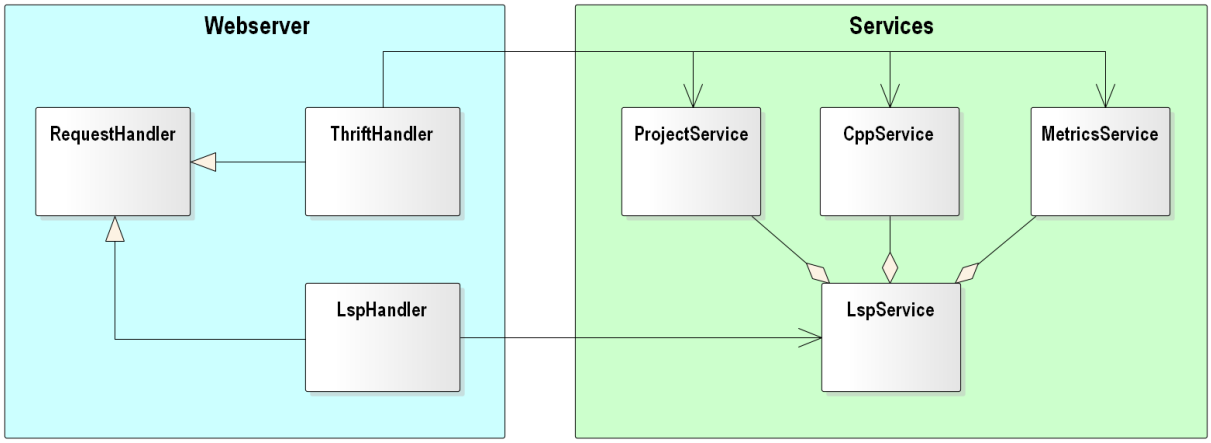

Fig. 2. Class diagram of the LSP integration into CodeCompass.

University, Budapest. It provides various navigational functions and textual search about the processed code by not only relying on the codebase but by obtaining information from the build system. The latter is done by processing the compilation database of the software [8] and using the JSON file that contains the compilation commands.

CodeCompass possesses a web user interface which provides interactivity by depicting clickable dependency diagrams that navigate the user through the modules, classes and methods of the software. Our purpose was to expand the capabilities of CodeCompass and support its usage in external source code editors. Visual Studio Code became the showcase of this experiment since it is also an open source software that supports the creation of plugins. LSP was used to connect CodeCompass to VSCode.

Functionalities in CodeCompass are organized into services (*ProjectService*, *CppService*, *MetricsService*, *SearchService*, etc.), being responsible for the features their names suggest. Their public API is served by the webserver component through Thrift protocol [9]. Since LSP requests are cross-compliant with lower level functions in CodeCompass, we defined a wrapper service which combines the existing functionalities for LSP.[2] This wrapper is named `LspService`.

Thrift and LSP use different constructions for their requests, therefore a new request handler module named `LspHandler` was also introduced to manage the transformation between LSP messages in JSON format and the strongly-typed inner representation of the program, as shown in Fig. 2.

V. Integration into Visual Studio Code

According to the Extension Guide [10] the language server in VS Code consists of two components.

Language Client : a normal VS Code extension written in TypeScript (use `vscode-languageclient` library)

Language Server : a language analysis tool running in a separate process (use `vscode-languageserver` library)

A. Context menu – context dependent dynamic menu items

Unfortunately LSP doesn't have a feature to place a context menu at an arbitrary spot in the document, where the user could choose from context dependent list of executable commands. Although the protocol supports the execution of commands for certain predefined request types (one command for each type), these commands can only be assigned to previously defined spots in the document (e.g. see Code Lens). All IDEs supporting LSP have context menus, these cannot be extended freely. New Menu items are automatically created and displayed when a supported request type is implemented.[3] However it is not possible to customize through the protocol.

Despite the lack of support for full customization in the protocol, the feature can be implemented without changing the VS Code integration modules – client and server – or enhancing the LSP protocol, by a non standard usage of the code completion feature. By taking advantage of this possibility a dynamic context dependent menu can be created (menu item types and quantity depends on the the environment where it was effectuated)

Basics of implementation:

- Code completion can also be initiated by a trigger character (in case of such use of code completion the `context.triggerKind` and `context.triggerCharacter` properties of the `CompletionParams` parameter are filled). Listing the context dependent menu items / commands can be

[2]For example requesting the definition location for a symbol is a single call in LSP, while with the lower level API of CodeCompass, first the AST node identifier has to be queried, resulting in two calls.

[3]E.g. in case of VS Code *goto definition* or *find all references* items can be displayed in the context menu when they are implemented.

achieved by setting the trigger character to a rarely used character, and by basically overriding the standard behavior based on a condition of the trigger character field's content. If the code completion had been initiated by the special character, instead of displaying the normal list of keywords for code completion, our own special method takes over, and a list of executable commands can be returned to the context menu. The list of available commands can be based on the position in the code as well (position property of the request parameter).

- Documentation can also be provided for menu items by supplementing the `detail` property of the `CompletionItem` property of the response for better understanding.
- Opening such context menu would normally insert a code piece into the source code (since this is basically still a code completion feature), however this insertion can luckily be avoided by customizing code completion in such manner that no actual insertion would take place, what more the special character triggering the special context menu can also be deleted (see: `textEdit` and `additionalTextEdits` properties of `CompletionItem` property).
- Furthermore LSP provides functionality to set a command that would be executed after selecting a menu item (see: `command` property of `CompletionItem` property).

Overall using this method for creating a context sensitive dynamic menu enables the IDE to display a position based list of custom menu items at arbitrary places in the source code without actually entering any new codes and at the same time executing a command based on the selected menu item. On top of this the custom created menu triggered by the special character and the code completion functionality stays independent of each other, so in the end the features have been extended without losing any standard functionality.

In our solution we use the context menu to be able to select from a list of diagrams provided by CodeCompass. Triggering the menu on a specific place in the code would send a request from LSP to CodeCompass to get the list of appropriate diagrams specific to that code context.

B. Displaying diagrams

LSP does not support displaying pictures (diagrams) on selecting a code piece, therefore we created new request type which has the following request parameter:

- in case of diagrams related to the whole document

```
interface WholeFileDiagramParams {
  textDocument: TextDocumentIdentifier;
  diagramType: string;
}
```

- in case of diagrams specific to position in the code:

```
interface PositionDependentDiagramParams {
  textDocument: TextDocumentIdentifier;
  position: Position;
  diagramType: string;
}
```

Response is the diagram in SVG format.

If the user selects a certain diagram type from the context menu list, the Language Client will send the server this specific diagram type, the file ID, and - in case of position specific diagram - the current position in the file. The server returns the diagram in SVG format, that will be saved to the file-system of the client as a picture - as VS Code does not handle SVG a conversion occurs here to PNG -, and finally the client will display the diagram (the converted PNG picture) in VS Code.

C. Remote Language Server

LSP's model does not support remote servers. There are no such parameters among the initialization settings that would specify the location of the server (e.g. IP address, port). The definition in the protocol only specifies that the language server must be a separate process. Since it is not supported in LSP an attempt to create a remote server without enhancing the protocol itself would most probably result in custom solutions that are specific to a given code editor and a language server (due to the lack of standardization in the middle layer - LSP). Although some experts say that the remote server feature of language tooling is not where the science is heading currently, there are still applications where it is more or less inevitable. A transparent way of implementing such feature within LSP's client settings could be located e.g. in the `InitializeParams` interface:

```
  serverip: string
  serverport: int
```

The reason why the client must contain these parameters is simple: since the language server is started by the client, and the language client send requests to the server, it has to know where the server resides. Also as can be found in the documentation, server lifetime is managed by the client: *"It is up to the client to decide when to start (process-wise) and when to shutdown a server"* [5].

In our solution we used the "official" language server as a proxy towards the CodeCompass. As a bonus on top of the previously mentioned advantages, required conversions could be performed during the process (e.g. CodeCompass starts counting rows and columns from 1 whereas VS Code starts from 0).

As a demonstration for the interaction between the language server and client of VS Code and the LSP components in CodeCompass introduced in Sec. IV, the sequence diagram depicted in Fig. 3 shows how a component diagram produced by CodeCompass displayed inside Visual Studio Code upon the request of the user:

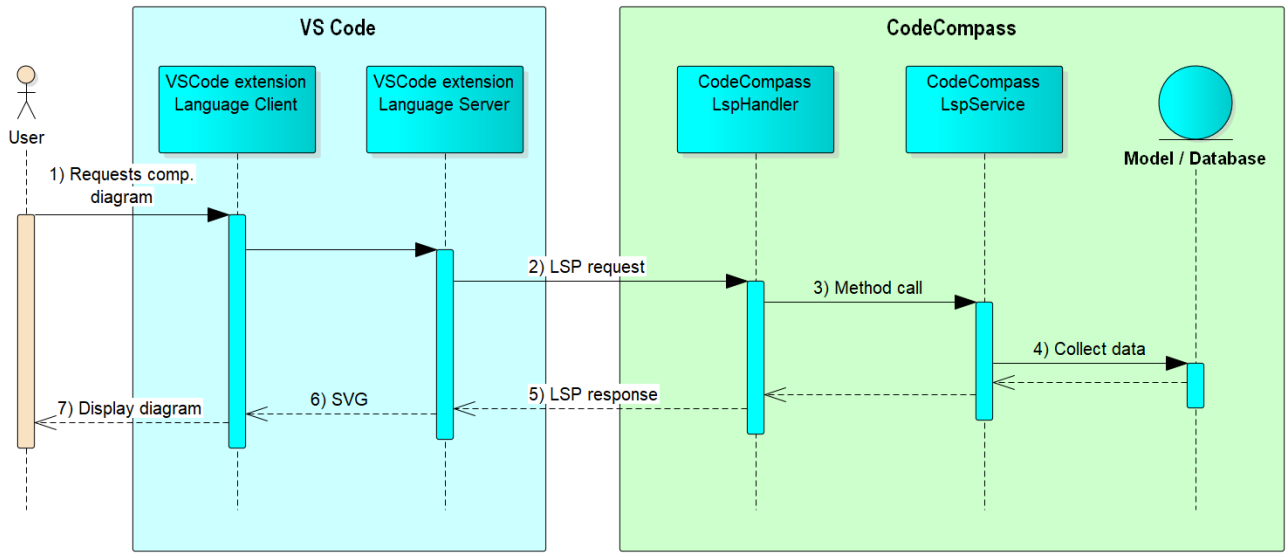

Fig. 3. Interactivity between VS Code and CodeCompass components to serve a diagram request.

1) The request for the diagram is issued by the actor through e.g. a context menu.
2) The language server constructs the corresponding LSP request towards the CodeCompass webserver.
3) The `LspHandler` component in CodeCompass processes the request and performs the necessary calls on the `LspService` component.
4) The required data is pulled from the underlying model layer (and ultimately from the workspace database) to build the diagram.
5) The result diagram is returned wrapped in an LSP response message.
6) The SVG diagram is extracted from the response.
7) The requested diagram is displayed to the user.

VI. Conclusions and Future Work

Maintaining and developing legacy software is a general challenge software industry faces nowadays and most likely in the future. By delivering features of state-code comprehension tools into popular code editors, companies can ease the work for newcomer programmers, meanwhile reducing the development time and cost. In our paper we demonstrated a prototype integration of the CodeCompass backend and the Visual Studio Code IDE through LSP in a robust, reusable and cross-platform way.

Future work will extend the range of supported IDEs to further LSP compliant editors, e.g. Eclipse and vim. To provide an improved comprehension feature set, we also aim to integrate the incremental parsing [11] feature of CodeCompass into mentioned editors to provide real-time reanalysis of the modified source code.

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Multitasking on Microcontrollers using Task Oriented Programming

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***Abstract*—Microcontroller Units (MCUs) are all around us powering many of our so called *smart* devices. Most programs running on MCUs are control applications performing multiple jobs at the same time. Examples of these jobs are: blinking a status LED, reading button states, talking to sensors or communicating with the world. Often these jobs are dependent on each other and require communication between them. Small MCUs have no support for multiple threads, therefore the programmer needs to manually interleave the tasks. The job structure bears great similarities with tasks in Task Oriented Programming (TOP). Tasks representing work that needs to be done, can be interleaved and combined to form compound tasks. The embedded Domain Specific Language (eDSL) mTask is a TOP language that works on even the smallest of MCUs. This paper explains how to write multi-task control applications for MCUs using a TOP language such as mTask.**

I. Introduction

Smart devices are all around us and they are often powered by MCUs. They connect to the Internet of Things (IoT), sense the environment and act thereupon. Most of these computing devices are hidden in thermostats, smoke alarms, doorknobs, wearables, light bulbs and other household items. The MCUs powering them are cheap and energy efficient. As a consequence, they are weak in terms of computing power. A fair share of the programs for MCUs are control applications, doing many things at the same time. It is very intuitive to program these separate jobs as processes or threads. However, the severe hardware restrictions disallow the use of a feature rich OS. There are methods that allow for the specification of light-weight threads but they come with the cost of flexibility such as lack of local state or absence of possible dependencies between jobs. Without the support for threads, the programmer needs to divide all tasks in short pieces of work and manually interleave them. This is an error prone process and results in spaghetti code that is not very well maintainable.

TOP is a novel programming paradigm in which the basic building blocks are tasks. Tasks represent observable work that needs to be done by human beings or computer systems. They function as lightweight communicating threads and can be automatically interleaved because the work is inherently divided up into small rewrite steps. A programming language providing TOP for the web is iTasks [1], an eDSL hosted in Clean [2]. Data can be safely shared between tasks using Shared Data Sources (SDSs). Developing software using TOP gives the programmer a high separation of concerns.

The mTask eDSL is a TOP language for MCUs [3]. The language is shallowly embedded using class-based, or tagless [4], embedding. As a result, it supports multiple independent backends such as Arduino code generation, pretty printing, symbolic simulation and bytecode generation. The hardware requirements for mTask are very low which makes it suitable for very small MCUs.

Research Contribution: In this paper we show that many components in MCU development map directly on TOP components. Furthermore, we show by means of a case study how to write multithreaded control applications using a TOP language. This shows that TOP yields concise and maintainable MCU code. As a bonus it integrates well with TOP for the web.

II. Microcontroller Programming

This section shows some examples of traditional MCU programming and reveals a problem. The code examples will be given in the Arduino C++ dialect[1].

A. Blink

The first program one writes when trying a novel programming language often is the *Hello World!* program. Said program is unusable for MCUs since they do not have screens. Nevertheless, most MCUs do have a one-pixel screen, namely an LED. In the *blink* program, an LED is turned on and off repeatedly. Listing 1 shows a typical implementation of the blink program that blinks the built-in LED, connected to the digital General Purpose Input/Output (GPIO) pin 13 on the Arduino UNO, every 500 milliseconds.

```
void setup () {
    pinMode(13, OUTPUT);
}

void loop() {
    digitalWrite(13, HIGH);
    delay(500);
    digitalWrite(13, LOW);
    delay(500);
}
```

Listing 1. Blink in Arduino

[1]https://www.arduino.cc

An Arduino program requires two functions to be defined, namely `setup` and `loop`. The `setup` function is executed once at the boot of the device and usually contains code to initialize the global state and setup the peripherals. In this blink program the pin mode of the digital GPIO pin 13 is set to output so that it is put in low-impedance state and that it can provide substantial current. When the `setup` function is finished, the `loop` function is continuously called. It first sets the state of the digital pin to `true`, turning the LED on to be followed by waiting 500 milliseconds. After that the digital pin state is reverted to `false` just to wait another 500 milliseconds. Because the loop function is called continuously, the LED is blinking.

B. Threaded Blinking

Now say that we want to blink multiple blinking patterns on different LEDs concurrently. For example, blink three LEDs connected to pins $1, 2$ and 3 at intervals of $500, 300$ and 800 milliseconds. Intuitively you want to lift the blinking behaviour to a function and call this function three times with different parameters as done in Listing 2

```
void setup () { ... }

void blink (int pin, int wait) {
    digitalWrite(pin, HIGH);
    delay(wait);
    digitalWrite(pin, LOW);
    delay(wait);
}

void loop() {
    blink (1, 500);
    blink (2, 300);
    blink (3, 800);
}
```

Listing 2. Naive approach to multiple blinking patterns in Arduino

Unfortunately, this does not work because the `delay` function blocks all further execution. The resulting program will blink the LEDs after each other instead of at the same time. To overcome this, it is necessary to slice up the blinking behaviour in very small fragments so it can be manually interleaved [5]. Listing 3 shows how three different blinking patterns might be achieved in Arduino using the slicing method. If we want the blink function to be a separate parametrizable function we need to explicitly provide all references to the required state. Furthermore, the `delay` function can not be used and polling `millis` is required. The `millis` function returns the number of milliseconds that have passed since the boot of the MCU. Some devices use very little energy when in `delay` or sleep state. Resulting in `millis` potentially affects power consumption since the processor is basically busy looping all the time. In the simple case of blinking three LEDs on fixed intervals, it might be possible to calculate the delays in advance using static analysis and generate the appropriate `delay` code. Unfortunately, this is very hard when for example the blinking patterns are determined at runtime.

```
long led1 = 0, led2 = 0, led3 = 0;
bool st1 = false, st2 = false, st3 = false;

void blink(int pin, int delay, long *lastrun, bool *st) {
    if (millis() - *lastrun > delay) {
        digitalWrite(pin, *st = !*st);
        *lastrun += delay;
    }
}

void loop() {
    blink(1, 500, &led1, &st1);
    blink(2, 300, &led2, &st1);
    blink(3, 800, &led3, &st1);
}
```

Listing 3. Threading three blinking patterns in Arduino

This method is very error prone, requires a lot of pointer juggling and generally results into spaghetti code. Furthermore, it is very difficult to represent dependencies between threads, often state machines have to be explicitly programmed by hand to achieve this.

III. Task Oriented Programming

TOP is a novel flavour of declarative and functional programming that describes work as tasks. In TOP, tasks represents an actual piece of *observable* work. The observability implies from the fact that other tasks can view the *task value* of the task in progress. Tasks are modelled as stateful rewrite engines. Single rewrite steps are very small and tasks can therefore be interleaved. Events triggering a rewrite can be anything ranging from user input, clocks or an event within the host system such as a peripheral. Tasks can be represented as trees that consist of basic or leaf tasks (e.g. reading input) and combinators, (e.g. a combinator running two tasks in parallel).

Every task emits a three state task value on every rewrite step representing either no value, an unstable value or a stable value. No value means that the task is unable to emit a complete value. E.g. a serial port without data. Unstable values represent complete values that may change in the future. These values in a basic task often represent a side effect. An example of a task emitting an unstable value is the task for reading an analog pin. A stable value never changes, often found in a finished side effect such as a finalized web form. Not all state transitions are legal, Figure 1 shows the state diagram.

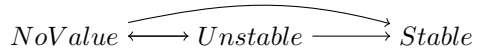

Figure 1. State diagram for the legal transitions of task values

Tasks share data via their task values or via SDSs. SDSs form a read/write abstraction on, possibly impure, data. In iTasks there are SDSs for files, time, random data, database tables but also SDSs to provide introspection on the system such as for the list of running tasks. Tasks can register or watch an SDS, subscribing to events for the SDS. When the SDS is written to, the registered task is triggered for a rewrite. As well as tasks, SDSs can be transformed with SDS combinators and transformers.

IV. mTask

The mTask eDSL is a TOP language for MCUs [3]. It is shallowly embedded using a class-based, or tagless [4], embedding. The technique allows for multiple independent backends such as Arduino code generation, pretty printing, symbolic simulation and bytecode generation.

All constructs in mTask are expressed as type classes. A backend in mTask, e.g. a pretty printer for printing the code, is a type implementing *some* of the type classes. Adding functionality does not interfere with existing backends and is as easy as defining a new class and implement it with *some* backends. Analogously, adding a backend does not interfere with existing functionality, a new backend is just a new type implementing *some* of the classes. The eDSL functions are often the same function as in the original host language and therefore a disambiguating name is required. This is done by postfixing the function with a full stop. For example, addition in mTask is named `+.` to not clash with the existing `+` function in the host language.

An mTask program is always of the form `MTask v t` where `v` is the backend and `t` is the type of the task. Not all types are suitable for MCUs. Therefore, many eDSL functions have class constraints on the type of the task or expression. Amongst other things, these constraints restrict the use of functions as values, recursive data, make sure serialization is possible. Listing 4 shows an example function in mTask that *does* include this constraint together with some expression examples.

```
class arith v where
    lit :: t → v t | type t
    (+.) :: (v t) (v t) → v t | type t & + t & zero t
    ...

fourtytwo = lit 37 +. lit 5
factorial =
    fun λfac=(λx→If (x ==. lit 0) (lit 1) (x *. fac (x -. lit 1)))
    In {main=fac (lit 5)}
```

Listing 4. Arithmetic function with class constraints

The mTask eDSL contains constructs for expressions, functions and tasks. All functions are defined on the top level, cannot be used in a curried fashion and are strict in their arguments. Functions can be defined recursively and full tail-call optimization is available. The `:: Main a = {main :: a}` is used to enforce the top-level definition restriction. To safeguard for curried use, the arguments are always represented as tuples instead of higher-arity host functions. For task support, mTask has basic tasks and task combinators. They will be explained on demand with the examples. All details regarding the exact types and the actual class definitions can be found in the repository[2].

A. Translating the Blink Program to mTask

Tasks are represented as trees and rewrite on every event that interests them. Nodes in this tree are called task combinators and leafs are called basic tasks. Rewriting is always done recursively, starting from the root node down to all the leafs. Since delays, and all other tasks, are non blocking, rewrite steps are quick. Different branches of the task tree executed are therefore highly interleaved.

While counter intuitive and not very maintainable, it is possible to literally translate the blink program to mTask as is done in Listing 5. This arises from the fact that most Arduino functions have a similar mTask counterpart. For example, sequencing tasks is done with the `>>|.` combinator. It first executes the left-hand side and when that side is stable, executes rewrites to the right-hand side. Nonetheless, the semantics of the translated program are very much different because of the different execution model. For instance, there is no notion of `setup` or `loop` code in mTask. `loop` like functionality can be simulated using the `ever` function. This task will rewrite the argument task until it is stable and when it is, it will start all over again with the original task. The `ever` function is just a regular task and therefore multiple `loop`s can be simulated with ease.

```
blink :: MTask v ()
blink = {main=ever (
            delay (lit 500)
        >>|. writeD D13 (lit True)
        >>|. delay (lit 500)
        >>|. writeD D13 (lit True)
    )}
```

Listing 5. A literal mTask translation of blink

B. Threaded Blinking

The `delay` *task* does not block the execution but *just* emits no value when the target waiting time has not yet passed and emits a stable value when the time is met. In contrast, the `delay` *function* on the Arduino is blocking which prohibits interleaving. To make code reuse possible and make the implementation more intuitive, the blinking behaviour is lifted to a recursive function instead of using the imperative `ever` construct. The function is parametrized with the current state, the pin to blink and the waiting time. Creating recursive functions like this is not possible in the Arduino language because the program would run out of stack in an instant and nothing can be interleaved. With a parallel combinator, tasks can be executed in an interleaved fashion. Therefore, blinking three different blinking patterns is as simple as combining the three calls to the `blink` function with their arguments as seen in Listing 6.

```
tblink :: MTask v ()
tblink = fun λblink=(λ(st, pin, wait)→
                delay wait
            >>|. writeD d13 st
            >>|. blink (Not st, pin, wait)) In
    {main = blink (lit True, D1, lit 500)
        .||. blink (lit True, D2, lit 300)
        .||. blink (lit True, D3, lit 800)
    }
```

Listing 6. Threaded blinking in mTask

[2]https://gitlab.science.ru.nl/mlubbers/mtask/tags/4cows18

C. Combinators

In the examples, tasks are sequenced using the `>>|.` combinator. Introduced above, the `>>|.` combinator is a specialization of the step combinator (`>>*.`), the Swiss army knife of sequential combination (Listing 7). The right hand side is *observing* the task value of the left hand side. The value produced by the task on the left-hand side is matched against the continuations (`:: Step`) on the right-hand side. If a predicate matches, the task steps and rewrites to the task in the matched predicate.

The `>>=.` combinator is a specialization of the `>>*.` combinator and is similar to the monadic bind. If the left hand side is stable, it feeds the value to the function on the right hand side and rewrites to the resulting task. `>>|.` is similar but does not use the argument, i.e. monadic sequence.

```
(>>*.) infixl 1 :: (MTask v t) [Step v t u] → MTask v u

:: Step v t u
  = IfValue ((v t) → v Bool) ((v t) → MTask v u)
  | ...
  | Always (MTask v u)

(>>=.) l r = l >>*. [IfValue (λ_→lit True)      r]
(>>|.) l r = l >>=. [IfValue (λ_→lit True) λ_→r]
stepExample = readA A3
    >>* [IfValue (λx→x >. lit 100) λx→writeA A4 (x /. 2)]
```

Listing 7. Sequential task combination

There are two combinators in mTask to achieve parallel execution of tasks. Disjunction (`.||.`), first rewrites the left hand side and then the right hand side. Conjunction (`.&&.`), also combines two tasks but also combines the values into a tuple meaning that both sides must have a value. The stability is determined by the disjunction and conjunction respectively of the stability of the arguments. Since `blink` is not terminating, the behaviour of `.||.` and `.&&.` is identical in Listing 6.

D. Shared Data Sources

As of now, mTask supports SDSs representing global, well-typed variables but no SDS specific combinators or transformers yet. These SDSs may represent iTasks SDSs that are automatically synchronized with the server. SDSs are used to share data between tasks having no sequential relation. Listing 8 contains an example of a blink program for which the delay can be set using a button. It first defines an SDS containing the current blinking interval. This is followed by a modified blink function that first reads the number of milliseconds it needs to wait from the SDS before actually blinking. Two tasks run in parallel, the first task is the blinking itself. The second task is constantly checking the button state using the `pressed` task. If a button is pressed, the SDS containing the increment is updated.

```
sblink =
    sds λlag=500 In
    fun λblink=(λ(st, pin)→
                getSds lag
            >>=. λwait→delay wait
            >>|. writeD d13 st
            >>|. blink (Not st, pin)) In
    {main = blink (lit True, D13)
       .||. ever (
                  pressed upButton   >>* [IfValue id (rtrn (lit 100))]
              .||. pressed downButton >>* [IfValue id (rtrn (lit -100))
     ↪ ]
            >>=. λincr→getSds lag
            >>=. λoint→setSds lag (oint +. incr))}
```

Listing 8. SDSs interface

V. Thermostat

As a case study, this section will describe the development of a thermostat in mTask. The proposed thermostat has multiple jobs to take care of at the same time, namely the viewer, heater and updater. The viewer will read the temperature from the connected Digital Humidity and Temperature sensor (DHT) and show it on the connected LCD. The heater checks if the temperature is meeting the goal temperature. If the temperature is lower than the goal temperature, the heater turns on and conversely if the temperature is higher. The heating unit is connected via a relay to digital pin 0. The updater checks whether the up or down button is pressed and changes the goal temperature accordingly.

A. Defining the SDSs and Peripherals

An mTask program always starts with the global definitions such as peripherals, SDSs and functions. This preamble shows similarities with the `setup` function in Arduino but is completely declarative. There are two peripherals connected to the MCU, namely the LCD and the DHT. They are defined with a similar technique as SDSs are declared using host language lambdas so that they are used in a type-safe way. With the `dht` function, the DHT is declared, being connected to digital GPIO pin 1. The 2×16 character LCD is defined after that using the `lcd` function connected to the standard pins. There are two data sources that need to be shared between tasks and are represented as SDS. The current temperature (`temp`) and the target temperature (`goal`). Both SDSs store values of type `Int` and represent the temperature in degrees Celcius.

```
thermostat :: Main (MTask v ())
thermostat =
    DHT D1 DHT22 λdht→
    LCD 16 2 [] λlcd→
    sds λtemp=0  In
    sds λgoal=20 In

    fun λviewer=( ... ) In
    fun λheater=( ... ) In
    fun λupdate=( ... ) In
```

B. The Main Tasks

The main program is divided into four tasks that are connected using the parallel disjunction operator. The tasks very closely match the jobs that were described. All tasks are created using (recursive) functions to either have a reuse of code or to keep an intermediate state.

```
{main = viewer (lit 0)
    .||. heater (lit False)
    .||. ever (update (lit UpButton, lit 1))
    .||. ever (update (lit DownButton, lit -1))}
```

Listing 9. Thermostat main tasks

C. Viewer

The viewer reads the temperature and communicates that to the user using the LCD. The `viewer` function is parametrized with the old temperature, which is 0 on the first call. The task it generates first reads the temperature from the DHT using the `temperature` task. This task reads the temperature continuously and emits it as an unstable task value. The `>>*.` combinator is used to only continue execution when the temperature is not the same as the old temperature. This makes sure the LCD and SDS are not continuously written. When the `>>*.` steps, the `temp` SDS is set and the value is written to the LCD. Finally a recursive call to itself is done with the new temperature so that it will continuously execute.

```
fun λviewer=(
    λoldtemp→temperature dht
        >>*. [IfValue (λt→t !=. oldtemp) (setSds temp)]
        >>=. λntemp→printAt lcd (lit 0) (lit 0) ntemp
        >>|. viewer ntemp) In
```

Listing 10. Measure and show the temperature

D. Heater

The second job is the control of the heater and this is written as a single task that calls the `heater` function. This function takes the current state as an argument and is initialized with the off state. It reads the `temp` and `goal` SDSs in conjunction instead of in sequence to make sure the latest values are always checked. If the temperature is over the goal and the heater is turned on, the heater is turned off. If the temperature is under the goal and the heater is off, the heater is turned on. After the step, the `heater` function is called recursively with the new heater state so that it will run forever.

```
fun λheater=(
    λon→getSds temp .&&. getSds goal
        >>*. [IfValue (tup λ(temp, goal)→temp >. goal &. on)
                    λ_→writeD d0 false
             ,IfValue (tup λ(temp, goal)→temp <. goal &. Not on)
                    λ_→writeD d0 true]
        >>=. λnst→heater nst) In
```

Listing 11. Control of the heater

E. Update

The third and last job is controlling the goal temperature and this is split up in two tasks that are both built using the `update` function. This task is lifted to a function solely to be reused with different arguments. The `update` function checks whether a button is pressed using the `pressed` task. This task returns an unstable `Bool` value representing the button state. If the given button is pressed, the `goal` SDS is updated with the given value. This step value is either 1 for the up button or -1 for the down button. There is no recursive call which means that the function only executes once. To make sure the buttons are always checked, the task is wrapped in an `ever`.

```
fun λupdate=(
    λ(button, step)→pressed button
        >>*. [IfValue id λ_→getSds goal]
        >>=. λnv→setSds goal (nv +. step)
        >>=. λnv→printAt lcd (lit 1) (lit 0)) nv In
{main = viewer (lit 0)
    .||. heater (lit False)
    .||. ever (update (lit UpButton, lit 1))
    .||. ever (update (lit DownButton, lit -1))}
```

Listing 12. Monitoring the buttons

VI. Integration with an iTasks Server

Another strong point of the TOP approach is that the thermostat is programmed using an abstraction that also works for other domains. The iTasks framework is a TOP implementation for collaborative web applications and supports seamless integration with mTask [6]. SDSs can be shared between iTasks and mTask and mTask tasks can be lifted to iTasks tasks. Therefore, creating a web interface to set and view the thermostat can be done just by changing a few lines of code. The resulting program will show a web interface in which the user can change the target temperature and view the current temperature (Figure 2).

```
thermostat :: (Shared Int) (Shared Int) → Main (MTask v ())
thermostat tempref goalref =
    ...
    liftsds λtemp=tempref In
    liftsds λgoal=goalref In
    ...

webThermostat :: Task Int
webThermostat =
    withShared 0 λtemp→
    withShared 20 λgoal→
    withDevice {TTYSettings | defaultValue
            & devicePath = "/dev/ttyUSB0", baudrate = B115200} λdev→
        liftmTask dev (thermostat temp goal)
    -||- viewSharedInformation "Temperature" [] temp
    -||- updateSharedInformation "Target" [] goal
```

Listing 13. Integration with iTasks

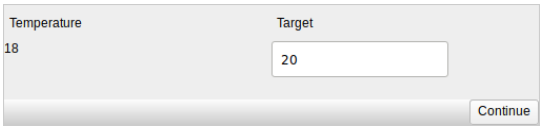

Figure 2. Thermostat web interface

VII. Related Work

A. Functional Programming on Microcontrollers

Pure lazy functional programming is seldom used on MCUs because it has high memory requirements. Nevertheless, microscheme is a subset of scheme that offers a compiler for even the smallest of the Arduino family [7]. It does not support multithreading however. Functional Reactive Programming (FRP) [8] shows similarities with TOP and Juniper offers FRP for MCUs [9]. In FRP there are behaviours and events. Behaviours are declarative descriptions that hold on time and can reason over time. Events can come from within the system

but can also be predicates on behaviours. TOP differs from FRP in the sense that tasks are not modelled explicitly after time but after progress.

B. EDSLs for Microcontrollers

In the eDSL field there are many solutions for providing a higher level of abstraction for programming MCUs. Grebe et al. created Haskino, a remote monad in Haskell executing imperative code on the Arduino [10]. It differs from mTask in the sense that the threads are imperative and have their own stack and thread-safe communication between them has to be done explicitly. In mTask the expressions are not interleaved, only the tasks are and therefore all communication is automatically safe because of the SDS semantics. Ivory is an eDSL written in a functional language that provides a safe C interface to program embedded systems [11]. It does not support threading.

C. Multi-threading on MCUs

Threading on MCUs is approached in multiple ways ranging in flexibility and memory requirements. Protothreads are stackless threads that provide an abstraction over state machine processes for sensor networks and can be interleaved [12]. Protothreads are similar to tasks in the sense that they can be interleaved but differ in the sense that they are imperative programs and share their stack with other threads but therefore cannot have local variables. Moreover, they must always be defined within the same function. There are also more general solutions available for doing multiple things at the same time on MCUs that generally do not work anymore on the very small ones. TinyOS is an OS designed for sensor systems that compiles to a static firmware for MCUs [13]. Threads in TinyOS differ from tasks in the sense that they are imperative and event driven using explicit atomicity annotations. Other solutions use a full-fledged Real-time Operating System (RTOS) such as ChibiOS, mbed or RTOS that just do not run on small MCUs. For example, QDuino that builds on the Quest kernel [14] or RT-Arduino, the Arduino extension offering an interface to the RTOS provided by the Erika kernel [15]. All these solutions have real threads and therefore require much faster MCUs than required for mTask.

D. Future Work

Stutterheim et al. described Task Oriented Software Development as an approach for developing TOP/iTasks applications in the multi-user web application domain [16]. The extension of mTask for integration with iTasks servers was hinted at in Section VI. This extension allows all layers of IoT to be programmed in one abstraction level, namely TOP. Different layers in TOP for web development match different stakes in software development. It might be the case that this holds for the MCU domain or both domains at the same time as well.

Gay et al. described how to implement several design patterns from Object Oriented Programming in TinyOS [17]. It would be interesting to see whether some of the design patterns have a dual in Functional and Task Oriented Programming as well by implementing them in mTask.

VIII. Conclusion

Creating multi tasking applications on MCUs is difficult with conventional means. The solutions either limits the flexibility or require much faster hardware. In TOP, tasks provide an abstraction on work that needs to be done. Task can be executed in parallel since they are automatically divided in atomic rewrite steps. The case study supports that creating multi-tasking applications for MCUs is very intuitive using a TOP language such as mTask. There is a high separation of concerns due to the fact that data, peripherals and tasks are modelled independently. The jobs that need to be done can often be literally translated to mTask tasks such that the program is very close to the design. Moreover, the seamless integration with iTasks allows entire systems to be programmed from one abstraction level.

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Designing Early Testing Course Curricula with Activities Matching the V-Model Phases

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***Abstract*—This work addresses the gap between software engineering process terminology in formal education, and the practical skills relevant to testing related work. The V-model is a commonly referenced description of how the software engineering processes are tied to the different software testing levels. It is used in software engineering education to illustrate which type of testing work should be carried out during a certain development stage. However, the V-model is mainly conceptual and tied to the steps in the Waterfall model, leaving the students with little knowledge about what is actually done. To solve this problem, we propose an approach to map the V-Model development phases and testing levels with corresponding, actual testing techniques. We then evaluate the approach by designing the weekly topics, learning goals and testing activities for a 7 week introductory course on the basics software testing and quality assurance. Based on the course outcomes and recent literature, we discuss the strengths and weaknesses of the proposed curriculum.**

I. Introduction

Software testing and quality assurance (QA) form an integral part of software engineering processes and therefore should be an equally integral part of software engineering education. Testing education improves software quality, as testing-savvy students learn techniques that lead to more reliable program code [1]. For example, the ACM curricula for software engineering [2] integrates testing and quality assurance into other domains of computing education. However, the ACM curricula has been criticized for not conveying a strong enough testing and quality assurance mindset [3]. Our proposal to address this issue is to design concrete learning objectives and testing activities that follow the principles of constructive alignment [4], [5]. This approach carries over from our previous work in using constructive alignment, creating high-level guidelines for software testing education from the industry practices [6].

The motivation behind designing a dedicated undergraduate testing course and its activities was that currently software testing education research has mainly focused on the implementations of such courses and not in course content design. Although previous research has also established approaches to integrating testing and QA work into larger projects [7], [8], many institutions organize an undergraduate course in the methods and models of software testing separately. In addition, the software industry leaves a lot of responsibility in QA work to the shoulders of individual employees, while acknowledging that personnel do not always have the necessary skills in testing beforehand [9]. We therefore feel that the objectives of this study are of interest to many in higher education.

In order to place the testing activities into a software engineering context, we contrast them with the phases in the V-Model [10], [11]. The V-Model (see Figure 1) is a generic software development process model where requirement analysis, specification, architectural design, and detail design are linked with the levels of testing, namely acceptance testing, system testing, integration testing, and unit testing. These development process phases and testing levels are often referenced in software engineering education. However, in the education and training context, the practical impact of these activities may play an auxiliary role or even be neglected. Hence, students might be familiar with the development process phases on an abstract level but fail to understand which practical activities should happen within them.

To summarize, our research questions in this paper are as follows.

- RQ1. What learning activities can we map to the high-level testing concepts?
- RQ2. Which actual testing techniques can be utilized?

In order to answer the research questions, we used the principles of constructive alignment [4], [5] to design and implement an undergraduate course on the fundamentals of software testing. We planned the topics and activities for a 7-week (one period), first-year freshman course. The course had no other prerequisites except the freshman course on introductory programming. Various techniques for testing were adapted from Swebok [12] and the ISO/IEC Software testing standard, which covers a multitude of testing techniques in ISO/IEC 29119 Part 4 [13]. These testing techniques were used as a starting point for designing assignments demonstrating the practical testing work on each testing level. Additionally, these topics and learning activities were mapped to fit the V-model, so that students would be able to relate the practical testing work conducted during this course with software engineering process steps in their later studies and working life.

The rest of this paper is organized as follows. Recent studies on software testing education are presented in

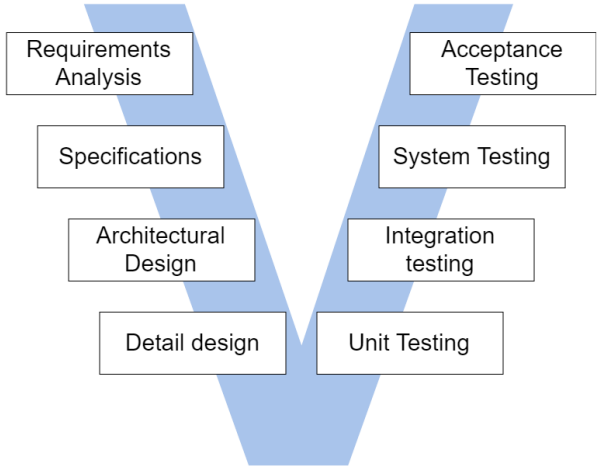

Fig. 1. The software testing V-Model, adapted from [11]

Section 2. Section 3 introduces our course implementation and its results. Discussion and implications are discussed in Section 4. Finally, we conclude in Section 5.

II. Related Work

Educators face challenges when it comes to testing concepts. For example, students find it difficult to digest testing concepts unless they are introduced one at a time [14]. In addition, many instructors do not have the necessary knowledge that should be taught to students [1]. Additionally, the motivational aspects especially in technically challenging topics are well-known factors influencing the outcomes of a learning scenarios to a significant degree [15].

Testing course content has been studied in different countries, for example by Šošić in Serbia [16], Bin in China [17] and Kasurinen in Finland [18]. According to Kasurinen, students want software testing education to be practice oriented, using real-world tools with a real software project to promote the motivational aspects of learning something practical, which provides skills applicable in real-life software development work.

Experiences from running traditional university courses in software testing, or software verification and validation, have been previously reported by Mishra et al. [19] and Lopez et al. [20]. Van Eijck et al. [21] designed a flipped classroom version of the testing course in addition to bundling the course contents around Microsoft's developer software [22].

Gamification in education is a rising trend in the testing field. Fraser [23], Valle [24], Fu [25], and Soska [26] all present recent approaches for gamifying software testing education. In general, gamification can be used to increase student motivation and communication [27].

Other approaches for increasing student motivation on the testing course include using large, real-world projects. For example, Krutz et al. [7] used open-source projects and Garousi industrial software projects [8]. Another interesting approach employed by Chen et al. infused research topics into the testing curriculum [28].

All in all there is an extensive body of related work to software testing education. The studies focusing on testing education at university level have been mapped in, for example, [20] or [29]. However, these curriculum design or testing course implementation studies have not been carried out with introductory software development courses.

This research gap in early software testing education has previously been addressed by Scatalon et al. [30], who point out that early testing helps build better understanding of the programming process, and testing is widely recommended to be addressed in the beginning of studies. However, the study also reveals that there are potential drawbacks to integrating testing into the first programming courses, such as additional workload on course staff, or students' negative attitude towards testing, favoring programming over testing. In this context we feel that a curriculum for a separate, early testing course is relevant to the software engineering educators.

III. Course Implementation

In the academic year 2017-2018 the course Principles of Software Testing was arranged in parallel with a basic course on C programming. The course population consisted of first year computer science students, and also students majoring in other technology programmes such as electrical engineering, mechanical engineering, computational engineering, and industrial engineering management. The objective of the course was to cover the most common software testing methods, give the students an overview of how testing and software engineering are related, and give the students the transferable skills to perform testing related work autonomously or as part of an organization.

We created the course syllabus by taking the high-level objectives and relating the required testing-related skills to the ones that can be acquired by mastering the V-Model. During the process we also mapped the development phases and testing levels from the V-Model to the set of weekly lecture topics on software testing practices.

During the mapping process we used the theory of constructive alignment as the guiding principle when setting learning goals and designing course activities. Constructive alignment is an outcomes-based approach to teaching in which the learning outcomes that students are intended to achieve are defined before teaching takes place [5]. Teaching and assessment methods are then designed to best achieve those outcomes and to assess the standard at which they have been achieved. The teaching environment, practices and evaluation should support learning goals and the student's future environment [4]. We summarize the principles of constructive alignment [4], [5] as follows:

- Learning goals should be clear, serve a purpose, and set in advance.
- Students need to be placed in situations and environments that elicit the required learnings, with declarative teaching minimized.

- Students are then required to provide evidence, either by self-set or teacher-set tasks, as appropriate, that their learning can match the stated objectives.

In the next phase, we took different testing activities and test techniques, and placed them under the weekly lecture schedule. The testing techniques were taken from the ISO/IEC 29119 Software testing standard. The different testing activities were carefully selected to fit the development phase and test levels according to the V-Model activities. For example, Black-box testing and exploratory testing techniques were used as exercises on the system testing level, whereas the unit testing level used the White-box testing approach. Similarly, state transition testing, scenario testing and random testing were used as the approach to specification and requirement analysis, while the classification tree method was used on the integration testing level.

In total, the course consisted of seven weeks of instruction in the form of lectures and voluntary exercise (tutoring) sessions. The weekly course topics are presented in Table I.

The concepts and skills covered in the course material were assessed in two parts: First, the students performed, reported and planned a small-scale testing project using a small console application. The students were given the source code, and a manual detailing the different modules and source code files. The assignment was completed in groups of 2-3 and it accounted for 35% of the total course grade. A written exam worth 25% of the grade formed the second part of course assessment. Voluntary weekly exercises, also completed in groups, formed the rest of the course grade, but the emphasis in grading was on the project and the exam.

The testing project was graded by the head teaching assistant based on the completion of five individual parts. Parts 1 and 2 consisted of system testing activities. First, the tests were completed manually using exploratory testing as the main method. Then in part 2 the task was to automate some of the test cases developed in part 1 by recording the inputs and program outputs during the test.

In part 3 of the project we tasked the students with writing unit tests for individual modules of the software. Part 4 was an exercise in testing work from a managerial point of view, and students were to develop a testing plan for the project software as if it was a real product by a real software company. Part 5 consisted of reporting the whole project and documenting in the write-up which test cases they had developed, which of the test cases were automated, and what unit tests were added to the project repository. Additionally, the report included testing logs and bug reports from the manual system testing phase.

The project's problem description did not specify which testing methods or approaches should be used in the different parts as one objective of the project was that students select a suitable method and justify it in the test plan. The various testing techniques had been covered previously in the weekly exercises, where tools for unit testing and test coverage were also introduced.

The final exam consisted of two essay questions about the concepts presented in the lecture material. The exam was graded by the lecturer.

Descriptive course statistics are presented in Table II. In the end a total of 124 students worked actively on the course assignments. The average project grade was 3.4 and the average exam grade 3.8 (on a scale of 1-5 in passing grades). In addition to the course deliverables, a post-course survey was also conducted. Unfortunately, even though the survey got a 15% response rate in relation to the course population, the number of actual respondents remained low, and only 10 students gave written feedback.

Observations from the student testing projects are summarized in Table III. The themes listed were collected from the written feedback on the project given by the teaching assistant to the students. Overall, 37% of the comments in the feedback were positive, and 63% negative pointing out flaws in the implementation or clear misconceptions in the report.

IV. Discussion and Implications

In assessing the proposed curricula, it is necessary to highlight the importance of an early testing course. Some approaches to software testing education emphasize using big, real world projects as the basis to prepare graduates for work in the industry (for example [7], [8]). However, as students first go work in the industry as early as 1.5 years into their studies [31], this approach can be difficult to employ early on.

The ACM Curricula Recommendation for undergraduate software engineering programmes infuses software verification and validation into larger projects and courses [2]. We take a step back and ensure the students have familiarized themselves with testing, verification and validation on the dedicated testing course. Our approach to teaching the testing discipline complements the approach of the ACM Curricula Recommendation: Once the students have acquired the appropriate testing mindset the testing skills can be used in other software engineering and computer science projects.

Next, we summarize the findings from our course by addressing the individual research questions. To answer RQ1, what learning activities can we map to the high-level testing concepts, it is possible to complete activities on all testing levels. The activities can vary from black-box to white-box testing, system testing to unit testing, or something in between.

For RQ2, which actual testing techniques can be utilized, we created weekly assignments for students employing a variety of different techniques taken from relevant literacy, such as Swebok [12] or the ISO/IEC Software testing standard [13]. We incorporated a number of different techniques for deriving test cases on different levels, and additionally covering static testing methods and code reviews. In our course we used exploratory testing, equivalence partitioning, boundary value analysis, combinatorial methods, state transition testing, scenario testing, random testing and static testing in conjunction

TABLE I
THE WEEKLY ACTIVITIES, COVERED TOPICS, AND TESTING TECHNIQUES

Week	Development phase (V-Model)	Test level (V-Model)	Weekly covered topic(s)	Activities and testing techniques applied in them	Learning goals
1	Specification and requirement analysis	System testing	Introduction to testing. Objectives of testing	Black-box system testing. Exploratory testing. Boundary value analysis. Defect reporting.	Understand the objectives of testing work. Student is able to create (Black-box) test cases. Student understands the scope, and limitations of the black box methods.
2	Detail design	Unit testing	Testing levels. Unit testing	White-box testing. Test case reporting. Equivalence partitioning.	Understand the concept of unit / module test. Understand the difference between Black-box and White-box testing.
3	Architectural design	Integration testing	Integration testing	Combinatorial methods and the classification tree method. Test stubs.	Understand the infeasibility of "testing everything." Student is able to select a technique for deriving test cases. Student understands the scope, and limitations of the software testing in the real world software projects.
4	Specification and requirement analysis	System testing. Acceptance testing	System testing	State transition testing. Scenario testing. Random testing.	Understand the objectives of system-level testing. Student is able to select an appropriate testing technique for system testing. Student understands the scope, and limitations of the system-level testing methods.
5	Detail design	Unit testing	Test automation and tools	Implementing unit tests in code, using a unit testing framework	Student is able to use a programming framework / library to implement module tests. Student understands the scope, and limitations of the unit testing tools.
6	Architectural design	System testing	Testing processes, documentation and planning	Creating test plans. Code review and static testing methods. Test coverage analysis.	Student understands the purpose of static testing methods and code review practices.
7	Specification, architectural design, detail design	System, integration, unit testing	Visiting lecture from a software company	Course project: Plan, design, implement and document testing for a small software item.	Student is able to demonstrate their knowledge by applying the course's activities autonomously in the testing project. Student is able to explain how test process activities would relate to the whole software project.

TABLE II
DESCRIPTIVE STATISTICS FROM THE INTRODUCTORY TESTING COURSE

Students working in the course	124
Students with passing grade	117 (94.4%)
Group projects returned	43
Average project grade (median)	3.4 (4)
Average exam grade (median)	3.8 (4.5)
Respondents in the post-course survey (%)	19 (15%)
"The course implementation helped me to achieve the learning outcomes of the course" (1 - very poorly, 3 - neutral, 5 - very well)	3.33
"The teaching methods used on the course supported my learning" (1 - very poorly, 3 - neutral, 5 - very well)	3.39

TABLE III
THE MOST COMMON TYPES OF PROJECT FEEDBACK GIVEN TO STUDENTS BY THE TA

Unit tests did not check that the functions manipulated data correctly, only that their return value reported 'success'	49% (21)
Manual system testing was comprehensive	37% (16)
Objectives of the testing project were unclear or undefined	35% (15)
Unit tests were implemented without the use of a testing framework. The results of the tests were often presented in a way which required the tester to verify the results manually.	16% (7)
The tests seemed to only concentrate on crashing the program using only bad/sketchy inputs.	14% (6)
Unit tests were comprehensive, and tested the actual data manipulation	5% (2)
Amount of generally positive feedback comments given	37% (16)
Amount of generally negative feedback comments given	63% (27)

with unit testing, integration testing, system testing, writing test stubs and drivers, and analyzing test coverage.

In short, we introduced different fundamental testing methods and techniques which the students are likely to encounter in the real world software development to

give them some practical experience on the methods, as recommended in for example [17] or [19]. Our seven week course content is aligned with the V-model. This in our opinion makes it easier for students to grasp how the software engineering processes presented in theory relate to work with real projects, and bridges the gap between formal software engineering terminology and the real world.

Finally we discuss the course outcomes in the context of our original objective, creating learning activities for testing education early in the curriculum. The project as a demonstration of learning worked generally well. Especially in the first part of the project, exploratory system testing, the project reports presented testing comprehensively. Students were able to use the different techniques and approaches combined with intuition and creativity to sufficiently cover possible errors. Even if the reports did not directly name a particular method which was used in order to arrive to the test cases, it appears that the students were either formally or informally adequately familiar with these techniques.

However, there are still some issues which need addressing in our course. The other parts of the project proved to be more challenging for the students. For example in the second part nearly all groups successfully employed an automated system testing pipeline, but it was unclear what the students had set as the objectives for automated testing. In most cases the students had simply recorded test cases which they knew would fail, resulting in nearly all tests failing.

We can see that the problems revolve around defining the objectives and implementations of testing. In part 4 of the assignment, drafting a testing plan and test reports, the actual testing objectives were either shallow or neglected to a large degree. It seems that for the students the testing meant finding errors and making the program crash - and not ensuring that the program works, or conducting internal tests, not just checking the I/O interface. Based on these observations, it can be argued that the students mostly understood the concept of testing work itself as defined by Myers [32], but not the concept of quality assurance or quality control practices as defined by Kaner et al. [33]. However, testing levels were often referenced in the reports, meaning that students were able to place the testing work within the V-model, and based on activities, most teams also grasped the fundamental concepts of using testing frameworks as development tools.

On the other hand the course outcomes were, at least from our perspective, positive: Over eighty percent of the student groups successfully used a testing framework and automated tools in their project, with two thirds of the projects having defined objectives and purposes for the testing work, regardless of their quality. In addition, almost 95 percent of the students who started the course also gained a passing grade. As the learning outcomes were set beforehand in accordance with the constructive alignment theory, we can say that after completing the course most students demonstrated at least an adequate level of knowledge in the software testing field.

V. Conclusions

The objective of this study was to map high-level learning objectives into concrete testing activities, and to ground the testing activities firmly into the software engineering processes by using the V-Model as a starting point. In order to accomplish this objective we designed an introductory software testing course, and using the principles of constructive alignment, mapped learning goals to actual weekly activities and testing techniques.

We assessed the course curriculum by examining the outcomes of our seven week testing course. Student's practical assignments were used as demonstrations of learning. We observed from the projects that students were able to adopt the testing mindset and carry out comprehensive and systematic testing on the system testing level. On the other hand, this systematic approach to testing work was mainly carried out on the system level, while many projects had problems with unit tests, integration tests and reporting of the project.

The limitations of the study and the validity of the results warrant some discussion. The assignment reports written as group work are of course not the perfect instrument to measure the learning of individual students. However, as the assignment was split into multiple subsections with each section focusing on individual activities (exploratory testing, system testing, unit testing, test planning and documentation), it was easy to see which concepts the students excelled in or struggled with.

Additionally, the lecture material and the reference book [34] used in the course will most certainly have had a significant impact on the student's perception of testing as a whole. If the reference material is biased towards some topics or does not cover a concept well enough, it can be expected that the student reports follow the same shortcomings. In our case, the course material covers all the concepts expected in the assignments. On the other hand, due to the practical limitations some content discussing more advanced topics had to discussed only on a high level.

As future work, one promising approach would be incorporating a knowledge acquisition measurement algorithm such as ACT-R or BKT to assess the student performance and learning during the course in order to establish which course components require more refinement. Other prospective area of interest would be the integration of the advanced topics, and including a larger project work, which integrates both the software engineering and software testing methods into one capstone assignment.

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Software Evolution and Profiling in a Competitive Environment

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***Abstract* - In this paper, we present our experience with software evolution and profiling at Master level of a technical university. We defined a set of tasks to find and solve an issue of an existing open source project on the web, extended by software profiling and improvement. This improvement has to be proved by application of a suitable software metric as well. The main aim of such a task is to emphasise the importance of program comprehension in software evolution. Our teaching approach on software evolution addresses comprehension in three ways: read, measure and use. Reading code is also important when preparing for evolution, measuring gives a second view on the system, but trying it out is the only way to complete comprehension. We also focus on the difference in students' behaviour that shows a kind of sobriety. We think this modest approach comes from the lack of experience and identify the need for change.**

Keywords - software evolution; profiling; measurement; student competition; open source

I. INTRODUCTION

Teaching software engineering is a challenge. It requires a strong focus on new technology and techniques [24]. For students, it is even a bigger challenge to pass a subject on software engineering.

Software is created, then evolved until it can serve to an aim. Evolution requires a certain level of comprehension to keep the quality of code acceptable and the evolution itself stable. Our teaching approach on software evolution addresses comprehension in three ways: read, measure and use. Reading code is also important when preparing for evolution, measuring gives a second view on the system, but trying it out is the only way to complete comprehension. The problem is that comprehension is not a fast process, therefore it is harder to measure when one has a limited time such as the length of a semester. To deal with this problem, we have to find software that is interesting to students, of a medium or smaller size with existing real-life issues. These requirements could be met by open source software from an issue tracking repository such as GitHub. One way of student motivation is to define a competition. We assumed the motivation to contribute to open source will have a positive impact on testing activities as well.

Software engineering is a complicated topic also because there are both well defined and less defined sub-topics included. While some topics can be presented mainly based on definitions, others require many examples to reach the same level of comprehensibility. This comprehensibility is addressed by the Intellectual outputs No. O1 and O2 of the Erasmus+ Key Action 2 (Strategic partnership for higher education) project No. 2017-1-SK01-KA203-035402: "Focusing Education on Composability, Comprehensibility and Correctness of Working Software" [2], [4], [9], [10], [22].

The focus on this paper is to present application example of the above mentioned Intellectual outputs. Applicability is not a question here. While teaching a subject containing selected parts of the teaching material, we had to face a serious problem. Although students had a significant software development experience as all of them participated on real projects at software companies besides their university study and we created a competitive environment, the majority of them was unable to perform any profiling of the software even that providing software evolution of the same software was successful.

Why profiling? Program comprehension is based on static and dynamic techniques. Static techniques are based on code analysis [8] while the dynamic ones require to build and run the system. Different levels of dynamic analysis could be identified starting with simple simulation (trying out the system), continued by more systematic black box testing to discover functionalities through white box testing to prove internal concept comprehension up to performance testing and profiling to discover limits of these implemented functionalities.

While by the earlier techniques one gains some basic comprehension, the latest one - profiling - provides a comprehension of the limits of the system as well. Another added value of performance testing to comprehension is by the systematic test case reuse. One has to rewrite existing test cases to cover a bigger part of the system or to extend the test base to increase data coverage by permuting and combining inputs and expected outputs. An even higher level of comprehension can be developed by guessing or calculating new expected outputs from the specifications.

As stated above, profiling and performance testing improves program comprehension in a significant volume, it provides a better understanding of all code-, component- and configuration-level.

We think that profiling is especially necessary in the case of software comprehension for predictive maintenance and evolution [6]. Other methods of software quality measurement such as white box and black box testing are also important, but profiling supports achievement of a new point of view on the software. This

new point of view also offers a better look at the non-functional requirements, and might also discover undocumented limits of the software application. The knowledge of limits helps to define new goals of improvement and to predict user-reported software failures caused by its behaviour close to the performance bottlenecks.

In our situation, profiling has been divided into three parts:

1. Did the students apply any performance metrics?
2. Did they identify any performance bottleneck (regardless on the use of any metric)?
3. Were the students able to improve the performance of the software by implementing a software change?

These results will be analysed in the upcoming sections of the paper, but first we present most significant related work in Section II. In Section III, the setup of the competitive environment at the university is described. The measurement method and sample selection is presented in Section IV. Analysis and discussion of results is located in Section V. Conclusion and future work is stated in Section VI.

II. Related work

Introducing competition into teaching is not new, all gamification in learning does that. Developing software from scratch [1], [7] has its favours too, but using open source projects in software engineering classes also has its proven benefits [20], mainly because of the need of comprehension of source code very often written using a different coding style and because the choice of technology and tools is done by others [3]. Results of [3] show that working on existing open source projects gives students a more realistic experience. The project 2017-1-SK01-KA203-035402 also focuses on comprehension, correctness and composition of software artefacts when engineering working software, its intellectual outputs published in Technical Reports of ELTE Faculty of Informatics [2], [4], [9], [10], [22] are proofs of that.

Software is user-centric, which means that the first focus is on the user interface [5] during development and testing. In later development phases, this focus is redirected on correctness of functionalities and specific routines [19]. At the end, performance in different aspects is improved.

First contact with a software is usually at user level — simulation of known and/or expected behaviour of the software. Second contact in the case of software developers used to be a look at the code [13]. This contact with the software used to be the first point to decide on maintainability in a subjective way. If the code is "ugly" [15] in any meaning such as style or language, evolution loses on speed right at the beginning as style [14] has to be improved first to prepare a smoother further maintenance and bug prediction [13].

Debugging of functionalities requires access to runtime information that is collected mainly during simulation or testing of software [16]. Authors of [21] use source code annotations for that, which technique is applicable when the author of the annotations is highly familiar with the aspects and concerns stored in the code. Adding such annotations to an existing codebase could be also considered as predictive maintenance [13] technique or even code quality improvement kind of software evolution.

A sound performance improvement topic for cloud computing and mobile computing [11], [12] is energy efficiency. This topic has a specific position in our curricula as well [24] and was also aimed to get evaluated during student competitions. Mobile platforms such as the Android ecosystem offer a well defined interface to energy profiling [18] of applications using tools, libraries or built-in mechanisms as well. These mechanisms and tools do not measure energy consumption only, but point out other performance data as well because of the strong correlation between these data and energy consumption of software. In general, there is no OS limitation on performance profiling [23]. The topic is old enough in practice that there is a tool for any operating system. Programmers can also build their own tools for specific purposes if the precision or fidelity of the measurements offered by existing tools is insufficient. The authors of [17] did it for the C++ language.

III. Environment setup

The measurement environment was set up in the frame of labs of a software systems evolution subject.

Student task definition: join an open source project on the internet, solve at least one software issue and improve the overall quality of the code.

Open source project has to be registered with a versioning and/or issue tracking system for transparency in activity tracking. Each student has to provide a link to the issue, including a public comment in the discussions section to that issue stating she will start solving it.

The issues cannot be created by a student of the subject. Non-trivial issues are more welcome. An issue is considered trivial if it can be solved without any coding or the coding does not require any in-depth analysis of the existing codebase. E.g. a "good" issue is a bug report or an extension request that by its nature requires a larger change in the existing codebase.

Improvement can be defined as fixing a bug, extending functionality and/or performance enhancement. The latest is the source of the problem we analyse in this paper. Performance enhancement requires to know a state of the software to be improved such as a bottleneck in performance. Further analysis is required to comprehend the relations between the bottleneck and the codebase, which is still just the starting point for an improvement.

Anything to be done in the frame of such task needs a portion of luck and intelligence - the person needs to reach a good enough comprehension of both the codebase and operating environment of the software.

On the other hand-side, searching for a bottleneck can be made easier using software profiling tools.

We suggested usage of IDE builtin or plugin profiling tools, in the case of their non-existence, specialised or generic tools could be also used. A specific focus was given to energy profiling as these concerns are resulting from combination of other performance measures and often could be improved easier as just focusing on a faster application or on one with a more effective memory usage. Applications relying on non-optimal database queries are an exception, but with an energy profile besides the speed performance, students would recognise

side-effects of focused code optimisation on other performance metrics.

Code improvement could be proven by presenting the measured characteristics before and after the implemented change. For this purpose, any chosen one or combination of software metrics could be used. We preferred those implemented in the used development tool.

IV. Measurement method

The measurement was performed in several steps. First, compliance to the time constraints was evaluated. Then, quality indicators of the selected issues and projects were evaluated. The performance related sub-task was the one most in our current focus.

A. Time Constraints in the Experiment

The competitors had 2 weeks to find an issue and join the project, another max 2 weeks to solve the issue. They also had 4 weeks for profiling and improvement if they were able to identify a bottleneck or other issue was detected/identified.

B. Student Motivation

To motivate the students to attend the competition, we have defined the possibility to achieve a bonus for the top players of the competitions. This bonus was the right to self-assign a question at the verbal part of the exam. The task on evolution of an open source software itself was the main task for the semester to all students.

C. Student Competition

The competition started at the first week of the semester and had several rounds to present a better overview on student activity (and project quality). The rounds are as follow:

- CR1. Who can take the best issue? Here we had a threshold value of 10 KLOC defined over the sum of estimated size of the issue solution and size of the whole codebase to be (partially) understood during the software evolution.
- CR2. Testing. Testing as a tool for software comprehension is an activity assuming the presence of soft skills related to creativity and curiosity. To be able to measure both actual state and progress of quality, code coverage by tests has been evaluated. In addition to that, one could receive a higher evaluation score if using test doubles in at least one of the test cases.
- CR3. Profiling. There are different aspects that could be used for profiling, which aspects are usually determined by a profiling tool and, tester experience often only plays a second level role. Profiling usually consists of measuring and data analysis to find a bottleneck of the system operation. In our case, a reaction to the achieved measurement results was also expected so that the repeated profiling over the evolved version of the software confirms a partial improvement of the profile. Depending on the application domain and implementation architecture, there exist suitable metrics for profiling.
- CR4. DevOps. A specific part of the comprehension process is the automation of selected steps for build and version management. When this level is achieved, there is enough knowledge collected for installation and a more generic evolution as one comprehends to the production, testing and operating environments of the software. In this specific case, own measure was used based on the number of DevOps toolchain elements used and total student effort needed for a successful use. As many projects already adopted DevOps, our evaluation also rated the level of software project structure analysis and comprehension in the case of presence of major DevOps toolchain elements in the original open source project.

V. Results

A. Problems Discovered

As the units of the experiment were students, it was obvious from the beginning that some of them will try to ignore all extra tasks or simply focus on the achievement of the minimum required score as fast as possible by not reacting to any more difficult possibility offered by the main task.

The discovered levels of student reaction could be classified into three categories:

- Incompetence, impotence or ignorance (I), where the student does not search or ask for advice to proceed with the task, just gives it up.
- Laziness (L), where the student has some at least basic knowledge to fulfil the task, but she decides to skip it. Usually because the score she can achieve is not really required by her.
- Bad luck (B), where the student tries her optimal or higher performance but someone is better in solving the issue. The main occurrence of bad luck is when two or more students select the same issue/task but there could be only one of them really solving it, obviously.

The above described situations were less typical for any competition round. Ignorance, laziness and bad luck were found happen in all of them. In CR1, there was a higher occurrence of B because of the parallel execution of the round with the Hacktoberfest. Hacktoberfest also influenced the strength of the selected issues - unfortunately negatively as students were able to find a large number of easy to comprehend problems, sometimes self-explaining ones. During CR2 to CR4, I or L were more typical, but a number of these could be a result of B in method selection for the specific competition round.

B. In Focus: Profiling

As we already announced several times since the abstract, our main focus in this paper is on profiling - CR3. Students failing this competition complained about the hardness of fitting and executing any profiling method they knew. We could classify these situations as B by the assumption that the chosen projects were specific in a kind. Much more typical was the I/L-case, when the students declared that they did not want to score in CR3 but they focus on the other 3 competition rounds. They also marked CR3 to be hard to complete because of the fact that the topics of all other competitions were already addressed by other subjects they already passed. Many students did not like the relatively new topic among the older ones and chose the lighter way saying “not everyone is competing for the highest score”.

I. TASK/STAGE FULFILMENT IN COMPETITION ROUND 3 FOR THE SAMPLE OF 47 STUDENTS

Stage	No. of students	% of students
Measuring performance	11	23,4
Finding a bottleneck	12	25,5
Improving the code that also performance improves	10	21,3
Passing all three above stages	8	17,0
Passing at least one of the three stages	15	31,9
No stages fulfilled	32	68,1

Those who passed the competition found metrics as processor load, memory usage, network traffic or energy consumption applicable. Their count was very low. Only 8 students were able to complete the whole task-set for profiling and improvement of a sample of 47 students, but some more students made it to measure or point out a bottleneck or improve by luck without proper measurements. Details are shown in Table I.

It was also interesting that 3 of the 8 projects were smaller in size than 10 KLOC, the other 5 were a bit bigger. We also have to mention that profiling was more successful with projects of native applications, while solutions for the web represented a harder profiling task for our students.

At the verbal part of exams, three questions were randomly assigned to each student. In the list of 53 questions, there were four that could be related to profiling or performance testing. Questions are published online in the first week of the semester. The list includes questions on Program comprehension and supporting tools (Question No. 28), Green software (Question No. 48), Invasive (Question No. 49) and Non-invasive measurement of software (Question No. 50). Despite the presence of the possibility to self-assign a question, no one chose any of the four profiling related ones. That would only mean that there are easier questions in the set, but two times assigned the student skipped the answer and another 6 times the answer was insufficient. For us, it already means that students dislike the topic, they probably do not see its importance. Further analysis of the results can be made based on our data presented in Table II and III.

II. STUDENT ANSWER EVALUATION IN THE SOFTWARE PROFILING RELATED TOPICS OF SOFTWARE EVOLUTION

Question No.	Times asked	Average score of 10
28	6	7,83
48	6	6,67
49	5	6,4
50	5	5,4

III. STUDENT ANSWER EVALUATION DETAILS IN THE SOFTWARE PROFILING RELATED TOPICS OF SOFTWARE EVOLUTION, EMPTY CELLS OCCUR BECAUSE OF A LOWER NUMBER OF TIMES ASKED.

Question No.	Answer evaluation (max = 10, skipped = 0)					
28	10	7	8	7	10	5
48	10	1	9	9	5	6
49	10	9	0	10	3	
50	0	2	10	5	10	

VI. CONCLUSION

We were focusing on the reactions and performance of students of Informatics study programme at our university while implementing a software evolution task of an open source project. They might be users but no maintainers of the object of the evolution, thus they required to increase or gain a required level of comprehension of the system to be able to evolve it. Suggested comprehension techniques were such as white box testing, performance profiling, project structure analysis and code inspection — all these are being addressed also by the intellectual outputs O1 and O2 of the 2017-1-SK01-KA203-035402 project. Combinations of the above were evaluated as part of the grading process of a related teaching subject. Most probably because of the lack of FP language projects and the OO profilation of the students, some aspects of the 2017-1-SK01-KA203-035402 project outputs were not covered.

The evaluation showed that profiling is marked as the hardest task by the students, and that in both practical and theoretical aspects. On the other hand-side, it is a strong filter to select students with the best analytical skills required for software comprehension.

We hope that the students learned that if they are not able to test, profile or comprehend the whole system, they will be still able to successfully introduce small changes into separated parts of that system under the condition they achieved the required level of comprehension of that specific software unit at least.

Open questions are:

How to motivate the students better? How to increase the competition that it becomes a common topic among all students? Students already know each other. This transparent knowledge of diversity might lower the enthusiasm in the average or below average students unfortunately. To provide equality principle in grading (as this has to be based on a global standard), but also offer equity to the average and below average students to reach the level of extraordinariness is a very hard task.

How to measure and evaluate better? This question is related to the metric system used in the competition rounds. We know that size metrics do only partially express the hardness of comprehensibility of the codebase and operation environment required for a quality evolution. Maintenance index or a variation of it could be one solution, although many programmers do not consider this calculations very useful.

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Project-Based Approach to Teaching Event-Driven Simulation

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***Abstract* - Project-based learning emphasizes gaining new skills and knowledge by exploring and solving real-world problems. This should capture students' interest and motivate them to invest substantial effort in the knowledge acquisition and practical application. In this paper we describe and evaluate an implementation of the project-based learning to a graduate course focusing on the event-driven simulation. To create simulation models, the course uses Coloured Petri nets. It is a modelling language, combining the diagrammatical form of Petri nets with the Standard ML functional language. The paper describes the curriculum of the course, shows how the project-based approach is incorporated into it and analyzes several aspects of the student projects.**

Keywords - project-based learning, modeling, simulation, Coloured Petri nets, Standard ML

I. INTRODUCTION

The project-based learning (PBL) is a student-centered pedagogy. It can be defined as "an activity in which students develop an understanding of a topic or issue through some kind of involvement in an actual (or simulated) real-life problem or issue and in which they have some degree of responsibility in designing their learning activities" [1]. As the bibliographic study [2] shows, PBL is gaining significant attention in the engineering education, from both the practical and research point of view. This is only natural as more and more countries are entering so-called universal higher education stage [3], a stage where more than half of the corresponding age group enters higher education. The work [2] names several positive aspects of PBL that have been confirmed by corresponding research studies. These aspects include student motivation increase, improvement of practical solution finding skills and improvement of academic performance and marketing. Several cases of a successful PBL implementation in university courses have been documented. For example, a power system modeling and analysis course at CQUniversity in Australia [4] and control engineering courses at China Three Gorges University [5].

In this paper we present another successful PBL application. It is an application to a graduate Modeling and Simulation (M&S) course, taught at the home institution of the author. The M&S course focuses on the event-driven simulation with Coloured Petri nets (CPN) [6] as the modelling language. Similarly to [5], the reason to utilize PBL was the higher education universalization. The universalization required a shift from a theory-oriented to an application-oriented approach. The course applies a hybrid form of PBL, which, in accordance with [4], combines PBL with classical lectures. However, in the case of the M&S course, the lectures are not used only to present the necessary theoretical knowledge. They also demonstrate how the students should carry out their projects in the PBL part.

The rest of the paper is organized as follows. Section II provides an overview of the M&S course. It also describes a plan the students follow when developing their projects in the PBL part of the course. Section III introduces supporting facilities for the PBL part and presents a simplified version of one of them. The presented facility is a small-size simulation study, which development is demonstrated during the lectures of the course. Section IV analyses several aspects of the projects, developed by the participants of the most recent run of the course. The paper concludes with a short evaluation of the PBL implementation.

II. PBL IN MODELLING AND SIMULATION COURSE

The M&S course is a 13-week optional graduate (master) course with two hours of lectures and two hours of practices per week. As it can be seen in Table I, the course starts in a traditional fashion. The traditional part includes the definition of basic terms (week 1), mathematical models of various types of systems (weeks 2 and 3) and selected topics, related to the event-driven systems (week 4). This is complemented by practices, where corresponding exercises are carried out by students. For example, during the 2nd and 3rd week the students design simple continuous-time simulation models in the *Scilab/Xcos* dynamic systems modeler and simulator.

A. Project-Based Teaching Implementation

The project-based approach is applied from the fifth week till the end of the course (gray background in Table I). Here, the students work in groups of two or three on projects. The projects are simulation studies of the system analysis type. Such study consists of a creation of a simulation model of an existing system, an introduction of certain modifications to the model and an evaluation of

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the modifications by simulation experiments. The modifications are introduced in the hope of improving the performance of the modelled system and the experiments evaluate the improvement. The simulation models are of the event-driven type. They are created and simulated in the *CPN Tools* software as timed CPN.

TABLE I. M&S COURSE CONTENT

Week	***Topic***
1	Introduction and basic definitions (system, environment, structure, behavior, similarity, model, simulation study, etc.)
2, 3	Taxonomy of systems and corresponding mathematical models (static/dynamic, linear/non-linear, continuous-state/ discrete-state, time-driven/event-driven, etc.) Continuous simulation
4	Random numbers and queuing systems
5	Basic concepts, structure and behavior of Petri nets
6	Colors, color sets and data expressions in CPN
7	Timed CPN
8	Input data analysis and application of its results to CPN models
9	Collection of data from simulations in CPN Tools
10	Simulation experiments: execution and results analysis
11	Logic simulation
12	Project presentations and evaluation, part 1
13	Project presentations and evaluation, part 2

There is a dedicated execution plan for the projects, consisting of the following steps:

1. *Selection of the group and the process to be modelled (weeks 1-4).* The students form groups of two or three, based on their own preferences. They also choose a particular process for their projects. The process should be such that it can be modeled as an event-driven system and data about it can be collected by the students. In addition, it has to be possible to propose modifications of the process. These modifications will be evaluated by simulation. The process has to be from the real world, not a fictional one.
2. *Creation of a basic Petri net model of the selected process (weeks 5-6).* The model should capture the essence of the process, such as its activities and events, order of their execution, decision processes and distribution of resources.
3. *Creation of the final, timed CPN, simulation model (weeks 7-9).* The students update the model from the step 2 with an appropriate data representation, expressions and functions. Then they add delays and other values, resulting from the analysis in step 4. The analysis is carried out in parallel with this step. The structure of the final model is usually very similar to the basic one.
4. *Collection and analysis of data about the process (weeks 8-9).* The students observe the process and collect essential data, such as activity durations, time intervals between subsequent arrivals of customers or jobs and a number of available resources. Subsequently they analyze the data to find corresponding probability distributions. They should also record data about the overall performance of the process.
5. *Simulation experiments with the final model (weeks 10-11).* First, the students validate their models by running simulations and comparing their results with the overall performance data, collected in step 4. If there is a significant difference, they modify the models and validate again. After the successful validation, they modify the models to include modifications that should increase the performance of the process. Subsequently they run simulations to evaluate the impact of the modifications.
6. *Experiments evaluation and completion of the project report (weeks 10-11).* Each group prepares a report, which includes
   a. description of the modelled process domain,
   b. definition of the problem they decided to solve by the simulation study,
   c. description of the simulation model,
   d. description of the simulation experiments and corresponding modifications of the model and
   e. simulation experiments results.

   The conclusion of the report should evaluate the effect of the introduced modifications on the performance of the process.
7. *Project presentation (weeks 12-13).* Each group is given five minutes to present their project to the rest of the course participants. After the presentations the students rate the projects. This rating is later included in the project evaluation. The students are also encouraged to prepare short standalone video clips about their projects. The best video clips are then published via the *YouTube* portal[1].

The plan is designed in such a way that its steps match the topics of the lectures, presented during the corresponding weeks (Table I). Step 1 may occur before CPN are introduced, because the students already know what the system analysis simulation study is from the first lecture and event-driven systems are explained during the third lecture. The *Logic simulation* lecture in the 11th week doesn't belong to the PBL part of the course. During the early runs of the course it occurred in the 5th week. It was moved in order to start with the project-related topics as soon as possible. This change also created some time for students to finalize their projects without receiving any new information directly related to the projects. Some steps are intended to be executed in parallel, by different members of the groups. The last step of the plan is included to support students' soft skills development.

[1] https://www.youtube.com/watch?v=dFaRsnmXnt4&list=PLsgDYGdo42kfqY6miOfzCL0YXu8Nw8NFn

III. SUPPORTING FACILITIES FOR PBL

Considering different abilities of its participants, the M&S course provides three facilities to support and guide the students through its PBL part:

1. *Textbook with a complete simulation study*. The textbook [7] for the course contains a medium-size simulation study and covers all the steps of its development.
2. *Small-size simulation study development demonstration*. The CPN-related topics of the weeks 5 to 10 are taught by developing a simulation model and performing data analysis and simulation experiments. This is done directly during the lectures by the lecturer.
3. *Consultations and progress check*. The practices in the weeks 5 to 11 are devoted to the development of the projects. The lecturer's primary role is to answer students' questions and evaluate intermediate results.

The students are expected to develop a model of the size and complexity between the one created during the lectures and the one described in [7].

A. Small-Size Simulation Study

The example study, performed during the lectures, has two purposes. First, it presents the corresponding knowledge in a practical way. Second, it introduces so-called *key structures* that should be present in the models created by the students. How it is done is shown here, on a slightly simplified version of the study from the most recent run of the course in the winter semester of 2018. The topic of the study was the serving process of a small stand selling hot-dogs.

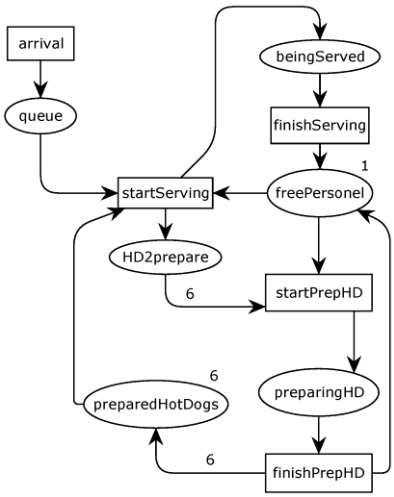

Figure 1. Basic Petri net model of the hot dog stand serving process

The result of the lecture in the 5th week was similar to the model in Fig. 1. During the construction of the model the basic principles of Petri nets (PN) have been explained. Namely, that PN have a graphical form, a bipartite graph with two types of vertices: places, drawn as ellipses and transitions, drawn as rectangles. The places hold tokens, which define the state of the net and the transitions can be interpreted as instantaneous events. A firing, or execution, of a transition changes the state by consuming existing tokens and creating new ones.

The net in Fig. 1 captures the basic workflow of the stand: A firing of `arrival` means an arrival of a new customer. This is represented by a token, added by the firing to the place `queue`. A firing of `startServing` means that one of the customers from `queue` is about to be served. However, this can happen only if at least three tokens are available. The first token has to be in the place `queue` and it represents a customer to be served. The second one must be in `preparedHotDogs` (i.e. a hot dog to be sold). The third token has to be in `freePersonel`, where it stands for an unoccupied employee, who is ready to serve the customer. After the firing of `startServing` a token in `beingServed` indicates that the customer is being served. The serving ends when `finishServing` fires. This also releases the employee by adding a token to `freePersonel`. The nodes `HD2prepare`, `startPrepHD`, `preparingHD`, `finishPrepHD`, `preparedHotDogs` and adjacent arcs represent a hot-dog preparation sub-process: After all 6 prepared hot-dogs are sold, the employee stops serving the customers and prepares a new batch of 6 hot-dogs. This model also shows the different roles the places may play in a Petri net. For example, the places `beingServed` and `preparingHD` represent states or activities of different entities while `preparedHotDogs` is a supply of resources.

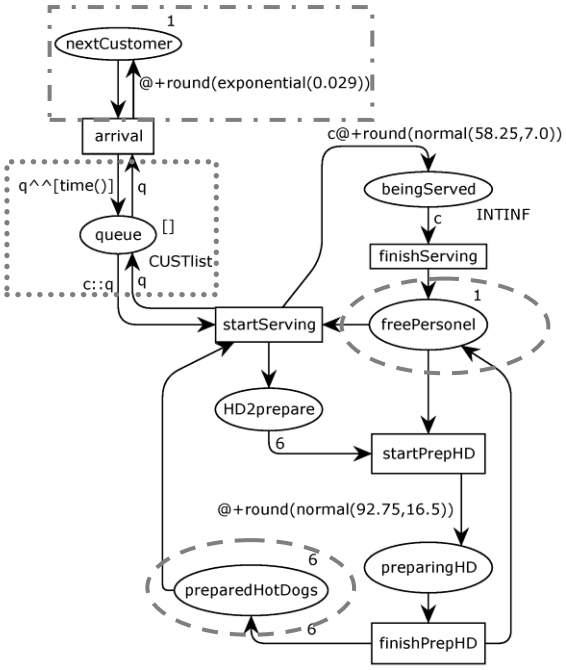

Figure 2. Final CPN model of the hot dog stand serving process with highlighted key structures

During the weeks 6 to 8 the net from Fig. 1 has been developed to the final form, shown in Fig.2. A new place, `nextCustomer`, has been added to the structure of the net. It is necessary for the implementation of a time

interval between two subsequent customer arrivals. The delay itself is defined by the expression

```
@+round(exponential(0.029))
```

which means that the delay is a random value, drawn from the exponential distribution with the parameter λ=0.029. Similar delays have been added for the duration of the customer service and hot-dog preparation. These random distributions and parameters follow from a data analysis, performed on the 8th lecture. The tokens representing customers now carry the time of the arrival. And the place `queue` always holds one token with a list of the waiting ones.

During the 9th lecture the model is extended by special functions, called monitors. These are used for simulation data collection. The 10th lecture deals with the evaluation of modifications by simulation experiments. In the case of the example study this means increasing the number of employees by changing the initial number of tokens in the place `freePersonel`.

The final model also shows three key structures:

- an arrival of customers or jobs (the grey dot-dashed rectangle in Fig. 2),
- a queue with the first-in-first-out queuing discipline (the grey dotted rectangle in Fig. 2) and
- a resource, human or material (the grey dashed ellipses in Fig. 2).

These structures correspond to the arrival, queue and service components of queuing systems. The students are expected to use them accordingly in their models; however they should not form the majority of the models.

IV. Diversity and Other Aspects of Student Projects

The freedom given to the students in the choice of the project domain leads to a significant diversity every year. During the most recent run of the course there have been 22 projects, covering seven domains (Fig.3).

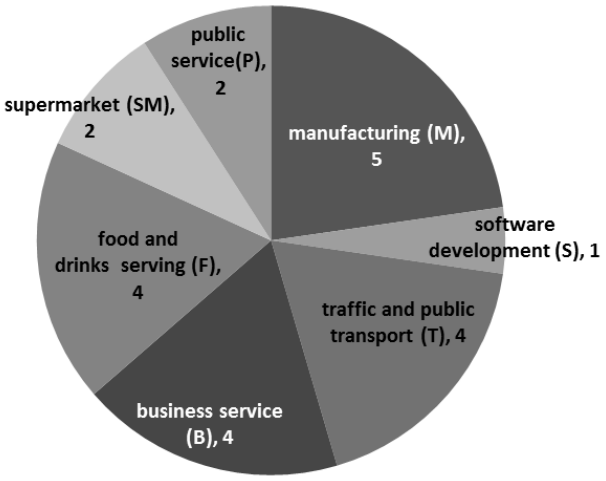

Figure 3. Domains chosen by students in the winter semester of 2018 and the number of corresponding projects

Eight of the projects required private access. These were all the projects from the manufacturing and software development domains, one from the public and one from the business service domain. They have been performed by students who are or are related to employees or owners of the corresponding enterprises and services. In the rest of the projects, the models have been created from the customer point of view. Naturally, the students chose businesses or services they visit, use or work for often. This minimized the effort needed for the data collection.

A. *Different Approaches to Process Modeling*

While most of the models, created by the students, share some similarity in structure and data representation, there are 2 to 3 cases that use a distinct approach every year. To illustrate these differences, let us compare two models[2], CPN_B and CPN_T, again from the most recent run of the course.

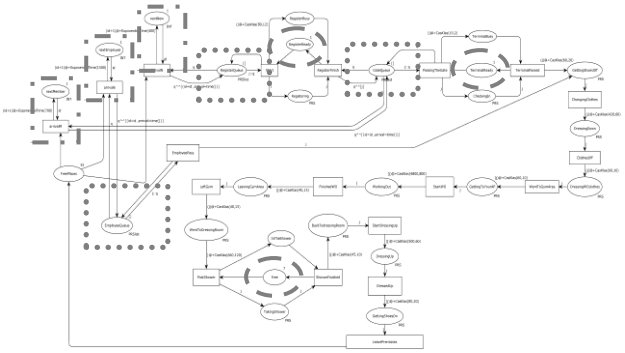

Figure 4. CPN model CPN_B from the business service domain with marked key structures

The model CPN_B (Fig. 4) is from the business service domain and represents the majority of the projects. It specifies the behavior of a fitness center customer – from the arrival through workout and showering to leaving the center. This model uses several instances of the key structures, introduced in the small-size simulation study. Three arrival structures are used for three different types of customers. The queues represent waiting for registration or payment. And the resources are showers and employees of the center. The most of the process is captured in the structure of the net and data structures and expressions are quite simple. The influence of the small-size study and the study from [7] is clearly evident.

The second model, CPN_T (Fig. 5), is from the public transportation domain and captures the passenger boarding and unboarding process for two bus lines. The arrival structures are used for bus deployment and passenger arrival. The busses represent the resources. Queues are used but not in the simple, straightforward, manner as in the small-size study or the model CPN_B: They are a part of data structures, stored in the tokens. In CPN_T the emphasis is on data manipulation and the structure is simpler than in CPN_B.

[2] The purpose of Fig. 4 and Fig. 5 is to present the layout of the models and to show how the key structures are used. Therefore, the inscriptions in them are not intended to be readable.

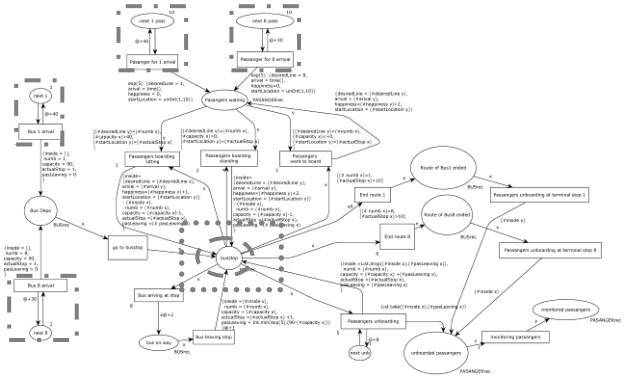

Figure 5. CPN model CPN_T from the public transportation domain with marked key structures

B. *Project Quality vs Presentation Ranking*

Each project has been evaluated for a maximum of 25 points at the end of the course run. The evaluation consisted of two parts: quality of the project, assessed by the lecturer (up to 20 points) and project presentation ranking, given by the students (up to 5 points).



Figure 6. Project evaluation results for the winter semester of 2018 M&S course

The evaluation results from the most recent run can be seen in Fig. 6. The graph show the points gained by the projects in the percentage of the maximum number of points for given part. Individual projects are labeled by shortcuts of their domains. The shortcuts are given in Fig. 3 (in brackets). It is evident that these two measures do not correlate. This is not surprising as the presentational skills of the students can be very different from the analytical and modelling ones.

V. CONLUSION

The implementation of PBL to the Modelling and Simulation course led to an increased student satisfaction and involvement in the education process. Students were motivated to search for interesting domains for the projects and have been willing to study and collect data about corresponding real-world processes during their spare time. The systems modeled ranged from easily accessible and common ones, such as pubs, restaurants and shops, to rare ones. The most exotic cases were a welding machines manufacture and regional elections from the election commission point of view. Because of the varying skills of the students, the quality of some projects was lower and some groups required increased involvement of the lecturer. Here, the provided supporting facilities proved to be very helpful. Most of the models, developed by the students, bore some resemblance to the example studies. However, the key structures, presented during the lectures, never formed more than 50% of the models. There is also a short version [8] of this PBL implementation, suitable for short-term courses, such as summer schools. It is more interactive and requires a greater amount of guidance from the lecturer. All the CPN models presented in this paper can be obtained by request from the author.

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Influence of Student Computer Literacy on Qualifications for Creating Virtual Learning Environments

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Abstract - This paper presents the results of research into computer literacy among students from informatics study programmes, and their qualifications in the area of creating virtual learning environments. The participants in the study were students from Serbia, Croatia, Hungary, Macedonia and Slovakia. It is evident that clear differences exist, but similarities as well in terms of computer literacy among students at technical universities in the region. Computer literacy is seen to influence the choice of methods employed for testing the effectiveness of web applications. It is necessary to make changes to the curricula at informatics faculties, and to highlight web usability terms, as well as to introduce subjects that will deal with testing web applications in the context of virtual learning environments.

Keywords: virtual learning environments, computer literacy, web applications, cognitive walkthrough

I. INTRODUCTION

Given that virtual learning environments (VLE) are becoming more accessible to students, and that limitations have largely disappeared when it comes to learning and work, particularly for those studying information technology, there is a need to explore student abilities and skills in the area of creating virtual learning environments independently. In the course of exploring this, we are able to compare the extent to which students are prepared to create virtual learning environments, from the computer literacy standpoint. However, global changes affecting our universities today call for guidance and agreement on defining teacher functions in virtual environments and their corresponding competencies [1].

One of the many uses of VLEs is that they provide opportunities for the designers to make use of various learning tools such as course announcements, online course documents, online or database self-assessment tests as well as making use of other online examination forms, and links to webpages that can aid learning. These tools provide students with the ability to make use of such resources as are not only convenient but also immediate [2].

II. THEORETICAL BACKGROUND

A. Virtual learning environments

A VLE is "a collection of integrated tools enabling the management of online learning, providing a delivery mechanism, student tracking, assessment and access to resources" [3].

The basic function and the main task of such systems is generally to enable students to design, organize and present courses easily. Due to the proliferation of information on the Internet, it is evident that a large amount of unverified or incorrect information is used by students completing assignments.

B. Research goals and hypothesis

At universities, there is autonomy in creating the study programme curriculum. Hence, there are many different study programmes that relate to IT. No research has been conducted which compares study programmes and their unification in terms of developing standard competences that IT engineers should have when creating virtual learning environments. This paper seeks to examine the habits of students from IT courses in different regions where they create virtual learning environments, as well as the use of information technology in general. It also aims to determine which evaluation techniques students use when testing the usability of their web applications.

The research hypothesis is: The choice of techniques when creating virtual learning environments, as well as the ability to test web application usability, depends on student computer literacy.

Sub-hypotheses: Students are familiar with the term web usability; Students practice testing the usability of their web applications.

Procedures that prove the existence of similarities or differences between subsamples confirm the hypothesis regarding similarity, or else reject it (they confirm the alternative hypothesis), i.e. indicate the existence of

differences. During hypotheses testing, the critical value of p is used, which indicates the risk involved in drawing conclusions. If $p>0.100$ there is no reason not to accept the initial hypothesis. To reject the initial hypothesis, two thresholds of significance will be used. In the case where $0.10> p>0.05$ an alternative hypothesis is accepted, with an increased risk of concluding, when $p<0.05$ an alternative hypothesis is accepted, and it is said that there are substantial (significant) differences.

Defining hypotheses for implemented procedures is performed in the following manner:

By MANOVA procedure, hypothesis H1 is tested, and it reads as follows:

H1 There are no significant differences between the subsamples for the observed thematic unit.

A1 There are significant differences between some subsamples for the observed thematic unit.

Hypothesis H2 is tested by discriminant analysis procedure:

H2 There is not a clearly defined boundary between subsamples for the observed thematic unit.

A2 There is a clearly defined boundary between some subsamples for the observed thematic unit.

C. Survey instruments

A questionnaire featuring 33 fields was created for the purpose of this survey. The first three questions relate to respondents' gender, year of study, and the faculties at which they study. The following operational tasks have accordingly been set in the research:

- to present basic parameters for student ability to create virtual learning environments, according to the faculty at which they study,
- to identify similarities and differences in abilities among students from technical sciences faculties to create virtual learning environments, according to the faculty at which they study,
- to define student characteristics for each faculty,
- to determine homogeneity among students from each faculty.

The area of this research consists of 5 thematic units:

- the ability of students to use computers, which is examined according to their potential to use Text (txt_ed), Picture (pic_ed), Sound (sound_ed), Video (video_ed), Animation (anim_ed), and Database editors(db_ed);
- student habits when using the Internet (the time students spend online, devices they use to access the Internet, Internet availability, the social networks they use);
- examining students according to their use of smart phones and their operating system;
- student characteristics in terms of using distance learning systems (Cloud technology, E-learning material, Online courses, E-learning technologies, experiences in creating e-learning materials);
- the ability to create virtual learning environments (most often the use of Web applications, creating WA experience, Web usability, Testing web applications, Usability testing with users).

Each assessment has 3 modalities: beginner (beg), medium (med) and expert (exp).

D. Participants and data collection

Participants in the research were students at the following faculties:

- Technical faculty "Mihajlo Pupin" (TFMP), Zrenjanin (97 respondents);
- Subotica Tech (ST) - College of Applied Sciences/Department of Informatics (33 respondents);
- Óbuda University, Budapest (6 respondents);
- Eotvos Lorand University (ELU) - Faculty of Informatics (74 respondents);
- South-West University "Neofit Rilski", Blagoevgrad (2 respondents);
- Faculty of Electrical Engineering and Informatics, Technical University (TUKE) of Kosice (206 respondents);
- University Goce Delcev (UGD) in Stip (63 respondents);
- University of Shkodra "Luigj Gurakuqi" Albania (1 respondent);
- Faculty of Organization and Informatics (FOI), University of Zagreb (176 respondents, students in the first year of undergraduate studies).

III. RESULTS

In accordance with the research goals, by means of a methodological approach and the set hypotheses, the difference within the 5 thematic units will be analyzed in the cause of this research. Based on the implemented analyses, we shall determine the characteristic of each subsample, as well as the distance between them, in order to calculate the contribution of characteristics, and the contribution of the thematic unit to the characteristics. This paper presents the results related to student computer literacy and its influence on qualifications for creating virtual learning environments and testing web applications.

TABLE I. CHARACTERISTICS AND HOMOGENEITY OF STUDENTS

	TFMP	ST	ELU	TUKE	UGD	FOI	dpr %
txt_ed	beg"	med"	exp"	-	exp*	beg*, med*	35.885
pic_ed	exp"	-	beg*	med*	exp*	beg"	20.574
db_ed	beg"	beg*	med*	med"	exp*	-	15.311
anim_ed	exp"	beg"	beg*	-	exp*, med"	med*	14.354
video_ed	exp*	exp"	beg*	beg"	med*	-	7.656
sound_ed	exp*	med"	beg*	beg"	med*, exp"	-	6.220
n/m	53/97	20/33	43/74	120/206	37/63	109/176	
%	54.64	60.61	58.11	58.25	58.73	61.93	

hmg - homogeneity; ctb % - contribution from marking according to characteristics

Based on the consideration and sample analysis of 649 respondents, in accordance with the applied methodology, the logical sequence of the research is to determine the that there is a clearly defined border between the faculty at which the respondent's study, i.e. it is possible to determine the characteristics of each faculty at which the respondent's study, in relation to the assessment on the use of computers.

The feature of each subsample is mostly defined by students with Text editor, because the contribution from marking the characteristics is 35.89%, followed by: Picture editor (20.57%), DB editor (15.31%), Animation editor (14.35%), Video Editor (7.66%), and Sound editor (6.22%). Homogeneity, TFMP is 54.64%, ST is 60.61%, ELU is 58.11%, TUKE is 58.25%, UGD is 58.73%, and FOI is 61.93%.

Based on the above, it can be said that 53 out of 97 respondents have TFMP characteristics, homogeneity is 54.6% (lower), which means that 44 respondents demonstrate other characteristics, and not the characteristics of their own group, and ST characteristics are seen for 20 out of 33 respondents, homogeneity is 60.6% (higher), because 13 respondents show other characteristics, ELU characteristics are seen for 43 out of 74 respondents, homogeneity is 58.1% (lower), because 31 respondents show other characteristics, while TUKE characteristics are seen for 120 out of 206 respondents, homogeneity is 58.3% (lower), because 86 respondents show other characteristics, and UGD characteristics have 37 out of 63 respondents, homogeneity is 58.7% (lower), because 26 respondents show other characteristics, also FOI characteristics are seen for 109 out of 176 respondents, homogeneity is 61.9% (higher), because 67 respondents show other characteristics.

TABLE II. GROUPING STUDENTS ACCORDING TO COMPUTER LITERACY

	distance
TFMP,FOI	.45
TUKE,UGD	.65
TFMP,TUKE	.71
TFMP,ST	.90
TFMP,ELU	1.26

The analysis will be conducted based on an assessment of student ability to use and create a virtual learning environment through their experience of creating Web applications, and years of experience in creating Web applications, Web usability knowledge, as well as habits during the testing of web applications, and habits during usability testing with users.

Based on the results it is possible to discern the characteristics of students from each faculty in relation to their experience in creating Web applications. Therefore, TFMP has a more expressed feature of N". ST feature is not defined. ELU feature is not defined, TUKE has a more expressed feature of Y", UGD has a more expressed feature of Y*, FOI has a more expressed feature of N*.

Since p=.000 $\chi 2$ –on the test, one can say that there is a correlation between the faculty at which they study and Web applications, since χ=.351 the correlation is low.

TABLE III. SIGNIFICANCE OF THE DIFFERENCE BETWEEN THE STUDENTS ACCORDING TO CREATING VIRTUAL LEARNING ENVIRONMENTS

	χ	R	F	p	k.dsk
wb_app	.351	.375	21.116	.000	.006
WA_exp	.391	.397	24.127	.000	.034
web_us	.123	.124	2.003	.076	.010
test_WA	.343	.346	17.485	.000	.135
test_user	.284	.242	8.002	.000	.037

Legend: k.dsk represents the discrimination coefficient

As p <.1 the alternative hypothesis A3 is accepted, which means that there is a significant difference between some faculties at which the respondent's study, in: Web applications (.000), Creating WA experience (.000), Web usability (.076), Testing web applications (.000) and Usability testing with users (000).

The discrimination coefficient indicates that there is the largest contribution to discrimination between the faculties at which the respondent's study in relation to web applications, i.e. that the difference is biggest, in: Testing web applications (.135), Usability testing with users (.037), Creating WA experience (.034), Web usability (.010), Web applications (.006).

A. *Characteristics and homogeneity of students in relation to creating virtual learning environments*

The feature of each student subsample is mostly defined by Testing web applications, because the contribution from marking according to characteristics is 60.81%, followed by: Usability testing with users (16.67%), Creating WA experience (15.32%), Web usability (4.50%), Web applications (2.70%), and the faculty at which they study (.00%). Homogeneity in TFMP is 50.52%, in ST it is 60.61%, in ELU it is 64.86%, in TUKE it is 55.34%, in UGD it is 60.32%, and in FOI it is 77.27%.Based on the above, it can be said that TFMP characteristics are seen for 49 out of 97 respondents, homogeneity is 50.5% (lower), which means that 48 respondents have characteristics other than the ones of their group, and ST characteristics are seen for 20 out of 33 respondents, homogeneity is 60.6% (higher), because 13 respondents have other characteristics, ELU characteristics are seen for 48 out of 74 respondents, homogeneity is 64.9% (higher), because 26 respondents have other characteristics, and TUKE characteristics are seen for 114 out of 206 respondents, homogeneity is 55.3% (lower), because 92 respondents demonstrate other characteristics, and UGD characteristics are seen for 38 out of 63 respondents, homogeneity is 60.3% (higher), because 25 respondents have other characteristics, also FOI characteristics have 136 out of 176 respondents, homogeneity is 77.3% (higher), because 40 respondents demonstrate other characteristics.

IV. DISCUSSION

The results of the above research indicate that the following are established:

1) the difference between the students (.000) in relation to computer literacy, at Text editor (.000), at Picture editor (.000) at Animation editor (.000), at Sound editor (000), at DB editor (.000), at Video editor (.001). The existence of the border (000) is confirmed for Text editor, Picture editor, DB editor, Animation editor, Video editor, and Sound editor.

2) the difference between the students (.000) in relation to the habits when creating virtual learning environments, at Creating WA experience (.000), at Web applications (.000), at Testing web applications (.000), at Usability testing with users (.000), at Web usability (.076). The existence of the border (.000) is confirmed for testing web applications, Usability testing with users, Creating WA experience, Web usability, and Web applications.

Based on the assessments of respondents on computer literacy, it can be said that:

- TFMP has the following characteristics: for Text editor, values are beg", for Picture editor, values are exp", for DB editor, values are beg", for Animation editor, values are exp", for Video editor, values are exp*, for Sound editor, values are exp*, and homogeneity is 54.64% (53/97).
- ST has the following characteristics: for Text editor, values are med", for Picture editor, values are -, for DB editor, values are beg*, for Animation editor, values are beg", for Video editor, values are exp", for Sound editor, values are med", and homogeneity is 60.61% (20/33).
- ELU has the following characteristics: for Text editor, values are exp", for Picture editor, values are beg*, for DB editor, values are med*, for Animation editor, values are beg*, for Video editor, values are beg*, for Sound editor, values are beg*, and homogeneity is 58.11% (43/74).
- TUKE has the following characteristics: for Text editor, values are -, for Picture editor, values are med*, for DB editor, values are med", for Animation editor, values are -, for Video editor, values are beg", for Sound editor, values are beg", and homogeneity is 58.25% (120/206).
- UGD has the following characteristics: for Text editor, values are exp*, for Picture editor, values areexp*, for DB editor, values are exp*, for Animation editor, values are exp*, med", for Video editor, values are med*, for Sound editor, values are med*, exp", and homogeneity is 58.73% (37/63).
- FOI has the following characteristics: for Text editor, values are beg*, med*, for Picture editor, valuesare beg", for DB editor, values are -, for Animation editor, values are med*, for Video editor, values are -, for Sound editor, values are -, and homogeneity is 61.93% (109/176).

Based on the research results on the habits when creating virtual learning environments, one can say that:

- TFMP has the following characteristics: for Testing web applications, values are "othr", for Usability testing with users, values are -, for Creating WA experience, values are no_exp", 2-4 y", for Web usability, values are -, for Web applications, values are N", and homogeneity is 50.52% (49/97).
- ST has the following characteristics: for Testing web applications, values are heur_eval", for Usability testing with users, values are summ_UT*, don't use*, for Creating WA experience, values are -, for Web usability, values are N*, for Web applications, values are -, and homogeneity is 60.61% (20/33).
- ELU has the following characteristics: for Testing web applications values arecog_walk*, don't use, for Usability testing with users, values aresumm_UT", don't use", for Creating WA experience, values are2-4 y*, for Web usability,

values areN", for Web applications, values are-, and homogeneity is 64.86% (48/74).

- TUKE has the following characteristics: for Testing web applications values are don't use*, cog_walk", for Usability testing with users, values arethk_al", for Creating WA experience, values are2- y", for Web usability, values are-, for Web applications, values areY", and homogeneity is 55.34% (114/206).
- UGD has the following characteristics: for Testing web applications values areheur_eval*, othr*, for Usability testing with users values arethk_al*, othr*, for Creating WA experience, values are2- y*, 5+ y*, for Web usability values areY*, for Web applications, values areY*, and homogeneity is 60.32% (38/63).
- FOI has the following characteristics: for Testing web applications, values are-, for Usability testing with users, values areeye_track*, "othr", for Creating WA experience, values areno_exp*,for Web usability, values are-,for Web applications, values areN*, and homogeneity is 77.27% (136/176).

When it comes to the assessment of respondents on the use of computers, the border is clearly defined between the faculties at which they study, and so it is possible to determine their characteristics.

V. CONCLUSION

We must find ways to discover how students respond to the content. For example: making sure you have accurate, consistent contents; focus on action points during each week's homework assignment. How many students are failing to submit their homework on time? How much revision have students engaged in over the semester?

The best web-teachers make it part of their weekly routine to interact with students. There is no greater skill you can develop than to have a deep understanding of how your students think. There is only one way to develop this: by consistent interaction with your individual students.

Test usability once per week. Monitor how each student tries to complete a task in a week.

In the research presented in this paper, we analyzed a sample of 649 respondents drawn from the population, which was divided into 6 subsamples according to the faculty at which they studied.

The main research hypothesis, that the choice of techniques when creating virtual learning environments as well as the ability to test the usability of web applications depends on the computer literacy of students, is confirmed.

Sub-hypotheses: students are familiar with the term web usability and students practice testing the usability of their web applications have not been confirmed, because it is observed that many students are not familiar with the term web usability, as well as that a small percentage of students practice testing the usability of their web applications. It has been noticed that there are clear differences, but also similarities in the computer literacy of students from technical faculties in the region. It has been noticed that computer literacy influences the choice of method for testing web applications. It is necessary to make changes in the curricula at informatics faculties, and to point out web usability terms, as well as to introduce subjects that will deal with testing web applications within virtual learning environments.

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Smart Education for Digital Economy

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Abstract - **Recently, artificial intelligence (AI) receive increasing attention within the field of developing smart digital education. Researchers have been used the computational intelligence (CI) and machine learning techniques methodologies to develop a smart tutoring systems (STSs). On the other side, the convergence of AI, data science and Internet of Things (IoT) is enabling the creation of a new generation of web-based smart systems for all educational and learning tasks. This paper discusses the CI and knowledge engineering paradigms for developing the smart educational and learning systems. In this study the two popular CI paradigms; case-based reasoning and ontological engineering are discussed and analyzed namely. The main objective of this study is to determine and exploration the benefits and advantages of such intelligent paradigms to increase the effectiveness and enhancing the efficiency of the smart tutoring systems. Moreover, the paper addresses the challenges faced by the application developers and knowledge engineers in developing and deploying such systems.**

Keywords - Knowledge engineering and management, Artificial intelligence in education, Smart tutoring systems, Computational intelligence, Machine learning.

I. INTRODUCTION

Currently, the large-scale digitalization of all spheres of economic activity is manifested not only in the mass introduction of information and communication technologies (ICT) in a variety of spheres of human activity, but also in the convergence, integration of the digital and physical world through the use of smart digital solutions. The digital economy contains a significant reserve for an improvement in the lives of the population of various countries around the world. Nevertheless, the use of the potential of smart technologies of digital economy is possible on condition of existence of enough the people having competences for development and application of such technologies. This puts forward new requirements for the education system, first, in terms of the development of new areas of training in universities in order to prepare highly qualified personnel for the ICT sector, and secondly, in terms of the integration of ICT competencies in all areas of training to expand the skills of application of smart technologies in all areas of economic activity, and thirdly, in terms of creating new educational models that are adequate to the requirements of the digital economy. In this case, it is important to speak about establishment of Smart education.

Smart education (SE) represents a collection of e-services that employ digital media and ICT for supporting educational processes. SE is interdisciplinary area, encompassing many aspects of the educational technologies that cover instruction, training, teaching, learning, pedagogy, communication and collaboration. Moreover, the field of artificial intelligence in education has become the most challenging area in the last several years [3, 4, 13, 14]. The goal of the field is to deliver knowledge-based software which can be used in real teaching, learning and training situations.

Theoretical research in the subject field and the development of the concept of Smart education are associated with the convergence of three interrelated areas: the design of new smart technologies (engineering paradigm), the development of digital economy (technological paradigm) and the transformation of the education system, university models, and labor market (innovative, economic, organizational and management paradigms). In this case, we are talking simultaneously about the transformation of educational models and processes and the modernization of technologies and teaching methods [1, 2, 3, 4, 5]. Various attempts to determine the research framework of smart education have been made in recent years in a number of scientific papers [6,7]. The researches cover an engineering perspective [8] and organizational and management issues related to the educational process [9,10]. At the same time, there is clearly an insufficient number of works considering these two sides of the formation of the system of smart education.

II. SMART TUTORING SYSTEMS (STSS) CHARACTERISTICS

Using AI concepts, computational intelligence techniques, and knowledge engineering paradigms, new forms of smart educational software can be created that allow the computer to act as a smart tutor. Such AI-based smart tutoring system (STS) can adjust its tutorial to the student's knowledge, experience, strengths, and weaknesses. It may even be able to carry on a natural language dialogue. In addition, automatic generation of exercises and tests is an important feature of STS.

STS is knowledge based software that act as an intelligent tutor used in real teaching. STS is also used in learning, and training situations. The main characteristics of such systems are the ability of reasoning, inference and based on static and heuristic

knowledge. From the technical point of view, STS is composed of the following software components: (a) expert model, (b) student mode, (c) instructional module, (d) interface and (e) knowledge acquisition module. STS components are complex to build and complex to maintain. For more technical information, see [11,14].

III. Knowledge Engineering Methodology for Developing Smart Tutoring Systems

A. Constructing the knowledge-base Process

This process includes, knowledge collection, acquisition, compilation and representation. In this respect, there are many knowledge representation and management techniques, e.g.; lists, trees, semantic networks, frames, scripts, production rules, cases, and ontologies [1,3]. The key to the success of such systems is the selection of the appropriate technique that best fits the domain knowledge and the problem to be solved. That choice depends on the experience of the knowledge engineer.

B. Selecting the reasoning and inference methodology

In this process, there are many methodologies and approaches of reasoning, e.g.: automated reasoning, case-based reasoning, commonsense reasoning, fuzzy reasoning, geometric reasoning, non-monotonic reasoning, model-based reasoning, probabilistic reasoning, causal reasoning, qualitative reasoning, spatial reasoning and temporal reasoning [12]. In fact these methodologies receive increasing attention within the community of AI-based smart tutoring systems industry [8, 13, 14].

C. Selection of Intelligent Authoring Shells

Intelligent authoring shells allow a course instructor to easily enter domain and other knowledge without requiring computer programming skills. The authoring shell automatically generates an ITS/IeLS focusing on the specified knowledge. It also facilitates the entry of examples/exercises, including problem descriptions, solutions steps, and explanations. The examples may be in the form of scenarios or simulations. It allows organized entry of the course principles and the integration of multi-media courseware (developed with well-known authoring tools) which includes descriptions of the principles or motivational passages. In addition to course knowledge, the instructor specifies pedagogical knowledge (how best to teach a particular student), and student modeling knowledge (how to assess actions and determine mastery). The most common authoring shells are DIAG, RIDES-VIVIDS, XAIDA, REDEEM, EON, INTELLIGENT TUTOR, D3 TRAINER, CALAT, INTERBOOK, and PERSUADE [11].

From the above discussion, one can concludes that, the main difficulty and challenge in developing of STS for specific task is the knowledge-acquisition process. So, efficiency of STS is based on the selection and determination of the appropriate knowledge representation technique, reasoning methodology and the choosing of the suitable authoring shell. Therefore and from the technical point of view, STS systems are complex to build and complex to maintain.

IV. Case-Based Reasoning (CBR) for Developing STS

A. CBR Approach

From knowledge engineering point of view, the "case" is a list of features that lead to a particular outcome. (e.g. The information on a patient history and the associated diagnosis). CBR is an analogical reasoning method provides both a methodology for problem solving and a cognitive model of people [15]. CBR means reasoning from experiences or "old cases" in an effort to solve problems, critique solutions, and explain anomalous situations. It is consistent with much that psychologist have observed in the natural problem solving that people do. People tend to be comfortable using CBR methodology for decision making, in dynamically changing situations and other situations were much is unknown and when solutions are not clear.

Determining the appropriate case features is the main knowledge engineering task in developing case-based IeLS. This task involves defining the terminology of the domain and gathering representative cases of problem solving by the experts. Representation of cases can be in any of several forms (predicate, frames, scribes). From the computational point of view, CBR refers to a number of algorithms and techniques that can be used to record and index cases and then search them to identify the ones that might be useful in solving new cases when they are presented. In addition, there are techniques that can be used to modify earlier cases to better match new cases and other techniques to synthesize new cases when they are needed. CBR has already been applied in a number of different applications in many domains, e.g., medicine, industry, law, banking [15,16,17].

In smart case-based e-learning systems, the case can include: (a) A multi-media description of the problem, (b) A description of the correct actions to take including optimal and alternative steps, (c) A multi-media explanation of why these steps are correct, and (d) A list of methods to determine whether students correctly executed the steps. Determining the appropriate case features is the main knowledge engineering task in case-based AI software. This task involves defining the terminology of the domain and gathering representative cases of problem solving by the expert Representation of cased can be in any of several forms (*predicate, frames, scribes*).

B. Benefits of CBR to STSs

The idea of CBR is becoming popular in developing intelligent eLearning/tutoring systems because it automates applications that are based on precedent or that contain incomplete causal models. Research reveals that students learn best when they are presented with examples of problem-solving knowledge and are then required applying the knowledge to real situations. The case-memory of examples and exercises capture realistic problem-solving situations and presents them to the students as virtual simulations.

On the other hand, there are several benefits where students/learners should be able to perform better using CBR methodology, e.g.,

- With more cases available, students will be able to recognize more situations and the solutions that go with these cases include failure cases,

students will be able to benefit from the failures of others.

- Retrieval cases will allow students to better recognize what is important in a new situation. Cases indexed by experts would recall and will show the student ways of looking at a problem that he might not have the expertise for without the system.
- Student will have access to obscure cases that they otherwise would not able to make use of. These obscure cases can help with any of the tasks previously listed.
- During a training period CBR system provides the student with a model of the way decision making ought to be done, for example, what things ought to be considered and provides them with concrete examples on which to hang their more abstract knowledge.
- For tasks where there is much to remember, CBR systems can augment the memories of even educators. Also, both educators and students tend to focus on too few possibilities when reasoning analogically or to focus on the wrong cases.

V. ONTOLOGICAL ENGINEERING (OE) PARADIGM FOR DEVELOPING STS

A. OE approach

The term "ontology" is inherited from philosophy, in which it is a branch of metaphysics concerned with the nature of being. The main objective of using ontologies is to share knowledge between computers or computers and human. Computers are capable to transmit and present the information stored in files with different formats, but they are not yet compatible to interpret them. To facilitate communication and intelligent processing of information, it is necessary that all actors of the digital space (computers and humans) have the same vocabulary. Ontologies are the foundation of cooperation and the semantical understanding between computers (running a lot of nonhomogenous software programs) and of the cooperation between computers and humans.

Most of the usages of ontologies in the field of computer science are related to knowledge based systems and intelligent systems. These types of ontologies include a small number of concepts and their main objective is to facilitate reasoning. For example, in multi-agent systems, the knowledge representation is accomplished through a basic ontology, privates ontologies and a knowledge base. Private ontologies of the agents are derived from the basic ontology. The names of the concepts used in private ontologies of the agents are unknown, but their definitions use terms from the basic ontology. During the last decade, increasing attention has been focused on ontologies [18]. At present, there are applications of ontologies with commercial, industrial, medical, academicals and research focuses [19,20,21,22].

B. Benefits of Ontology Paradigm to STSs

Ontologies' usage in educational systems may be approached from various points of view: as a common vocabulary for multi-agent system, as a chain between heterogeneous educational systems, ontologies for pedagogical resources sharing or for sharing data and ontologies used to mediate the search of the learning materials on the internet [23].

The abstract specification of a system is composed of functional interconnected elements. These elements communicate using an interface and a common vocabulary. The online instructional process can be implemented successfully using artificial Intelligence techniques. Sophistical software programs with the following features give the intelligence of the machine: adaptability, flexibility. Learning capacity, reactive capacity, autonomy, and collaboration and understanding capacity. This approach enables to solve the complexity and the incertitude of the instructional systems. An intelligent learning system based on a multi-agent approach consists in a set of intelligent agents, which have to communicate. They collaborate through messages. Software agents can understand and interpret the messages due to a common ontology or the interoperability of the private ontologies.

VI. TRANSFORMATION OF EDUCATIONAL SYSTEM: SMART DIGITALIZATION

The successful development of the digital economy requires the transformation of the educational system and the establishment of smart education using all enumerated smart educational technologies in three main interrelated areas.

First of all, it is important to strengthen and expand engineering areas of training at universities to increase the number of specialists capable of creating new smart solutions to meet the needs of the digital economy. Secondly, the mass introduction, penetration and dissemination of smart educational technologies in all areas of training is required, which allow, on the one hand, improve the quality of the educational process and the level of competency of graduates, on the other hand, provide students with the skills to use smart ICT in real practice. Thirdly, it is important to consider the question of the establishment of educational institutions of the new formation. Smart technologies make it possible to transform both the content of education and the management of the university.

VII. CONCLUSIONS AND FUTURE WORK

In this concluding part, we identify some of the major open problems that must be addressed to ensure the success of developing robust intelligent e-learning systems. In summary, the development of intelligent e-Learning/educational systems is a very difficult and complex process that raises a lot of technological and research challenges that have to be addressed in an interdisciplinary way. Today's the fusion of computational intelligence and machine learning techniques with the knowledge acquisition techniques solves many of the technical problems and difficulties in designing new generation of intelligent e-Learning/ educational systems. Further research however is needed to convergence the knowledge engineering, artificial intelligence, machine learning, and educational technology with the recent trends of Internet of Things (IoT) technology. Such convergence will create a new generation of web-based intelligent e-learning and tutoring systems. The web based of such systems can enhance the online education/ learning/training

processes through the web. So, the integration of these approaches and educational technologies is beneficial for designing efficient, robust and smart e-learning systems. In addition, ensuring the success of such systems to the cloud is an important challenge.

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PAPERS

Using Convolutional Neural Networks for Emoticon Classification

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***Abstract*—The problem of automatic classification of photographs, graphics and spatial data is increasingly being addressed via advanced machine learning methods and related models like Convolutional Artificial Neural Networks (CANN). In the scope of this work, we conducted a study of application of the CANN to an example of emoticon classification.**

In this paper, chosen methods are described as well as solutions for data collection and processing. Methods for training and evaluation of the model are offered. The presented results show successful application of the model.

***Keywords*—convolutional neural networks, classification, emoticons, image processing, computer vision**

I. Introduction

Automatic classification of imagery has shown numerous applications in the fields of scientific research and is actively being applied in various industries with a particularly large impact on big data and automated image processing.

Convolutional Artificial Neural Networks have been around since the 1980s [1], although at the time considered computationally ineffective, in recent years with hardware performance improvements, introduction of task-specific hardware (GPUs and more recently TPUs) and distributed computation, CANNs have truly been revived and improved to the point of becoming state-of-the-art models for image classification [2].

In our study, we addressed the problem of recognizing rendered images of emoticons (e.g. smiley face, frowning face, winking face, etc.) using a CANN architecture and tuning it for best possible performance on our curated datasets.

We explored multiple variations of the network architecture, choices of hyperparameters, various regularization methods, techniques for artificial dataset expansion and otherwise curated the datasets to find a suitable model for the task.

The emoticon datasets were gathered from multiple sources [3], [4], including Google image search and even by generating emoticon images using a simple program we had developed for the very purpose.

As supervised models are evaluated, the resulting accuracy is inevitably a mixture of the model fitness and the quality of the dataset, hence the data collection and model searching are often two interleaving processes which also involve numerous experiments. Such is the case in our study as well. Nevertheless, we find it more comprehensive for the reader to present these processes separately.

II. Curating the datasets

The initial emoticon samples were collected from the emojipedia.org [3] website along with their meta data (class labels). Although 33 classes in total were prepared, there were only 12 samples per class on average which is insufficient for typical dense and convolutional models (e.g. the MNIST dataset [5] contains 7000 samples per each decimal digit class).

Given the small ratio of samples per class to the number of classes, the samples were curated to form a dataset called COMMON_6 containing only six classes of our choosing as shown in Figure 1.



Fig. 1. Samples from the COMMON_6 dataset. Each image represents one sample of their associated emoticon class, from left to right: *astonished-face*, *crying-face*, *fearful-face*, *slightly-frowning-face*, *slightly-smiling-face* and *winking-face*. These particular samples were collected from [3] and were produced by Apple Inc.

Similar to the common six, equivalent subsets of emoticons called COMMON_3 and COMMON_4 were prepared to evaluate how the number of classes affects the model performance.

Due to the foreseen low performance of initial models evaluated on COMMON_6 (50-68% accurate), the dataset was extended with additional samples obtained via Google image search, producing the COMMON_6 EXTRA dataset which on average contains 25 samples per class.

Furthermore, to allow for emoticon detection (i.e. whether a square in an image contains an emoticon) rather than just classification (i.e. which emoticon is displayed in the square image), three additional background classes were generated as shown in figure 2. This combined dataset was appropriately named COMMON_6 EXTRA_WITH_NOISE, where the terms ”noise” and ”background” are used interchangeably.



Fig. 2. Samples from the background classes. Each image represents one sample of their associated background class, from left to right: *blank*, *circle* and *noise*. The rationale for introducing background classes is purely based on intuition and experiments. The *blank* class should help with recognizing blank portions of a screenshot. The *circle* should amplify the differences in the face expression rather than the mostly generic emoticon head. The *noise* class is to separate a meaningful set of shapes from a random patch of pixels.

A. Storing, parsing and preprocessing

Each dataset is stored in a directory structure where the class sub-folder is named after the associated label (e.g. "common-6/slightly-smiling-face/01.png") and all of the available samples of the same class reside together.

Splitting the data for training, testing and validation as well as image augmentation and preprocessing are all performed dynamically - prior to starting the training and evaluation loop.

Although this sacrifices run-time memory and initialization time (negligible compared to training time) rather than storage space, it provides more flexibility for experimenting and introduces a convenient means of selecting hyperparameters while the source data remains pure. Furthermore, caching can be utilized for subsequent runs to decrease the initialization time.

The size of the output layer of the model is directly tied to the number of classes advertised by the target dataset (i.e. by the number of sub-folders) making the model architecture implicit to the provided dataset.

B. Expanding the dataset

Given a very low number of samples per class (e.g. 25), the performance of initial models was unsurprisingly low. It proved increasingly harder to collect additional samples via image search, therefore we explored the possibility to generate emoticons with parameterized traits (e.g. size and shape of eyes, mouth, eyebrows, etc.).



Fig. 3. Generated samples of the *happy* class (*slightly-smiling-face* equivalent). Each sample represents a variation produced by a random but constrained selection of parameters affecting the facial expression traits, the head color and the border thickness.

The generated samples covered three classes of emotions: *happy*, *sad* and *surprised*, enough to evaluate existing models and compare the performance of the GENERATED dataset vs. the COMMON_3 equivalent (*slightly-smiling-face*, *slightly-frowning-face* and *fearful-face*).

It is fairly straightforward to generate simple variations of emoticons, however the actual samples obtained from [3] and other sources display more variety in style which is more difficult to reproduce (generate) using a classical approach.

Although it is out of scope of this study, we would argue that using Generative Adversarial Networks [6] to bootstrap the generative process would be worth exploring as a possible improvement.

C. Artificial expansion via augmentation

Another venue was explored which would allow the existing COMMON_6 dataset (and its expansions) to be further - artificially expanded. Although affine transformations such as translation, rotation, flipping and skewing were considered, a more novel approach of using elastic transformations [7] for image augmentation was favored.

Applying these kinds of transformations to produce image variations comes with multiple benefits. The trained model has better generalization due to the increased variance and never has to observe the original images, yet still produces a very low error on them (comparable to loss). Therefore, the unaltered training images (which are never observed during training) can instead be used as a validation set to prevent over-training the model.

Elastic transformations also produce an effect similar to the affine transformations when observed on local segments of the image (e.g. a slightly rotated eyebrow).

To the human observer, the augmented images may appear as if smudged or observed through rippled water, yet still recognizable. The intensity of the transformation should be controlled so as to preserve the traits and keep the emoticon distinguishable from other classes.



Fig. 4. A random elastic transformation applied to a grid (top right) and an emoticon image (bottom right). The image is distorted but still recognizable to the human eye which is used as a guiding principle for automatic recognition as well. Using multiple different (random) transformations provides the means of artificially expanding the training dataset for the classifier.

III. Choosing the classifier

The goal of the study was to develop a convolutional model which can successfully classify at least six emoticon types and which is no less than 85% accurate on the evaluation dataset. As mentioned via introduction, the process of finding a suitable model coincides with curating the datasets to provide sufficient description for the model to learn from the data.

A number of iterations in which either the model or data was adjusted to increase performance were conducted. Within the constrained scope of our study, the experiments have shown that using two convolutional groups and three dense groups while training on six emoticon and three background classes produce the best overall results.



Fig. 5. The CANN network architecture for emoticon classification. Experiments show that using two convolutional groups yields best performance on the 6/3 emoticon/background dataset. The output of the 2nd convolutional group is reshaped to a one-dimensional vector and passed to a classical dense group of neurons towards the output layer for predictions.

A convolutional group is comprised of the convolutional layer, a max-pooling layer and an optional leaky rectified linear unit layer (commonly known as leaky ReLU) as depicted by figure 6.

Although the convolutional groups also have an optional dropout layer, our experiments and recent studies [8] have shown that they should be excluded.

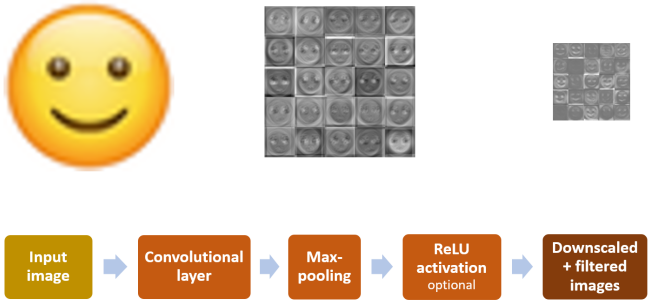

Fig. 6. Layers of a convolutional group in an artificial neural network. The input image is presented to the convolutional layer which extracts features by applying edge-detection filters, further passed to the max-pooling layer which scales the image down by a factor of 2. The ReLU activation is optional, but in some circumstances it can be useful to increase non-linearity.

A fully-connected (i.e. dense) group computes the matrix product of the inputs and the neural weights with added biases. Two optional layers can be applied: a leaky ReLU for activation and a dropout layer for regularization.

The boundary between the convolutional groups and the dense groups is occupied by a simple ”unrolling” operation which reshapes the multidimensional outputs of the last convolutional layer to a one-dimensional vector.

The very last group of the network omits the ReLU layer and contains exactly N outputs (i.e. logits) where N implies the number of distinct classes.

IV. Training

The training program was designed with experimentation in mind - the choice of dataset, model architecture and other hyperparameters are all configurable either through a file or directly using command line arguments.

Implicit parameters, such as the output layer size which is tied to the dataset class number are stored in the model configuration for running post-training predictions and producing evaluation reports.

For comprehensiveness, the parameters have been categorized into three groups. Firstly, the ones which affect the model architecture (i.e. model selection) as shown in table I. The image size affects the input layer while the dataset selection affects the output layer. Optional layers for ReLU, max-pooling and dropout are controlled via binary switches for convolutional (C) and dense (D) groups:

$$C_i, D_j \in \{0, 1\}: \quad D_3 D_2 D_1 C_2 C_1 \tag{1}$$

TABLE I
Parameters affecting the model architecture

Argument	Description	Constraints
–dataset	Dataset selection - implicitly affects the trained model's architecture.	COMMON_3 COMMON_4 COMMON_6 ...
–image-size	Target image size - the square side length	Integer, e.g. 24
–num-channels	Number of color channels for the input image conversion.	1 or 3
–filter-size	Size of the filters in the convolutional layers	Integer, e.g. 8
–pooling	Switches for max-pooling in convolutional layers.	Integer, e.g. 3 (00011_2) for both convolutions
–relu	Switches for ReLU activations.	Integer, e.g. 12 (01100_2) for the first two dense layers
–dropout	Switches for dropout layers	Integer, e.g. 4 (00100_2) for after the first dense layer
–dropout-rate	Rate for the dropout layers.	[0.0, 1.0), e.g. 0.7

Secondly, the data transformations prior to training are controlled by arguments described in table II. The image augmentation using elastic transformations and the train/test split are both tied to the random number generator (RNG), which can be explicitly set for reproducibility.

TABLE II
Parameters for training data preprocessing

Argument	Description	Constraints
–random-seed	Initial value for the RNG - affects data splitting and other pseudo-random preprocessing.	Integer. e.g. 271941
–split-ratio	Ratio for the train/test data split.	(0.0, 1.0), e.g. 0.7
–expansion-factor	Number of augmented images to generate via elastic transformations, when set to 0 originals are used.	Non-negative integer, e.g. 100

Finally, the training process is configurable with training hyperparameters detailed in table III. These parameters are exposed by the momentum optimizer which was selected for training.

TABLE III
Training hyperparameters

Argument	Description	Constraints
–batch-size	Number of samples for each training step	Integer, e.g. 20
–momentum	Training hyperparameter	Small positive decimal, e.g 0.6
–learning-rate	Training hyperparameter	Small positive decimal, e.g. 0.01
–training-steps	Number of steps per epoch for periodic evaluation	Integer, e.g. 100

A. The training process

The train/test split occurs prior to the optional train set expansion and the test images are only observed during evaluation while the model is frozen (i.e. backpropagation may not occur).

Per convention, an epoch implies that the model has observed the entire training dataset. Due to the cumulative effect of backpropagation, the model weights are readjusted to optimize the loss after each observed batch.

The output layer is evaluated for loss using the sparse softmax cross-entropy between the logits (measured outputs) and the ground truth labels. This implies that the output classes are mutually exclusive as documented in [9].

The model evaluation occurs after each 100 epochs and reports the training error (loss), validation set error and the test set error. If the training is run on an expanded dataset using only the augmented images, then (as described in II-C) the validation set is comprised of the original images from the training portion of the train/test split.

After running initial training experiments, the stopping conditions have been determined empirically. The training process will run at least 500 epochs and afterwards (by checking every 100 epochs) will stop if either:

1) the validation set accuracy has surpassed 99.9%
2) the exact same validation set accuracy was subsequently reported more than twice
3) the training ran for more than 5000 epochs.

B. Tracking the performance

For each training session, the model performance metrics were tracked in real time using TensorBoard [10]. Naturally, the main expectation was loss decrease (fig. 7) and accuracy increase (fig. 8) over time, providing confidence that the model is capable of converging.

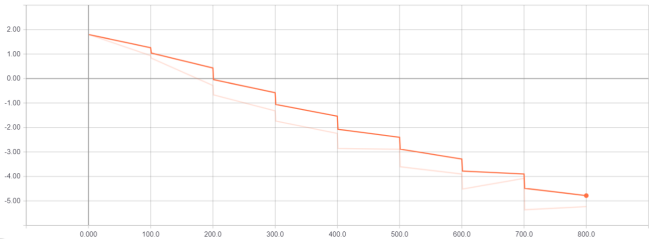

Fig. 7. Training loss observed over epochs for the best performing model. The curve is interpreted as healthy convergence of the model as the training error diminishes.

The reported performance curves, although automatically smoothed out, appear jagged due to a relatively small number of measurements. This occurs since the metrics are computed only every 100 epochs so as to speed up training.

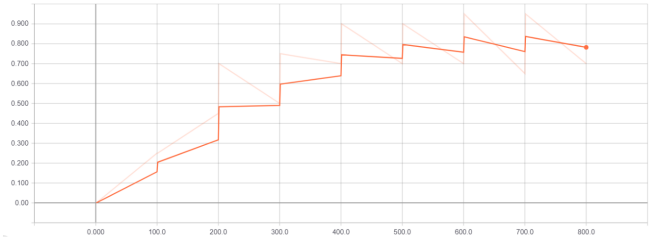

Fig. 8. Evaluation accuracy observed over epochs for the best performing model. The curve signifies a promising model as the accuracy is steadily increasing and surpassing 90% on the evaluation set.

Some extra metrics for debugging are also reported, such as the individual terms of the loss function. For example, the regularization terms are often tracked to ensure that over-fitting is prevented.

Even more insight is provided with visualization - firstly, the input images which are subjected to preprocessing are displayed to ensure that the network receives valid inputs - and secondly, the convolutional filters can also be visualized as depicted in figure 9.

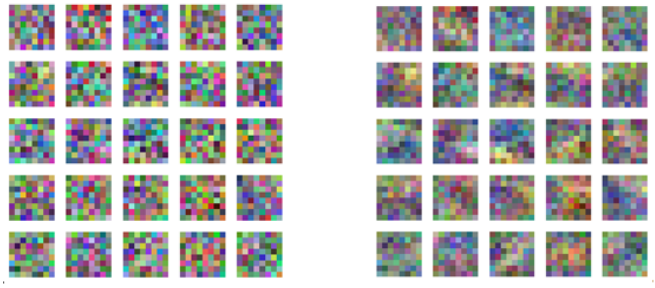

Fig. 9. Visualization of the 1st convolutional layer's filters, before training (left) and after training (right). While both images seem to represent noise, the average color distance between "pixels" of a trained filter is reduced - resulting in a "smoother" image which signifies convergence of the model.

V. Deep Evaluation and Reporting

The early stages of our work have produced more than a few low performing models. Although intuition suggested that the datasets were just too small to expect any significant accuracy, a deeper insight was required into the model behavior once they were expanded and some improvement has been observed.

Tracking the training process and reported accuracies provided only high level black-box observations of the model performance. Those metrics gave no specifics on the failures nor provided the insight into where improvements can be made.

Deeper insight into a model's behavior was achieved through a reporting tool we had developed.

The confusion matrices provided answers to which classes were often mistaken, accompanied by a display of individual samples for which the classifier made the error, as shown in fig. 10. Both representations were applied to the context of the training set, the testing set and the entire dataset respectively.

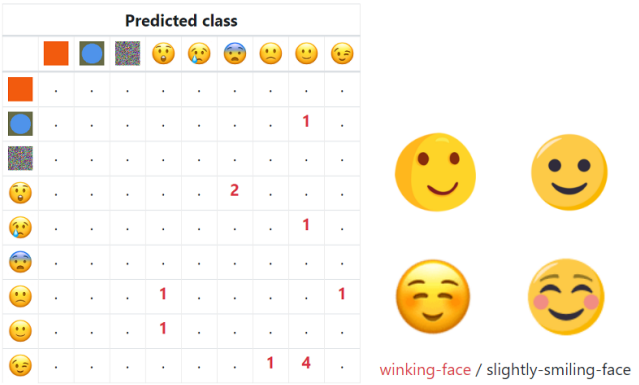

Fig. 10. Confusion matrix and error samples for the best performing model applied on the test set of COMMON_6 EXTRA_WITH_NOISE. Each matrix cell shows the number of errors for the ground truth and the predicted label pair. The chosen model is mostly mistaking the winking face for a slightly smiling face. Errors between the background classes themselves are not counted - e.g. mistaking a circle for a blank is not considered useful for classification.

VI. The Best Performing Model

Our best performing model achieved 91.24% accuracy on the testing set of COMMON_6 EXTRA_WITH_NOISE, classifying 125 of 137 (never before observed) images correctly. The model matched 315 of 320 (98.44%) images from the unaltered training images, hence for the entire dataset it successfully recognized 440 of 457 (96.28%) samples.

Although the training set and entire dataset accuracies are usually not considered for performance evaluation, in this case it is useful to report them since the model was trained only on augmented images and never observed the original unaltered samples.

By running a number of experiments through configurable parameters, the best performing model's architecture and the training hyperparameters have been found and are described in table IV.

As this model achieved the goal of surpassing the 85% accuracy mark, further experiments with hyperparameter optimization were no longer pursued.

TABLE IV
Parameters of the Best Performing Model

Argument	Value
–dataset	COMMON_6 EXTRA_WITH_NOISE
–image-size	36 –
–num-channels	3
–filter-size	8
–pooling	1 (00001_2)
–relu	12 (01100_2)
–dropout	4 (00100_2)
–droput-rate	0.5
–random-seed	271941
–split-ratio	0.7
–expansion-factor	150
–batch-size	20
–momentum	0.6
–learning-rate	0.01
–training-steps	100

The addition of background classes was shown as the leading factor which improved the model accuracy. For comparison, a similar model trained on COMMON_6 EXTRA achieved 31 of 44 matches (70.45%) while the denormalized accuracy (counting all background class errors) of an equivalent model on the 6+3 dataset is averaging over 80%.

Similar accuracies have been reported for expansion factors of 50 and 100 and no extra improvements were observed for larger expansions.

Deeper models such as ResNet-152 [11] were also evaluated, averaging 70% test accuracy.

VII. Conclusion

Our study has successfully applied a convolutional neural network for emoticon classification and showed significant results (accuracy over 90%) even while being impaired by small datasets.

Using elastic transformations for artificial dataset expansion and introducing background (noise) classes has substantially improved the overall dataset size, variance and consequently the model accuracy.

Experiments suggest that further improvements of CANN models could be achieved primarily through gathering more data and exploring methods for generating emoticons such as using Generative Adversarial Networks.

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Visualizations of the training process of neural networks

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***Abstract*—In this paper we present an approach to the visualizations of the neural networks training process. The main goal of such visualizations is to better understand the training process of neural networks, and to help with the creation and optimization of new neural networks. We implemented a tool which can be used to create a large number of visualizations by using different combinations of created transformations (for example: *diff*, *plot2*, *angle-path*, *vec-dist-dev*). To be able to visualize the learning process, we had to record all the weights from every n^{th} iteration. For experiments we used three neural networks: a neural network for digit recognition (DR), a neural network for word2vec representation of words (WV), and a neural network which learned the simple logical gate XOR, (XR). For the purpose of further comparisons, we also constructed one example of a damaged network (DR′, WV′, XR′) for each of the three original networks (DR, WV, XR). We constructed over 30 visualizations and then chose 6 visualizations which could be easily interpreted and present them in this paper. The results indicate that there may exist some regularities in the visualizations of original networks and that damaged network visualizations differ from the original networks.**

I. Introduction

Training neural networks consists of adjusting weights between connected neurons. Given the large number of connections in modern neural networks these changes can be regarded as high dimensional complex changes. The high dimensionality of these changes is perhaps the greatest problem. Understanding these changes would be useful for the creation and understanding of neural networks. In chaos theory, scientists used visualizations to help them understand chaotic systems. The learning process in neural networks is similar because observing raw data is not very helpful, visualizations can help make that data interpretable by humans.

The majority of related papers visualize only the last instance of a neural network, and the majority of these papers visualize activations in convolutions of neural networks which process images (and convolutions in such neural networks are two-dimensional by their nature) [1] [2]. They do not visualize the change that a neural network is going through while learning. We created a tool that can visualize the learning process of convolutional and fully connected neural networks. We use various combinations of created transformations (for example: *diff*, *plot2*, *angle-path*, *vec-dist-dev*). For experiments we used three neural networks: a neural network for digit recognition (DR), a neural network for the word2vec representation of words (WV), and a neural network which learned the simple logical gate XOR, (XR). For the purpose of further comparisons, we also constructed one example of a damaged network (DR′, WV′, XR′) for each of the three original networks (DR, WV, XR). These damaged networks were constructed by changing certain hyper-parameters or by removing some of the layers.

The aim of this research was to create new techniques for visualization and experiment with those visualizations of neural networks in order to determine the visual properties of the learning process. Furthermore, we compared the original networks with their damaged versions to check if there were certain regularities in the visualizations of the original networks.

Section 2 covers related work, Section 3 explains the fundamentals of neural networks, Section 4 explains the implementation and data, Section 5 shows the results, and Section 6 concludes the paper.

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II. Related Work

Visualizing convolutional networks is very useful for understanding what such networks have learned, and how they interpret the input data. It is possible to visualize the learned features [1], or to generate images that activate selected parts of a network [2]. There is only a small number of research which is focused on visualizing the training process of neural networks. In this section we summarize a few of the most relevant papers.

Among the methods which visualize the process of learning, the simplest one is the graph of the loss function, where at each iteration the loss is calculated. Even though it is simple, it provides very useful information. In [3] authors introduced a technique for qualitatively analyzing the loss functions. Using that technique, they visualized the cross-section of the loss function. They concluded that the objective function has a simple convex path along the cross-section.

By visualizing clusters of activations (by using dimensionality reduction), in [4] authors showed how those clusters are evolving through time.

In [5] authors made a tool for visual analysis of hidden state dynamics in recurrent neural networks. The tool allows users to observe local state changes.

In order to visualize the learning path (defined with learning parameters - weights), it has to be reduced from n dimensions to two or three dimensions. The reduction can be made with existing reduction techniques. In [6] and [7] authors used principal component analysis (PCA) for dimensionality reduction. The visualization was made by plotting two or three of the principal coordinates. PCA identifies the dimensions which have the most variance.

Similarly to [5] and [7], we implement visualizations that visualize the process of learning. However, in presented research we employ created transformations (for example: *diff*, *plot2*, *angle-path*, *vec-dist-dev*) which have not been employed in any previous work, at least not in combinations like in this work (to best of our knowledge).

III. Neural Networks

Artificial neural networks proved to be very good at solving problems which are intuitive for humans, but hard to explicitly explain [8]. Such problems are object recognition, playing the board game Go, speech recognition, and music generation.

An artificial neural network is an interconnected group of nodes. When signals pass through connections they are multiplied with weight factors. After that, the signals which come to the same nodes are summed and then the bias factor is added. Addition of the input signals is the most frequently used accumulation function, but there are other such functions. The resultant value is then passed to a non-linear function. The output is then passed forward. Non-linear activation functions allow neural networks to compute non-trivial problems using only a small number of nodes, but in some rare cases a linear function is used.

In the neural network shown in the Figure 1 the first column of neurons is the input layer in which each neuron represents one value from the input vector. After the input layer there are hidden layers, and the last layer is the output layer which represents the output vector (in this example that vector has only one element). Each of the neurons in the first hidden layer is making a simple decision by weighing input signals. The neurons in the next layer are making a decision by weighing up the results from the previous layer. The deeper layers are making decisions at more abstract levels [9].

This is how neural networks process input, but the learning process is more interesting. Using backward propagation (other algorithms are sometimes used), a gradient is calculated which is then used to change the weights in the direction which would reduce the output error of the neural network.

The number of connections in a neural network can be very large, and the number of weights is equal to the number of connections. By recording the weights from every n^{th} iteration through learning, we can capture the change which the neural network is going through. Because the number of weights is very large, visualizing that change is not a trivial task.

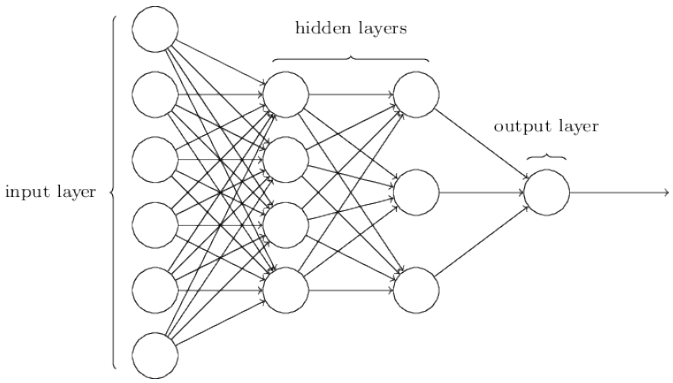

Fig. 1. Neural network

IV. Implementation

We implemented a set of transformation techniques which can be used sequentially in different combinations. After the transformations are used, the result is a 1D or 2D array which can be saved as a graph or a picture. Depending on the combination of transformations that is used, it is possible to create a visualization which can be useful.

A. Methods

The tool was implemented as a Python library in which we defined the transformations and other operations required for visualizing neural networks. For loading weights from recorded iterations of the learning process of neural networks, we used the TensorFlow library.

The main structure that holds all the weights is a matrix in which every column represents one iteration of the learning process, and every row represents one weight variable. By using the functions, the data in that matrix is being transformed. When a user has finished with the transformations, one of the functions for viewing or saving the matrix is used.

The transformations that were used to generate the visualizations shown in this paper are: *diff*, *vec-angle-diff*, *angle-path*, *diff-vec-mag*, *vec-dist-dev*, *vec-angle-dev*, *norm-col*, and *plot2*. The descriptions of these transformations are in Table I.

B. Data

We used three neural networks for experimenting: a neural network which learns word2vec representation of words (*WV*) [10], a neural network for digit recognition (*DR*) [11], and a simple neural network which learned logical rule XOR (*XR*) [12].

The neural network *WV* has only one hidden layer and it's fully connected to the input and output neurons. The neural network *DR* is more complex. The first two layers are convolutional, and the last two are fully connected layers. After each convolutional layer there is one pooling layer. The neural network *XR* has two input neurons, the hidden layer has two neurons as well, whilst the output layer has only one neuron.

TABLE I
LIST OF TRANSFORMATIONS AND DESCRIPTIONS

Transformation	Description
diff	calculates the difference between each two sequential iterations
vec-angle-diff	by using vectors as representations of the values in iterations, vec-angle-diff calculates the angular difference between each two sequential iterations
angle-path	calculates a path by using input values as turning angles
diff-vec-mag	calculates the distance between each two sequential vectors
vec-dist-dev	calculates a line going through the first and last point (vector or iteration) in n-dimensional space of learning, and then calculates the distance from each point to the closest point on that line
vec-angle-dev	calculates the angle of deviation from the straightest path towards the last point
norm-col	normalises the matrix by column
plot2	transforms the matrix into a set of coordinates by using the nth value as x coordinate and $n^{th} - 1$ value as y coordinate

To observe the visualized differences in the quality of neural networks, we created a damaged version for each of the three neural networks (*WV′, DR′, XR′*). The damaged versions were created by removing a few layers, or by changing the hyper-parameters such as learning rate and batch size. The damaged versions have lower prediction accuracies (for example *DR*: 0.97, *DR′*: 0.92).

V. RESULTS

Here we present and compare the visualizations between the different neural networks, and then we show the comparisons between the original neural networks and the damaged neural networks. During our research we constructed more than 30 visualizations, but here we describe only 6 visualizations which could be easily interpreted.

A. Comparison between neural networks

In this section we describe two different visualizations, the first one is generated by the transformations *diff* and *vec-angle-diff*, the second visualization is generated by the transformations *diff*, *vec-angle-diff*, and *angle-path(diff-vec-mag)*.

The visualization generated by the transformations *diff* and *vec-angle-diff* show how much the learning direction is turning. If the learning process is perceived about as a path through an n-dimensional space, where n is the number of weights, we have an n-dimensional path which we cannot visualize directly. By calculating the angle between every two sequential vectors, we obtain the turning value which can then be plotted on a graph.

In Figure 2.A it can be seen that the n-dimensional path is not turning very much at the beginning of the learning process, and the value of the turning angle has a fast growth until the 50th recorded iteration, after which it grows slowly. In Figure 2.B we see that the turning angle is not changing very much. Figure 2.C was most surprising because the *XR* neural network is very simple, yet it generated this visualization which has a sinusoid-like nature with a period that is growing over time.

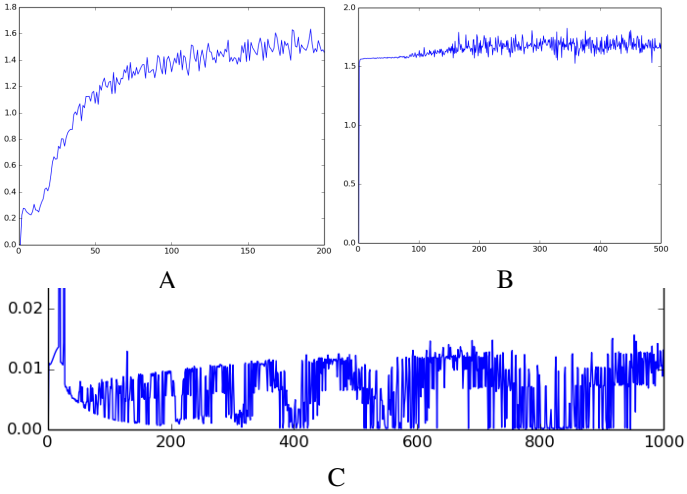

Fig. 2. Visualizations with transformations: *diff* and *vec-angle-diff*. The X-axis is time (or iterations), and the Y-axis is the angle between the sequential vectors, where every vector represents values of all weights in an iteration. The data is from (A) *DR* 4th layer, (B) *WV* 1st layer 50th neuron, and (C) *XR*.

The visualization generated with the transformations *diff*, *vec-angle-diff*, and *angle-path(diff-vec-mag)* uses values of the turning angle shown in the previous visualization to draw a simplistic path. The path is turning left using the calculated turning angle, and the length of each section of the path is calculated as the distance between each of the vectors (where each vector is a set of the weight values in each iteration).

The visualized path shown in Figure 3.A is approaching the endpoint from afar, and at the end is converging at that point. The path shown in Figure 3.B is circling around the endpoint from the beginning.

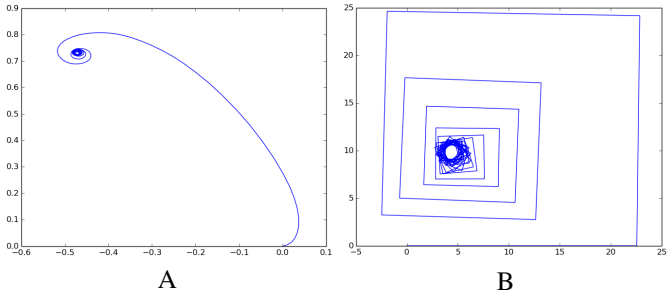

Fig. 3. Visualization by the transformations: *diff*, *vec-angle-diff*, and *angle-path(diff-vec-mag)*. A simplistic path is drawn in the two-dimensional space using the turning angle of the real learning path in the n-dimensional space, the length of each step is equal to the distance between every two vectors. The data is from (A) *DR* 1st layer and (B) *WV* 1st layer 50th neuron.

B. Comparisons with damaged versions

Damaged versions of original neural networks were created to show the visible difference in visualizations between more optimal and less optimal learning processes. In this section we

describe four different visualizations, the first one is generated by the transformations *diff*, *vec-angle-diff*, and *angle-path*, the second visualization is generated by the transformations *diff* and *vec-angle-dev*, the third visualization is generated by the transformation *vec-dist-dev*, and the fourth visualization is generated by the transformations *diff*, *norm-col*, and *plot2*.

The visualization generated by the transformations *diff*, *vec-angle-diff*, and *angle-path* uses the value of the turning angle (used in the previous section) to draw a simplistic path. In this visualization, the length of each step is equal.

Figure 4 shows the described visualization. Figure 4.A is the visualization of *DR* 1st layer, and Figure 4.B is the visualization of the damaged version (*DR′*). The visualization of the damaged version has more irregular convergence.

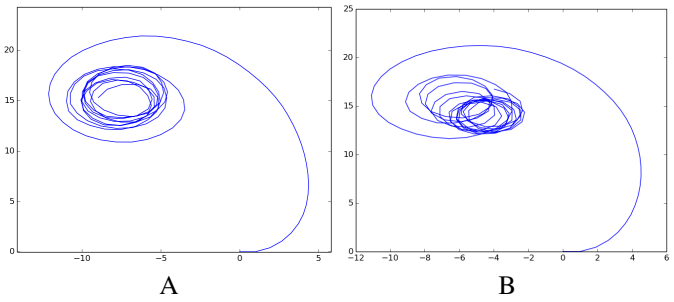

Fig. 4. Visualization by the transformations: *diff*, *vec-angle-diff*, and *angle-path*. A simplistic path is drawn in the two-dimensional space using the turning angle of the real learning path in the n-dimensional space. The data is from (A) *DR* 1st layer and (B) *DR′* 1st layer.

The visualization generated by the transformations *diff* and *vec-angle-dev* shows the difference between the direction of the learning process (at each iteration) and the direction towards the last n-dimensional point (vector or iteration).

In Figure 5.A, showing the visualization of *DR* 1st layer, the value reaches the maximum very quickly, after which it decreases, while becoming more irregular, until it approaches the last iteration. The visualization of the damaged version (*DR′*) shown in Figure 5.B shows similar behavior, but the value decreases faster, and after passing the midpoint of the learning process, the value remains around the same value.

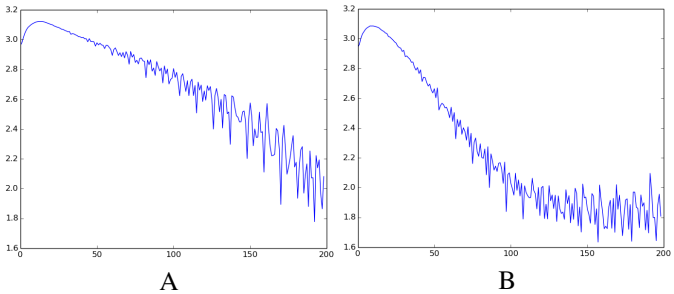

Fig. 5. Visualization by the transformations: *diff* and *vec-angle-dev*. The X-axis is time (or iterations), and the Y-axis is the value of the angle of deviation from the straightest path towards the last point. The data is from (A) *DR* 1st layer and (B) *DR′* 1st layer.

The visualization generated by the transformation *vec-dist-dev* graphs the distance between every point (vector or iteration) and the line passing through the first and the last point. This kind of visualization shows how much the path is deviating from the most optimal (and unrealistic) path.

Comparing the visualizations of *DR* and *DR′* in Figures 6.A and 6.B we can see that the damaged version is deviating from the path much more than the original neural network. Comparing the visualizations of *XR* and *XR′* in Figures 6.C and 6.D we can see similar results.

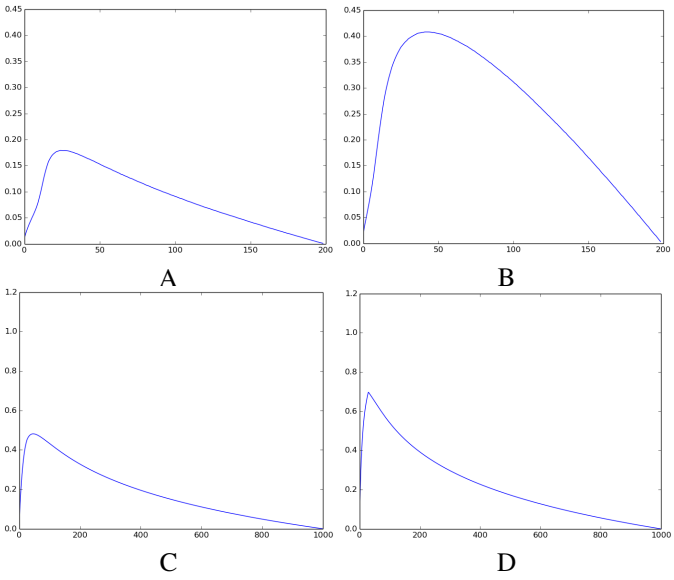

Fig. 6. Visualization by the transformation: *vec-dist-dev*. X-axis is time (or iterations), and Y-axis is the distance from the line going through the first and the last point in the n-dimensional space. The data is from (A) *DR* 1st layer, (B) *DR′* 1st layer, (C) *XR*, and (D) *XR′*.

The visualization generated by the transformations *diff*, *norm-col*, and *plot2* shows the general change of direction of weights in a neural network. The visualization is generated by calculating the difference between every two sequential iterations, normalizing the new values by iteration (in the matrix, by column), and transforming those values into coordinates by using values from the nth iteration as an X coordinate and values from the $n^{th} - 1$ iteration as a Y coordinate.

In the visualization of *DR* shown in Figure 7.A, we can see that the general direction of change is positive (because the bottom left part of the image is dense). The damaged version (*DR′*) shown in Figure 7.B is very spread out, meaning it did not converge to some n-dimensional point. The visualization of *XR* shown in Figure 7.C is very centred which can show us that the weights did not change preferably in one direction. The damaged version (*XR′*) shown in Figure 7.D is almost the opposite of the previous example.

VI. Conclusion

In this paper, we have presented the problem of understanding the learning process of neural networks and described the existing methods for the visualization of neural networks. We then explained our implemented techniques and showed some of the results generated using different combinations of the implemented techniques.

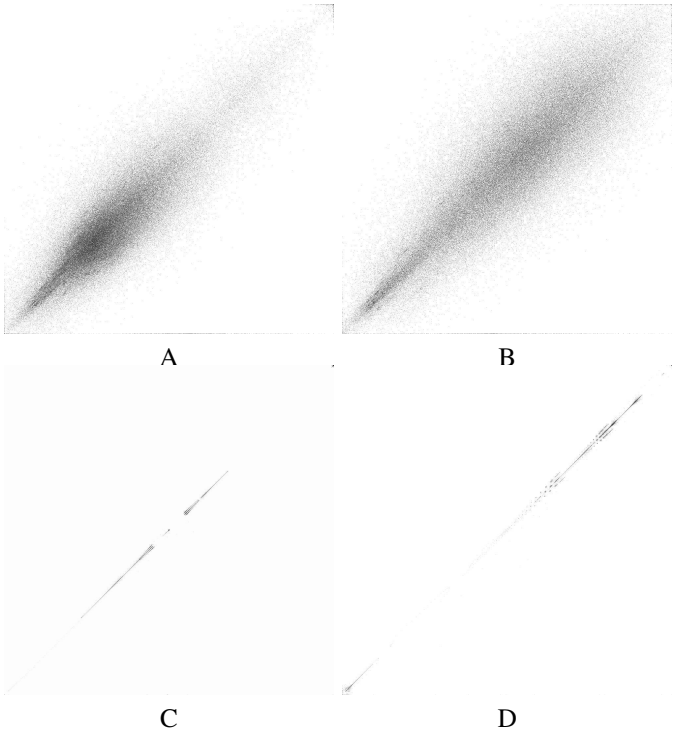

Fig. 7. Visualization by the transformations: *diff*, *norm-col*, and *plot2*. The transformation *plot2* plots each point, after *diff* and *norm-col* transform the values, by using the values from the nth iteration as X-coordinates, and the values from the $n^{th} - 1$ iteration as Y-coordinates. The image visualizes the direction of the change. The data is from (A) *DR* 1st layer, (B) *DR′* 1st layer, (C) *XR*, and (D) *XR′*.

We created a tool that can produce a large number of new visualizations. Using more visualizations while trying to understand an event or a problem can provide more perspectives which are always useful. In presented research we compared the visualizations of different networks (original networks), and the visualizations of the same networks but with varying a quality of the learning processes or architecture (damaged networks).

Our preliminary results indicate that there are certain differences in visualization patterns between original and damaged neural networks. More precisely, original neural networks have more regular patterns in their visualizations. This insight might help us in our future research of the application of deep learning models in the natural language processing domain.

There are some limitations in our approach. Loading every weight from each iteration from larger neural networks is not possible with a realistic memory size of working memory. For such networks, we visualized only a selected layer or even weights connected with a single neuron. To be able to visualize larger networks, new techniques have to be made which can dynamically load weights while reducing data and still retaining some useful information, and we plan to do more detailed research in the future.

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Mask R-CNN for Ear Detection

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***Abstract*—Ear detection is an important step in ear recognition pipeline as it makes or breaks the system. However, in the literature there is arguably the lack of ear detection approaches available. This poses a problem for opening ear recognition system to wider use and applications in commercial systems. To tackle this problem we present the use of Mask R-CNN for pixel-wise ear detection. Furthermore, we directly compare our approach to one of the previous best performing pixel-wise ear detection approach by using the same dataset and protocol. Our results with intersection over union score of 79.24% on AWE dataset show the superiority of our approach and present a viable approach for future use in ear recognition pipelines.**

***Keywords*—Mask R-CNN; Ear detection; AWE dataset**

I. Introduction

Pipeline of a typical biometric system consists of raw data acquisition, detection, feature extraction, classification and system evaluation. Performance of each step can greatly influence the performance of the whole system. In this work, we focus on pixel-wise ear detection and evaluate the performance of a convolutional neural network (CNN) architecture, Mask R-CNN [1]. We use 2D images captured under uncontrolled conditions, proving the feasibility of this approach.

The rest of this paper is structured as follows: a review of related work is given in Section 2, and Section 3 describes the Mask R-CNN approach. Mask R-CNN is described as a combination of five parts. In Section 4, training dataset and performance metrics are described and a comparison with PED-CED approach is given to evaluate the performance of our approach. Finally, Section 5 provides the conclusions.

II. Related work

Automatic ear detection approaches date all the way back to 2007, with the use of Hough Transform [2]. However, in this paper we overview only some of the more recent works. To get a more comprehensive overview of the field, the reader is referred to some of the ear detection surveys [3], [4]. In 2015 the authors of [5] presented an entropy-cum-Hough-transform-based ear detection approach. They used a combination of hybrid ear localizer and an ellipsoid ear classifier to enhance ear location predictions. Detection rate is defined as a ratio between number of successful ear localizations and number of all annotated ears. Ear localization is considered successful if detected area covers the entire ear and if the distance between center of the detected region and annotated ground truth is close enough. Authors achieved detection rate of 100.0%, 100.0% and 73.95% on UMIST [6], FEI [7] and FERET [8] datasets, respectively.

In 2016 authors of [9] proposed modified Hausdorff distance for automatic ear localization. This distance uses skin regions of side face image and ear template to locate the ear. Ear template was created by considering different structure of ears to detect ears of different shapes. To find the exact ear location authors automatically resized the ear template. Experimental results shows that the proposed approach is invariant to shape, pose, illumination and occlusion of ear images. Detection rate is again defined as ration between number of successful ear localizations and number of all annotated ears. Authors tested their approach on the CVL face database [10] and the ND-Collection E database [11] and obtained detection rates of 91.0% and 94.5%, respectively.

In 2017 authors of [12] improved traditional Faster Region-based Convolutional Neural Networks algorithm with Multiple Scale Faster R-CNN framework in terms of ear detection step. They evaluated their approach on three different databases, UBEAR [13], WebEar [12] and UND-J2 [14]. They achieved 100% accuracy on 1800 images from UND-J2 database, which includes ear images in controlled environment. On 200 ear images from WebEar database, which includes ear images from the web (uncontrolled environment), the approach achieved accuracy of 98%. Similar accuracy of 98.66% was achieved on 9121 ear images from UBEAR database. It must be noted that this approach uses bounding box detections.

In 2018 deep learning approaches for ear detection started to appear. The authors of [15] presented a novel ear detection technique based on convolutional encoder-decoder networks to address occlusions, ear accessories and variable illumination on images captured in unconstrained settings. Evaluation of this approach was tested on 250 ear images from AWE dataset [16], which consists of images gathered from the web (uncontrolled environment). The authors achieved accuracy of 99.4% and intersection over union score of 55.7%. As opposed to [12], this approach uses pixel-wise detections.

However, there are no standard benchmarks and evaluation methodology for ear detection. Existing approaches are evaluated on different performance metrics and also different databases which makes it harder to compare it among themselves. For example both [12] and [15] report evaluation on same performance metrics (accuracy, precision and recall). But authors in [12] use correct detections (true positives) on image level (number of correctly located ears) while authors in [15] use correct detections on pixel level (number of correctly classified pixels).

III. Methodology

Mask R-CNN [1] extends Faster R-CNN [12], which uses bounding box detection. Authors of Mask R-CNN method added a branch for predicting an object mask along with the existing branch for bounding box detection in Faster R-CNN. This branch is a fully connected convolutional network, which is applied to each region of interest (RoI) and predicts a pixel to pixel segmentation mask. The main advantage of Mask R-CNN is locating exact pixels of each object instead of just bounding boxes. We begin with a quick overview of Mask RCNN's predecessor.

A. Faster R-CNN

Faster R-CNN consists of two stages, one being Fast R-CNN [17] and the other being the region proposal network [12]. Fast R-CNN includes a feature extractor, classifier and bounding box regressor in a single convolutional neural network. Along with image, Fast R-CNN requires region proposals as an input. Authors of Faster R-CNN observed that convolutional feature maps calculated with Fast R-CNN could be used for generating region proposals. They managed to reuse results from Fast R-CNN and get the region proposals, which are candidates for object bounding boxes.

B. Mask R-CNN

Mask R-CNN has similar stages as Faster R-CNN with added pixel-wise prediction branch. We can break down this method to five parts:

1) convolutional backbone architecture,
2) region proposal network,
3) region of interest (RoI) classifier,
4) bounding box regressor,
5) Detection pixel-wise masks.

The authors instantiated Mask R-CNN with multiple **backbone architectures**. They evaluated ResNet [18] and ResNeXt [19] networks of depth 50 or 101 layers and also explored Feature Pyramid Network (FPN), proposed in [20].

Region proposal network scans the image with sliding window over anchors (red squares on Fig. 1) with different size and aspect ratios [21].

As mentioned region proposal network does not scan over the image but uses one of the feature maps generated by convolutional neural network. For each anchor the region proposal network outputs foreground

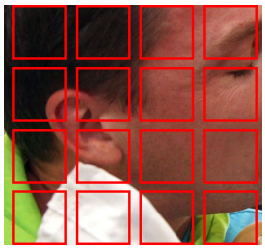


Fig. 1. Red squares represent anchors, which are scanned by region proposal network. These squares are drawn on the original image for illustration. RPN actually scans over the feature maps but areas on the feature maps correspond to areas on original image. These anchors are of different sizes and usually they overlap to cover as much space as possible.

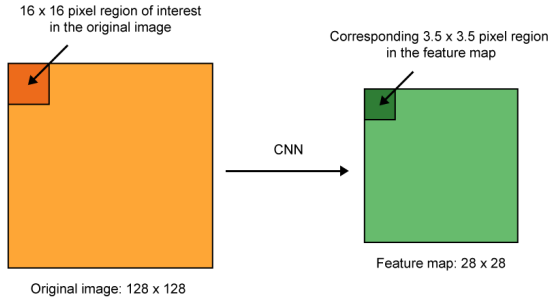


Fig. 2. Original image of size 128×128 pixels and corresponding feature map of size 28×28 pixels.

(object) or background class. Anchors that are most likely to contain objects are called regions of interest and are passed to RoI classifier [21].

The authors proposed **RoI classifier** called RoIAlign, which improves RoIPool [17] from Faster R-CNN. RoIPool is used for bounding box detections. Authors of Mask R-CNN realized that feature map calculated by RoIPool did not align with regions of the original image [22]. This is due to the fact that pixel-wise masks must be more precise that bounding box masks. RoIPool rounds RoI boundaries which leads to misalignment. If we take a look at Fig. 2, in RoIPool that would correspond to rounding region in the feature map from 3.5×3.5 pixel region to 3×3 pixel region. Contrary to RoIPool, in RoIAlign there is no rounding of RoI boundaries. However, in RoIAlign we use bilinear interpolation to get exact idea of what would be at pixel 3.5.

This classifier returns the class of the object in the region of interest. Unlike region proposal network, which has two classes, this stage is capable of classifying region of interest to more classes, such as person, car, airplane, etc.

The main purpose of **bounding box regressor** is to further refine the coordinates for the bounding box once the object has been classified.

Detection pixel-wise masks are the main advantage that extends Faster R-CNN. Mask branch is convolutional network which takes regions selected by ROI classifier and generates low resolution 28x28 pixels

masks for these regions [21].

C. Implementation

To perform ear detection on ear images we use Mask R-CNN implementation available online [23]. The implementation used, however, has some differences from the paper.

Mask R-CNN implementation uses standard convolutional neural network ResNet101 proposed in [18]. In addition to ResNet101 authors of [23] included feature pyramid network from [20], which uses connections to build in-network feature pyramid [1]. As already explored in [1], excellent gains in accuracy and speed are achieved using a ResNet-FPN backbone for feature extraction with Mask R-CNN. Feature pyramid network enables better representation of objects at different scales.

All images are resized to 1024×1024 pixels to support training multiple images per batch. If image is not square it is padded with zeros, to preserve the aspect ratio [23]. Image is then converted to a feature map of shape $32 \times 32 \times 2048$ while passing through the ResNet backbone.

Instead of RoIAlign authors of implementation use TensorFlow's *crop_and_resize* function for simplicity.

IV. Experimental results

In this section we describe images used for training, training protocol and performance metrics used to evaluate and compare Mask R-CNN ear detection approach with PED-CED approach.

A. Training dataset

For the purpose of training Mask R-CNN for ear detection, ear images were collected from the web. In that way the images were gathered in unconstrained environment and of different resolutions. RefineNet-based [24] detector was used to detect ears on all images. We examined results and annotated which ears were correctly detected. Next step was to remove failed detections after which we ended up with 12,500 ear images with their pixel-wise detection masks which were used as our ground truth. Images were split into train and validation set of 9,500 and 3,000 images, respectively.

B. Training

We train our model on Nvidia GeForce GTX 1070 graphics card with 8GB of memory. One image per GPU is used and we set number of epochs to 200 and number of steps per epoch to 30. For training starting point we use weights from https://github.com/matterport/Mask_RCNN/releases/download/v2.1/mask_rcnn_balloon.h5.

C. Performance metrics

We used the same performance metrics as in [15]. We have only two classes, ear and non-ear. We define:

- TP (true positives): number of pixels that are correctly classified as a part of an ear,
- TN (true negatives): number of pixels that are correctly classified as non-ear pixels,
- FP (false positives): number of non-ear pixels that are classified as a part of an ear,
- FN (false negatives): number of ear pixels that are classified as non-ear pixels.

First we define detection accuracy as

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}. \quad (1)$$

This accuracy has large TN value, since the majority class is non-ear. Hence we expect this measure to have value close to 1. Second metric is intersection over union (IoU), which is defined as

$$\text{IoU} = \frac{\text{TP}}{\text{TP} + \text{FP} + \text{FN}}. \quad (2)$$

IoU represents a ratio between pixels that are in annotated and detected ear regions (intersection) and pixels that are in union of annotated and detected ear regions. Perfect overlap gives us score of 1 while completely failed detection gives us score of 0. Third metric is recall, defined as

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}, \quad (3)$$

which tells us how many of ear pixels were actually detected. On the other hand we define precision as

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}, \quad (4)$$

which tells us how many of the detected ear pixels were indeed ear pixels.

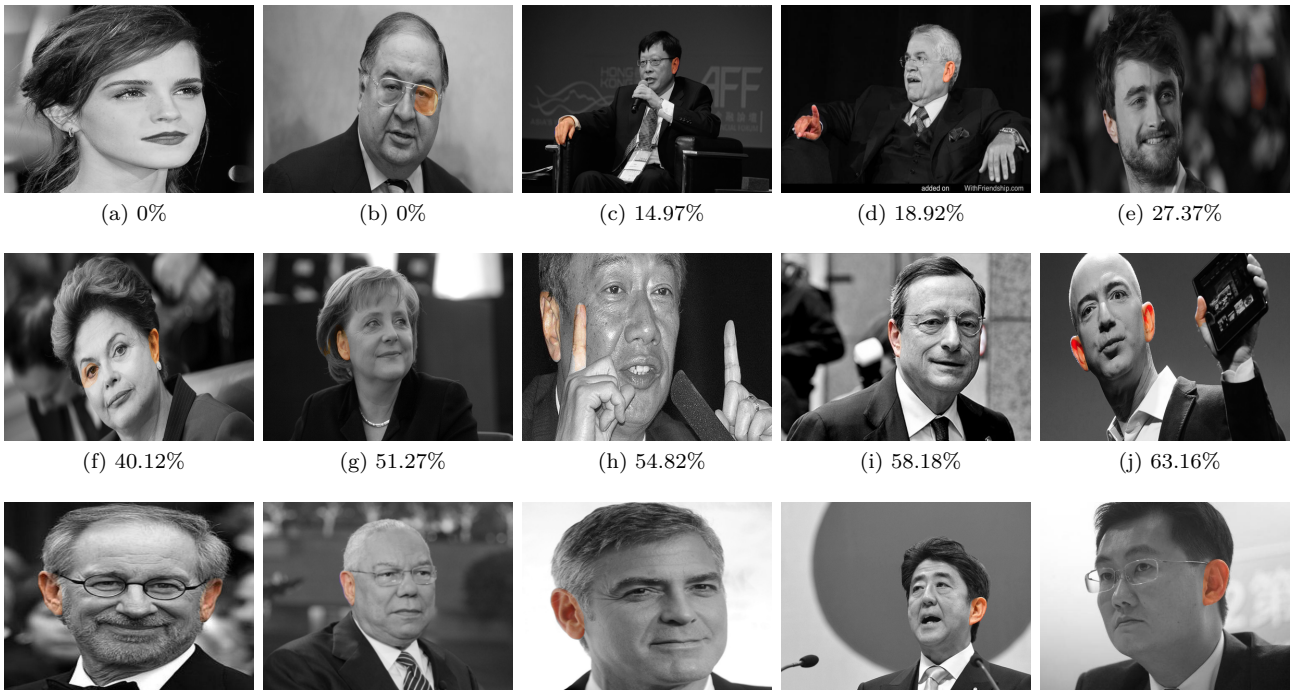
D. Detection evaluation

We evaluate our approach on 250 test images of AWE dataset [16] and compare it to [15]. We achieve similar detection accuracy of 99.7%, which is partly the consequence of background (non-object) being the majority class. Performance comparison on AWE dataset is shown in Table I.

TABLE I
Performance comparison of Mask R-CNN and PED-CED on AWE dataset.

Approach	IoU [%]	Precision [%]	Recall [%]
PED-CED	55.7±25.0	67.7±25.7	77.7±32.8
Mask R-CNN	**79.24±0.19**	**92.04±0.16**	**84.14±0.20**

In addition we evaluate our approach in terms of correctly detected ears. Ears on image are correctly detected if intersection over union is above 0.5. Our approach correctly detects ears on 232 images (out of 250 test images of AWE dataset) thus achieving detection accuracy of 92.8%.



(a) 0% (b) 0% (c) 14.97% (d) 18.92% (e) 27.37%

(f) 40.12% (g) 51.27% (h) 54.82% (i) 58.18% (j) 63.16%

(k) 90.81% (l) 92.36% (m) 93.63% (n) 95.03% (o) 96.13%

Fig. 3. Detection results ordered in terms of their increasing values of intersection over union score. Colored regions are classified as ears. In the top row there are some of the worst detections, the middle row shows average detection and the last row shows some of the best detections made by Mask R-CNN model.

The best ear detection on AWE dataset has IoU score of 96.13%. Fig. 3 summarizes some of the best ear detections, some average ear detections and some of the worst ear detections. From 3a we see that occlusions in form of hair covering part of the ear is, in some cases, still a problem for our model. Mask R-CNN also incorrectly classifies glasses and eyes as ears, which can be seen on 3b and 3f, respectively. In addition, fingers (3h and 3j) and hands (3c and 3d) are also classified as ears in some cases. In these cases creases on skin might be interpreted as pinna and therefore classified as ear. Hand and finger regions are elongated shaped just like ears in most of the cases. Our model learns that ears usually appear on both sides on portrait images. We can see from 3i that Mask R-CNN tries to find ears on both sides of portrait image. It correctly finds left ear but incorrectly classifies background object as right ear due to it's specific position on the image. From last row we can see that our model correctly detects one and more ears on the image with high accuracy (in terms of IoU score).

V. Conclusion

In this paper we describe Mask R-CNN and evaluate this approach for ear detection. We report pixel-wise performance in terms of detection accuracy, intersection over union precision and recall. We also report detection accuracy image-wise. We show that this approach performs very well for ear detection step, achieving detection accuracy of 99.7%, IoU score of 79.24%, precision of 92.04% and recall of 84.14% on AWE dataset. IoU score, precision and recall were all shown to be significantly higher than those achieved by PED-CED approach, while detection accuracy stays almost the same.

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Utilizing Apple's ARKit 2.0 for Augmented Reality Application Development

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***Abstract* - When it comes to practical augmented reality applications, mobile platform tools are the most deserving. Thanks to the nature of mobile devices and their everyday usage, the ideal basis for this kind of content has inadvertently formed itself. Consequently, within the *iOS* development environment, *Apple's Xcode* program enables application development using the *ARKit* library which delivers a host of benefits. Amongst the plethora of advantages, this paper focuses on utilizing features such as the ability to measure distances between two points in space, horizontal and vertical plane detection, the ability to detect three-dimensional objects and utilize them as triggers, and the consolidated implementation of *ARKit* and *MapKit* libraries in conjunction with the *Google Places API* intended for displaying superimposed computer-generated content on *iOS 11* and later iterations of *Apple*'s mobile operating system.**

Keywords – Apple, AR, ARKit, Augmented Reality, Computer Vision, Core ML, Custom Vision, Google Places, iOS, iPhone, Machine Learning, Map Kit, Microsoft Cognitive, POI, Points of interest, SceneKit, Swift, Xcode

I. INTRODUCTION

By virtue of recent technological advancements, computer-generated graphics have reached a level at which achieving a credible depiction of photorealistic content no longer presents a challenge, but rather serves as a stepping stone when it comes to defining the concept of reality through the convergence of real and virtual content. Therefore, it could be argued that the term *Augmented Reality* represents the backbone of the real and virtual worlds.

Since its inception, augmented reality has drastically changed the way information gets perceived. Although present for many years, augmented reality has flourished thanks to the emergence of sufficient hardware and software support towards the end of the 20th century. As a result, interacting with virtual objects superimposed over the real environment is no longer a matter of fiction, but a fundamental element of numerous applications and services which intend to simultaneously enhance and simplify interactions and consumption of all sorts of digital content.

Even though augmented reality gets utilized in a wide range of human activities, this paper intends to focus on a few specific and potentially practical implementations of *AR* within *Apple*'s *iOS* operating system.

Consequently, the applications depicted in this paper are based on *Apple*'s *ARKit 2.0* library which greatly simplifies the development of *AR* based applications in several key aspects with the use of *Apple*'s *Swift* programming language compiled through *Xcode*.

II. DISTANCE MEASURING APPLICATION

Thanks to recent advancements in technology, many everyday tools are gradually getting replaced and improved upon. One such example can be seen in the case of the classic ruler, or a tape measure whose role could be taken over by an application based on augmented reality.

The following application attempts to showcase the potential, and bridge the gap between reality and technology by utilizing augmented reality with the help of the *iOS* device's onboard camera as an input element in order to achieve a credible display of distance between two desired points in space (figure 1).

Displaying the distance was achieved by using the *UIlabel()* class which, amongst others, contains a *CGRect* element representing a rectangle on top of which a string of alphanumeric characters depicts the distance measured in centimeters with two or more decimal places.

Since the purpose of the application is to visually depict dots in space based on the user's input, the *SCNNode* method along with the *SCNMaterial()* instance represents the key component in translating touch input into a graphical interpretation of a dot on the screen of the device.

Lastly, the inclusion of the *UITapGestureRecognizer* class, which is responsible for perceiving the number of taps, represents the final ingredient necessary to combine the touch input with the distance measurements between the two separate points in space.

The basic idea behind the application rests on utilizing the distance formula based on the Cartesian coordinate system and applying it in the three-dimensional space. Combining that concept with *Apple*'s *ARKit* library, which is responsible for detecting horizontal and vertical surfaces, results in a credible distance measurement display based on the user's input throughout the device's touchscreen interface.

Through the process of testing the application several things stood out. Even though the desired points can be placed anywhere within the visible spectrum provided by the devices wide angle camera, the most precise measurements are achievable in the range of 10 to 300 cm. Also worth noting is the fact that the measurements get

more precise the closer the device is in regards to the object that is being measured. Where the *ARKit* implementation really shines is the fact that the measurement points don't need to be visible on the screen at the same time which ultimately translates to a high level of precision as long as the device is placed in closer proximity to the object that is being measured [4] (Figure 1).

In conclusion, thanks to *ARKit*'s tracking and mapping system, one could say that the points placed on top of the real world embody the definition of augmented reality.

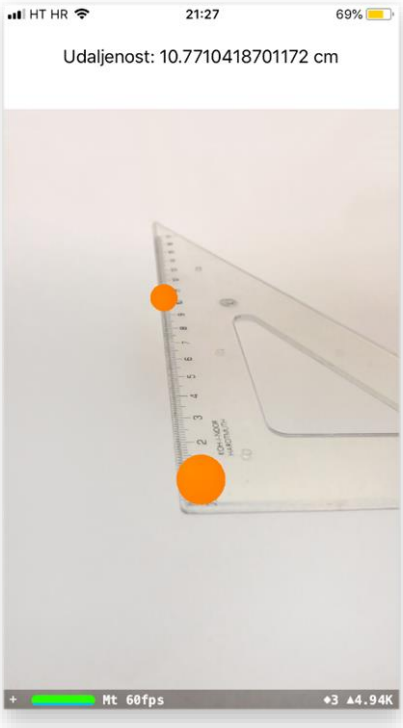

Figure 1. Demonstrating the basic capability of the distance measuring application

III. OBJECT RECOGNITION APPLICATION

In contrary to the previous way of implementing augmented reality, the following application utilizes standard elements of *ARKit* and *SceneKit* libraries in conjunction with the *Core ML* and *Vision* libraries.

While the *ARKit* and *SceneKit* libraries deliver data related to planar detection and store user defined parameters superimposed over the user's real environment, the *Vision* library introduces the ability to use *Machine Learning* and *Computer Vision* in order to be able to determine the name of the perceived object based on the specific predefined category it belongs to.

The category assessment process is done with the help of predefined *Machine Learning* models such as *Inceptionv3*, *Resnet50*, *MobileNet*, *SqueezeNet*, *GoogLeNetPlaces* and *VGG16* readily available withing the *Apple Developer* documentation [2]. Also, along with the aforementioned *Machine Learning* models, a custom Croatian language based model was designed specifically for the purpose of application testing and demonstration.

The functionality of the application itself rests on several key components. One such component is *VNCoreMLModel* from the *Core ML* library which is responsible for utilizing the *Machine Learning* model within the code [7].

Thanks to the inclusion of the *ARKit* library and its *UITapGestureRecognizer* class the application is able to recognize user input and translate it into a specifically defined action. In this case, similarly to the distance measuring app, the application generates white spheres with the addition of a three-dimensional text element attached to its node.

The *Vision* library's role comes into play once the perceived image needs to be compared to the desired *Machine Learning* model which is initiated with the *VNClassificationObservation* component (Figure 2).

Initializing the image request is done with the help of a *do – catch* statement accompanied with the keyword *try* which implies that the request might return an error. Following a successful *do – catch* statement the *Vision* request gets initiated with the help of the *perform* function.



Figure 2. Implementation of the custom *ARVision* model within the code using the *Xcode* interface

Another thing worth noting is the fact that the image perceived by the *ARKit* library gets recorded in a *YUV* format, which in turn means it needs to be converted to *RGB* values in order for the device to be able to interpret the image properly and ultimately ensure future compatibility with a broader range of *Machine Learning* models.

For the creation of the custom *Machine Learning* model, *Microsoft*'s *Cognitive* service under the name of *Custom Vision* was used. The purpose of the service is to simplify the creation and training of smaller *Machine Learning* models.

To ensure a more precise result, each specific object category contains a sequence of 100 to 500 photos. Since the model requires a series of repetitive training cycles, each cycle contained up to 60 different photos. The number of photos per object was determined based on their physical features, i.e. simpler objects needed fewer photos than more complex ones.

All of the uploaded photos, along with their respective tags used for determining the name of the class which they belong to, fall under the *General (compact)* domain within the *Microsoft Custom Vision* interface since that's the only way to extract the needed data in a format compatible with the *iOS Core ML* models.

In total, 5000 out of the maximum allowed 5000 photos were uploaded under 17 different tags (Figure 3). Also, 10 out of 10 model training iterations were used to ensure the model's capability to differentiate all 17 categories of objects it contains. Since the minimum acceptable

percentage of a usable model is considered to be upwards of 60%, and the achieved precision and recall percentages of 10 consecutive training sessions reached upwards of 86%, the custom *ML* model was successfully created and ready to be implemented within the application [4].

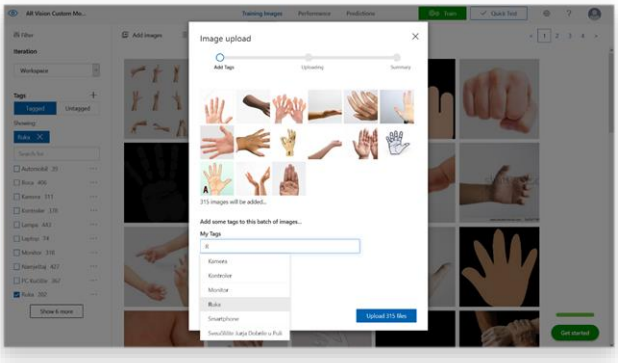

Figure 3. The uploading process of a sequence of hand images with appropriate tags for the purpose of training the custom *Machine Learning* model

Upon booting the application for the first time the user gets greeted with a white screen during which *ARKit* collects parameters and positions of the surrounding surfaces after which the application becomes ready for user input. Considering the number of characters in each tag, the recommended range of usage is between 20 and 200 cm.

More precise and reliable recognition is achieved when the device is placed closer to the object the user wants to identify by utilizing the built in *Machine Learning* model. The reason for that lies in the fact that the device tends to discern objects easier if they cover the majority of the frame as opposed to a more complex scene with several similar shapes and objects [4].

Bearing in mind the limitations of the application, it is recommended for the objects to be static because of the way the application collects and utilizes spatial parameters necessary for precise virtualization of computer-generated content. Therefore, objects that are static have a higher probability of being recognized by the algorithm as opposed to the ones that are changing their position relative to the device's location (Figure 4).



Figure 4. Testing the object recognition function of static objects while utilizing the Croatian machine learning model

Another prominent element of the application is the inclusion of statistical data located in the lower half of the display. The statistics include features such as a frame per second counter and the number of perceived nodes in the scene along with the total number of polygons. By going through the available statistics, provided thanks to the *SceneKit* library, the user can determine how many elements in the current scene the device has recognized and thereby influence its perception by slightly repositioning the device [4] (Figure 5).

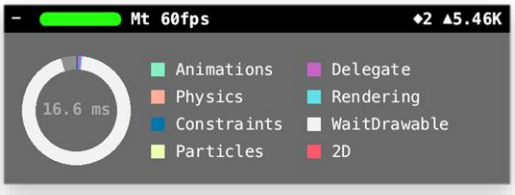

Figure 5. Scene statistics display based on the *showStatistics* function from the *SceneKit* library

IV. GOOGLE PLACES POINTS OF INTEREST AR APPLICATION

The purpose of this application is to identify and pinpoint the location of *Google*'s points of interest based on the user's current location. The display of the *POI* content is accomplished by combining the *HDAugmentedReality* library with the implementation of the *Google Places API* interface.

By utilizing the two aforementioned elements in combination with the device's built-in camera module, the application is able to display *Google*'s points of interest superimposed over the surrounding environment while simultaneously binding the floating *POI* labels to their actual location in space regardless of the direction the device is facing.

Achieving this complex task required several separate *Swift* based files to be created and combined. The first two files named *MjestaUcitavanje.swift* and *Mjesto.swift* are responsible for returning the query results as points of interest, based on the *Google Places API* interface, and storing them in appropriate classes within the code. The most important class in this case is *CLLocationManager* since it's responsible for starting and stopping the location data protocols required for successful execution of the application's main functionality [4] (Figure 6).

```
func locationManager(_ manager: CLLocationManager, didUpdateLocations
lokacije: [CLLocation]) {

  if lokacije.count > 0 {
    let lokacija = lokacije.last!

    if lokacija.horizontalAccuracy < 100 {
      manager.stopUpdatingLocation()
      let raspon = MKCoordinateSpan(latitudeDelta: 0.014,
longitudeDelta: 0.014)

      let regija = MKCoordinateRegion(center: lokacija.coordinate,
span: raspon)

      mapView.region = regija
    }
  }
```

Figure 6. Location data fetching syntax using the *CLLocation* class

Thanks to the aforementioned part of the code the application is able to fetch data relating to the current location of the device which in turn prepares it to fetch points of interest through the *Google Places API* interface.

Since the *Google Places API* is in essence a paid service, its usage and implementation require a registered *Google* account along with a valid credit card. Upon completing the registration and payment process, the service automatically generates an *API* key necessary for the proper implementation of *Google*'s services within the application [3]. In this case, the *API* key itself needed to be stored within the *MjestaUcitavanje.swift* file (Figure 7).

```
let apiURL = "https://maps.googleapis.com/maps/api/place/"
let apiKey = "AIzaSyBiLf1wcEZJpl4MFfIFCzL5pL6d5d_EVIs"
```

Figure 7. *Google Places API apiURL* and *apiKey* constants necessary for the proper execution of the code

In order for the points of interest to be displayed on the screen of the device, they first need to be passed to the *ViewController Swift* file with the help of the *startedLoadingPOIs* variable which is responsible for monitoring all ongoing requests (Figure 8). Since the *CLLocationManagerDelegate* method can initiate multiple requests after refreshing the location data, the larger number of requests is limited with the help of the *mjesta* variable which is meant to store all of the pereceived points of interest.

```
fileprivate var mjesta = [Mjesto]()
fileprivate var startedLoadingPOIs = false
```

Figure 8. The implementation of the *startedLoadingPOIs* and *mjesta* variables within the code

Taking into consideration the fact that the user might be located in an environment that doesn't have any points of interest nearby, the code contains a specific parameter to address this issue. By attaching a value of 5000 to the *radius* parameter, the application starts loading points of interest that are up to 5000 meters away from the device. In other words, if the returned value equals *null* the fetching radius gradually increases until a sufficient number of places of interest gets loaded into the *ViewController* [4] (Figure 9).

```
if !startedLoadingPOIs {
  startedLoadingPOIs = true

  let ucitavanje = MjestaUcitavanje()
  ucitavanje.loadPOIS(location: lokacija, radius: 5000) { placesDict,
error in

    if let dict = placesDict {}
  }
}
```

Figure 9. Part of the *locationManager* function responsible for determining the maximum radius of *POI* content fetching

By combining all of the above mentioned elements, the application is able to determine the user's location, load a number of nearby points of interest and store them inside their respective classes.

Since the application is meant to display the *POI* content in two ways, i.e. on a map and through the live view feed of the built-in camera module, the application needs to show a map with the user's current location on the initial screen.

Implementing the map element is achieved by utilizing the *MapKit* library within a separate *Swift* file named *MjestoAnotacija* the purpose of which is to bind together the fetched *POI* content details with their corresponding locations on the map (Figure 10).

```
import Foundation
import MapKit

class MjestoAnotacija: NSObject, MKAnnotation {
  let coordinate: CLLocationCoordinate2D
  let naslov: String?

  init(lokacija: CLLocationCoordinate2D, naslov: String) {
    self.coordinate = lokacija
    self.naslov = naslov

    super.init()
  }
}
```

Figure 10. Implementing the *MapKit*'s *MKAnnotation* protocol responsible for binding the *POI* data with the corresponding location on the map

With the initial map screen created, the only missing element is the actual implementation of augmented reality. For the user to be able to transition from a traditional map into the *AR* view, a *UIButton* element representing the camera shortcut needed to be created.

For the actual augmented reality part of the application to be functional, the *HDAugmentedReality* library needed to be utilized to simplify the process of running specific calculations geared towards determining the distance between the device and the points of interest it's aimed towards. The calculations in question imply the use of x and y coordinates of each individual *POI* element based on the Cartesian coordinate system as well as the use of the orthodromic distance formula which determines the precise distance between two points on a sphere. In short, the *HDAugmentedReality* library is responsible for keeping the *POI* content tied to its actual location in space rather than constantly being displayed on the device regardless of its orientation [1].

The *HDAugmentedReality* library itself contains a number of *Swift* files which are needed to identify the points of interest, create a view for the points of interest, define the basic settings and supporting methods, run calculations and control the video signal while simultaneously adding annotations into the visible spectrum. However, for the library to be usable its *ARViewController* needs to be implemented within the *ViewController* file (Figure 11).

```
var arViewController: ARViewController!
```

Figure 11. *ARViewController* implementation within the *ViewController Swift* file

Another crucial element of the augmented reality experience within the application is the *ARDataSource* protocol which is responsible for transferring data necessary for displaying the *POI* content. For that purpose,

a separate *Swift* file was created under the name *AnnotationView*.

Utilizing the *UIKit* library, the *AnnotationView* file contains several notable elements. The inclusion of the *ARAnnotationView* subclass provides access to the view element containing labels with names and distances of corresponding points of interest. Additionally, the *loadUI()* function is responsible for attaching specific settings to the labels in question.

For visualization purposes within the augmented reality segment of the application, three specific labels were created. While the variables under the names *nazivLabel* and *udaljenostLabel* represent the graphical background elements for the name and distance parameters respectively, the *strelicaLabel* variable represents the arrow underneath the annotation pointing towards the location it refers to [4].

All of the elements contained within the label were created using the *CGRect* structure which is commonly used for creating rectangles of various sizes. To create the arrow shape, a rectangular element was rotated by 45 degrees and placed underneath the rectangles containing the *POI* content. This was done using the *rotationAngle* command which depicts the rotation in radians rather than degrees, therefore requiring the value of *pi* to be divided by four. Since *pi*, in this case, represents 180 degrees, the result equates to a rotation of 45 degrees [6].

The remaining elements of the label consist of two basic rectangles with two curved corners each. The curved corners were achieved thanks to the *Core Animation* library supported by *iOS 11* and newer iterations of the *iOS* operating system. Through the use of an *if* statement containing the *maskedCorners* command, the *layerMinXMinYCorner* and *layerMaxXMinYCorner* variables were utilized to round off two specific corners by five units [5].

In order for all of the label elements to be displayed, they needed to be contained inside of the *layoutSubviews()* function followed by *UIKit*'s *touchesEnded* function. This way, the application is capable of discerning whether the display is being touched so it can run processes necessary for its successful execution (Figure 12).

```
override func layoutSubviews() {
    super.layoutSubviews()
    nazivLabel?.frame = CGRect(x: 10, y: 0, width:
self.frame.size.width, height: 40)
    nazivLabel?.layer.cornerRadius = 5.0
    nazivLabel?.layer.masksToBounds = true
    nazivLabel?.textAlignment = .center
    udaljenostLabel?.frame = CGRect(x: 10, y: 40, width:
self.frame.size.width, height: 20)
    strelicaLabel?.frame = CGRect(x: 65, y: 49, width: 28, height: 10)
  }

  override func touchesEnded(_ touches: Set<UITouch>, with event:
UIEvent?) {
    delegate?.didTouch(annotationView: self)
  }
}
```

Figure 12. Combining the label elements with the *layoutSubviews()* and *touchesEnded* functions

Bridging the gap between the *layoutSubviews()* and the actual *ViewController* file is the *UIAlertController* class contained within the *UIViewController* class (Figure 13). With the inclusion of the *UIViewController* class the user is able to get relevant information upon tapping the desired point of interest on the device's display.

```
func showInfoView(zaMjesto place: Mjesto) {
    let obavijest = UIAlertController(title: place.mjestoIme , message:
place.infoText, preferredStyle: UIAlertControllerStyle.alert)
    obavijest.addAction(UIAlertAction(title: "OK", style:
UIAlertActionStyle.default, handler: nil))

    arViewController.present(obavijest, animated: true, completion: nil)
  }
```

Figure 13. *UIAlertController* implementation

The last crucial component necessary for the successful execution of the application is the inclusion of the *NSCameraUsageDescription* key inside of the *Info.plist* file. The sole purpose of this specific key is to ask for the user's permission to use the device's built-in camera in order for it to be able to display the augmented reality content.

Upon running the application for the first time, the user is prompted to allow the usage of location services. Also worth noting is that the user will be prompted to activate the location services each time the application detects that the services aren't actively running in the background. This is to ensure the accuracy and reliability of the results shown within the application.

By activating the location services, the user allows the application to use the device's built in *GPS* module to determine its location in relation to the nearby points of interest. Shortly thereafter, the points of interest start appearing in line with the previously determined radius of 5000 meters (Figure 14). Pinching the map to zoom in or out reveals additional points of interest in the vicinity determined by their statistics fetched from the *Google Maps* server. Consequently, using the application requires a constant *Wi-Fi* or *Mobile Data* connection [4].

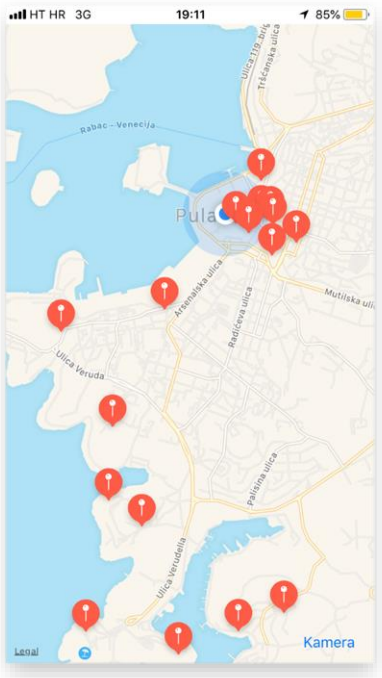

Figure 14. The home screen of the application displaying the user's current location (blue) and the closes points of interest (red)

Touching the *Kamera* button located in the lower right corner reveals the augmented reality portion of the application. In order for it to be functional, the user gets prompted with a pop-up notification requiring them to allow the usage of the device's built in camera module due to the previously mentioned *NSCameraUsageDescription* key contained within of the *Info.plist* file. Allowing the usage of the device's camera module results in the display being occupied with nearby points of interest floating above their actual location superimposed over the user's real environment [4].

Since the display of the *POI* content depends on the device's spatial orientation, the user needs to point the device towards the general direction the points of interest are located in order to be able to see their actual distance displayed on the screen of the device (Figure 15).



Figure 15. Displaying the names and distances of the nearest points of interest through the use of augmented reality

By tapping the name and distance labels the user can access additional information regarding certain points of interest depending on whether there is more information available on the *Google Maps* server. Exiting the information notification is achieved by tapping the *OK* button, while exiting the *AR* view is achieved by tapping on the dedicated button in the upper right corner (Figure 16).

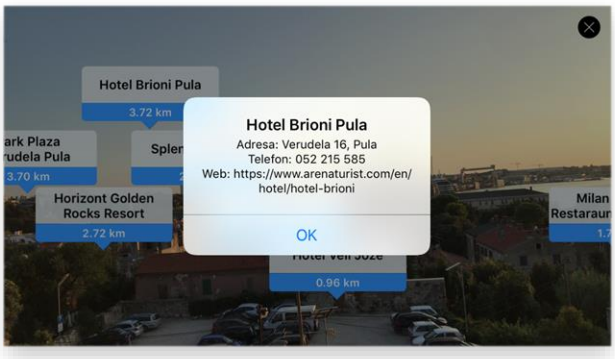

Figure 16. Displaying the additional information for a specific point of interest fetched from the *Google Maps* server

By moving through space the user can discover additional points of interest that weren't initially present depending on their popularity determined by the *Google Maps* server. The *Google Maps* server also offers 90 different categories of *POI* content which can be selectively displayed by utilizing the *types=* command within the code [3]. In case no category is defined, the user gets to see all of the available points of interest in their vicinity.

V. CONCLUSION

Contemporary augmented reality solutions such as the *Apple ARKit* are diligently upgrading their platforms and accompanying utensils with each coming iteration, thus providing developers with a broader range of tools intended to simplify tedious tasks and ultimately boost their productivity and creativity while consequently discovering new and innovative use-case scenarios.

Some innovative concepts of augmented reality implementation were materialized during the process of forming this paper, while their practical applications serve as a testament to the functionality and the potential of the synergy between mobile technology, the iOS platform and augmented reality as a way of consuming and interacting with digital content.

Based on the presented concepts that combine content that is of interest to users, i.e. potentially engaging and relevant, with modern technological innovations and augmentations, it can be concluded that augmented reality represents undeniable potential while serving as a useful alternative to a multitude of previously established modes of interaction with the environment.

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Development of Android Application for Gender, Age and Face Recognition Using OpenCV

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Abstract **- The idea behind the face recognition system is the fact that every individual has a unique face. Like the fingerprint, an individual's face has many unique structures and features. Facial authentication and facial recognition are challenging tasks. For facial recognition systems to be reliable, they must work with great precision and accuracy. Images captured taking into account different facial expressions or lighting conditions allow greater precision and accuracy of the system compared to a case where only one image of each individual is stored in the database. The face recognition method handles the captured image and compares it to the images stored in the database. If a matching template is found, an individual is identified. Otherwise, the person is reported as unidentified. This paper describes and explains in detail the entire process of developing Android mobile application for recognizing person's gender, age and face. Face detection and recognition methods that have been used are described and explained as well as development tools used in the development of Android mobile application. The software solution describes the details of using the OpenCV library and shows the actual results of the mobile application through the images.**

Keywords – face detection; deep neural network; face recognition; Android application; gender, age, face recognition; OpenCV; Android Studio

I. INTRODUCTION

Face recognition system is one of the most interesting and most important research fields in the last two decades. Reasons come from the need for automatic recognition and surveillance system, human interest in face recognition as well as communication between human and computer. Researches include knowledge and researchers from various research fields such as neuroscience, psychology, computer vision, pattern recognition, image processing and machine learning.

The first step to a reliable face recognition is detection of locations of faces in images where faces are present. Face detection is considered as a fundament to face recognition. However, it is a challeging task for computer system on which can affect issues such as location of the face, person orientation, face expressions, partial face coverage, lighting conditions etc.

This paper will explore the possibility of implementing a face recognition system, as well as gender and age recognition, onto a mobile device in the form of an Android application with the help of OpenCV library.

The remainder of the paper is structured as follows. Biometric system is briefly described in second section. Used algorithm for face detection and face recognition is explained in third section. The design and application functionalities are described in fourth section. Software solution is presented and thoroughly explained with code snippets and results in fifth section. Conclusions are drawn in last section.

II. BIOMETRIC SYSTEM

The biometric system is essentially a pattern recognition system that makes personal identification by determining the authenticity of a certain physical or behavioral characteristic possessed by the user. The biometric system can be divided into the data enrollment module and the identification module.

During the enrollment phase, the biometric characteristic of an individual is scanned by a biometric sensor in order to gain a digital representation of the characteristic. In order to facilitate matching and to reduce storage requirements, the digital representation is further processed by feature extractor to create a compact but expressive representation, called a template. During the recognition phase, the biometric sensor captures the characteristics of an individual to be identified and converts it into a digital format, which is further processed by a feature extractor to get the same representation as the template. The result of representation is entered in a feature matcher which compares it against the templates to determine the identity of an individual [4].

III. FACE DETECTION AND RECOGNITION

With the regard to the image, the purpose of face detection is to determine whether the face is in the image and, if it is present, to restore the location of the face in the image and the scope of each face. There are many related face detection issues. Some of the difficulties can be determining the position of the face in the image, detecting the presence and location of facial features such as the eyes, nose, eyebrows, nostrils, mouth, lips and ears, as well as face authentication that confirms the individual's identity in the image, assessing its location and orientation in real time and recognizing the emotional state of the face. Accordingly, the conclusion is that face detection is the first step in any automated system that addresses the above-mentioned problems [8].

Local Binary Patterns (LBP) is a very efficient texture operator that is defined as a grayscale invariant texture measure, derived from a general definiton of texture in a local neighborhood. Due to its discriminatory power and computational simplicity, LBP texture operator has become popular approach in various applications. It can be seen as a unique approach to traditional statistical and structural patterns of texture analysis. Perhaps the most important feature of an LBP operator in real world applications is its resistance to monotonic grayscale changes caused, for example, by variations in illumination. Another important feature is its computational simplicity, which enables the analysis of images in challenging real-time circumstances [7].

The original LBP operator forms labels for the image pixels by thresholding the 3x3 neighborhood of each pixel with the centre value and considering the result as a binary number. The histogram of these different labels can then be used as a texture descriptor [3]. Before applying LBP operation, it is necessary to train the algorithm with dataset of the facial images of the person we want to recognize, as well as, set an ID for each image in order for algorithm to use that information in output result.

As shown in Figure 1, on the facial grayscale image example, LBP operator takes 3x3 pixels part of the image which can be also represented as 3x3 matrix containing the intensity of each pixel (0-255). The central value of the matrix is used as threshold and to define the new values from the 8 neighbors. For each neighbor of the threshold, a new binary value is set. 0 if the value is lower than the threshold or 1 if the value is equal or higher than the threshold. The matrix will contain only binary values which if concatenated form a new binary value. Then, the new binary value is converted to a decimal value and set it to the central value of the matrix, which is actually a pixel from the original image. At the end of operation, a new image is created which represents better the characteristics of the original image.

LBPH (Local Binary Pattern Histogram) algorithm uses four parameters; radius, neighbors, grid X and grid Y. The radius is used to build the circular local binary pattern and represents the radius around the central pixel, it is usually set to 1. Neighbors represents the number of sample points used to build the circular local binary pattern, it is usually set to 8. Grid X represents the number of cells in the horizontal direction, it is usually set to 8. Grid Y represents the number of cells in the vertical direction, it is usually set to 8.

Extracting the histograms for face recognition, the image is divided into multiple grids with grid X and grid Y parameters, as shown in Figure 2. Each histogram from each grid will contain 256 positions representing the occurences of each pixel intensity. Final histogram is created with concatenation of each histogram and represents the characteristics of the original image. When performing face recognition, each final histogram is used to represent each image from the training dataset against final histogram of given input image. Comparing two histograms, input image and training image, algorithm returns the image with the closest histogram[8].

IV. Design and Functionalities

Use case diagram, shown in Figure 3, describes the design of interaction with mobile application where all possible options of interacting with mobile application are displayed and described.

The home screen shows the option of choosing three different actions, gender, age, or face recognition. Pressing any desired action triggers the selected activity. At the start of each activity, a camera is initialized in order to process real-time images. Also, by initializing

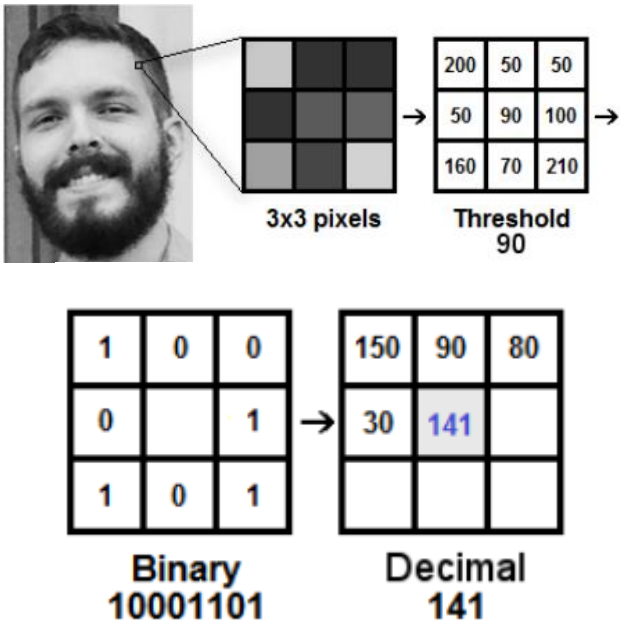

Figure 1. Example of LBP operation [8]

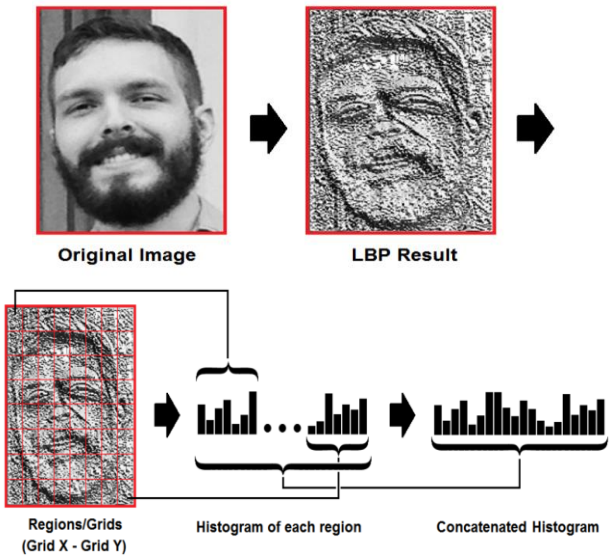

Figure 2. Example of extracting histograms [8]

the camera, face detection classifier loads in the background of mobile application. When gender or age recognition activity starts, the data of pretrained model for gender and age recognition is loaded in the background.

Application supports simultaneous detection of all faces, but does not support simultaneous recognition of all faces due to limited mobile device resources. By selecting face recognition, a training activity is initiated in which the user has to take a certain number of facial images of the person (s)he wants to recognize. In training activity, it is possible to capture and save images of faces in device memory, to create a face recognition model and automatically save extracted facial features in device memory, to delete all images of faces, as well as to delete facial features classifier and to run face recognition activity after fullfiling certain above metioned conditions. In the recognition process, only one face must be in the camera frame, and then the process of recognizing gender, age or face is automatically initialized.

The face detection result is visible as rectangular shape scoped around each detected face in the camera frame and the recognition results are written, accordingly to their activity, above the rectangle that appears around the detected face. Possible values for gender recognition outcome are; „MALE, FEMALE“. When recognizing the age, the possible values of the outcome may be; „0-2, 4-6, 8-13, 15-20, 25-32, 38-43, 48-53, 60+“. In face recognition, the value of the outcome is actually the image number that has the highest probability of matching the person's face in camera frame.

V. SOFTWARE SOLUTION

Every interaction with the camera is performed through OpenCV abstract class, CameraBridgeViewBase. The task of class is to interact with the camera and OpenCV library. The main responsibility is controlling when the camera can be enabled, camera frame processing, calling external interfaces for any camera frame adjustments and rendering camera frame results to the mobile device display. Interface that enables starting, stopping and camera frame manipulating is CvCameraViewListener2 and its methods, onCameraViewStarted(), onCameraViewStopped() and onCameraFrame(). Method onCameraViewStarted() is invoked when camera preview has started and then the frames are delivered to client via onCameraFrame() callback. Method onCameraViewStopped() is invoked when camera preview has been stopped for some reason and after no frames will be delivered to client through onCameraFrame() callback. Method onCameraFrame() is invoked when delivery of the frame needs to be done and the returned value is a modified frame which needs to be displayed on the screen. It takes CameraBridgeViewBase.CvCameraViewFrame input frame which represents a single frame from camera for onCameraFrame() callback and it must be manipulated by its default methods, gray() or rgba(), and returns specified Mat object with frame.

In order to be able to access mobile device camera, permission rights in file AndroidManifest.xml have been added. For face detection, OpenCV object detection class CascadeClassifier has been used, which allows us to load previously evaluated cascade classifiers. Face detection was achieved with the help of trained LBP face features classifier in the form of XML file.

A. Face detection

In order for face detection to be successful, the current camera frame uses Mat class in real time, which is

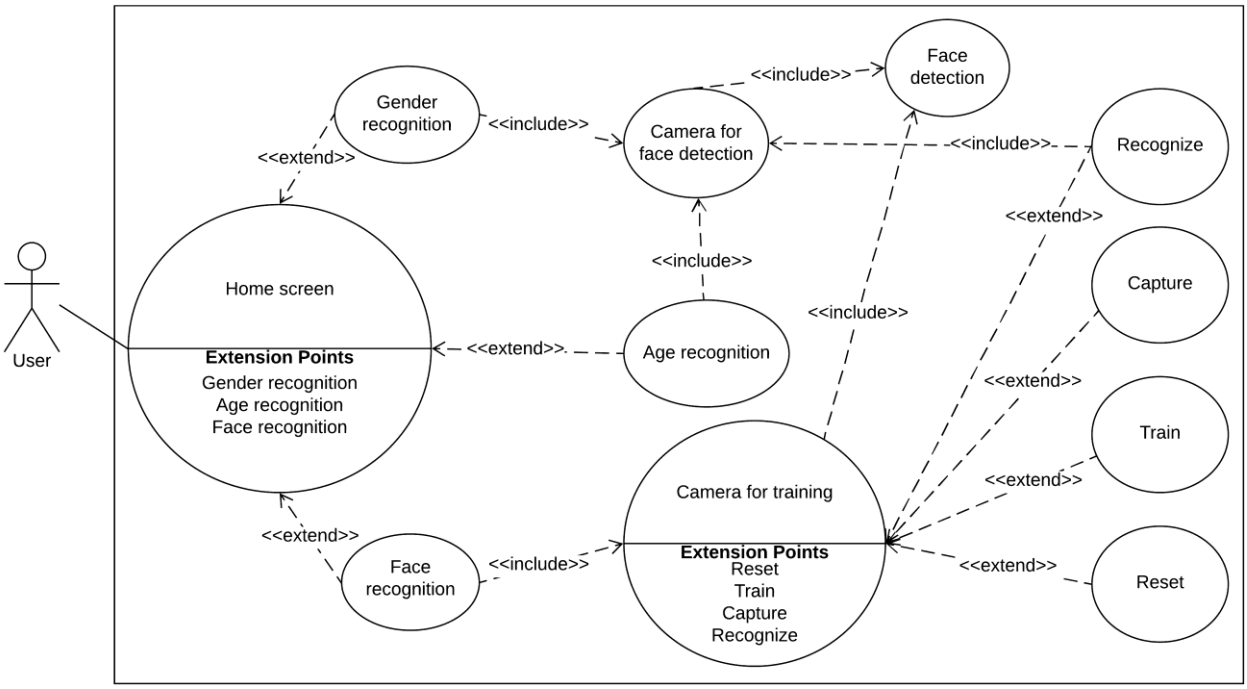

Figure 3. Use case diagram of an Android application for gender, age and face recognition

used in all OpenCV 2D computer vision applications. Mat class is actually basic image container. It can appear as a class with two parts of data. Matrix header, which contains information such as matrix size, method of storage usage, address of stored matrix and matrix pointer, which contains pixel values.

Using detectMultiScale() method, see Figure 4, we can detect faces of various sizes in a given camera frame, and save them to MatOfRect object. In order to be able to draw a rectangle around each of the detected faces in the image, all detected faces are stored in a 2D array. Drawing a rectangle around the detected face is performed by using the method rectangle() of OpenCV image processing module, Imgproc.

B. Gender and age recognition

Gender and age recognition are using Levi and Hassner's Caffe model [5]. The model is trained on the Adience collection of unfiltered faces for gender and age classification and contains 26.580 images of a total of 2.284 subjects. The source for the photos in Adience collection are the Flickr.com albums, produced by automatic upload from smartphones iPhone 5 or later that are publicly available through the Creative Commons (CC) license. All images were manually labeled for age and gender using both the images themselves and using any available contextual information (image tags, associated text, additional photos in the same album, etc.) [2].

The convolutional neural network contains three convolutional layers, each followed by a rectified linear operation and a pooling layer. The first convolutional layer contains 96 filters of 7x7 pixels, the second convolutional layer contains 256 filters of 5x5 pixels, the third and final convolutional layer contains 384 filters of 3x3 pixels. Finally, two fully-connected layers are added, each containing 512 neurons. At the end, the result is obtained from fully-connected layers which is the class attribute, in this case gender or age, to which the input image belongs [5]. The model was implemented with OpenCV module for deep neural networks, Dnn. The gender recognition result is described as the output value of 0 or 1, where 0 indicates a male person, and the value 1 indicates a female person. In age recognition, the result of the age estimation is described in the form of output values from 0 to 7, where each value represents a particular age group; 0-2, 4-6, 8-13, 15-20, 25-32, 38-43, 48-53, 60+.

```
MatOfRect faces = new MatOfRect();

    //Using detection classifier
    if (mFaceDetector != null) {
        mFaceDetector.detectMultiScale(mGray,
            faces, 1.1, 5, 2, new Size(mAbsoluteFaceSize,
            mAbsoluteFaceSize), new Size());
    } else {
        Log.e(TAG, "Detection is not selected!");
    }
    //Drawing rectangle around detected face
    Rect[] facesArray = faces.toArray();
    for (int i = 0; i < facesArray.length; i++) {
        Imgproc.rectangle(mRgba, facesArray[i].tl(),
        facesArray[i].br(), new Scalar(0, 255, 0, 255), 3);
        }
```

Figure 4. Face detection and drawing rectangles around detected

As shown in Figure 5, method for age recognition as parameters takes an RGBA frame from a mobile camera and a 2D array of detected faces. Within the method, a new Mat object is created that contains only the detected face within the entire frame. Then, the facial image is decreased to the required image resolution of the convolutional neural network we use, 227x227, and switched to the three-channel image of the BGR format. After the preliminary image processing, the image is sent through a deep neural network where the result of the highest value is retrieved via the static class MinMaxLocResult, which prints the gender or age group class number that the detected face belongs to and returns the result as a String variable. The result of age recognition is presented in Figure 6.

The only difference between age and gender recognition methods is the output result, as gender recognition has output values 0 or 1. The result can be seen in Figure 7.

C. Face recognition

Before it is possible to recognize a face, it is necessary to train a face recognition model with face images of a person which is going to be recognized. By pressing Capture on the mobile device display, the method for taking detected facial images is performed. The method parameters, as shown in Figure 8, are the image number, the RGBA frame and the face detection classifier. At the very beginning of the method execution, a directory called FacePics is created in the device memory where the face images will be stored, as well as the trained face recognition model in XML format. It follows with the preliminary image processing, converting RGBA frame to a grayscale image, detecting and extracting only a face from the overall image, reducing the resolution of the face image to 92x112 and equalizing face image histogram. Preliminary image

```
//Method for age recognition
private String predictAge(Mat mRgba,
                          Rect[] facesArray) {
    try {
        for (Rect face : facesArray) {
        Mat capturedFace = new Mat(mRgba, face);
        //Resizing pictures to resolution of Caffe model
        Imgproc.resize(capturedFace, capturedFace,
                       new Size(227, 227));
        //Converting RGBA to BGR
        Imgproc.cvtColor(capturedFace, capturedFace,
                         Imgproc.COLOR_RGBA2BGR);
        //Forwarding picture through Dnn
        Mat inputBlob = Dnn.blobFromImage(capturedFace,
        1.0f, new Size(227, 227), new Scalar(78.4263377603,
        87.7689143744, 114.895847746), false, false);
        mAgeNet.setInput(inputBlob, "data");
        Mat probs = mAgeNet.forward("prob").reshape(1, 1);
        //Getting largest softmax output
        Core.MinMaxLocResult mm = Core.minMaxLoc(probs);
        //Result of age recognition prediction
        double result = mm.maxLoc.x;
        Log.i(TAG, "Result is: " + result);
        return AGES[(int) result];
        }
    } catch (Exception e) {
        Log.e(TAG, "Error processing age", e);
    }
    return null;
}
```

Figure 5. Age recognition method

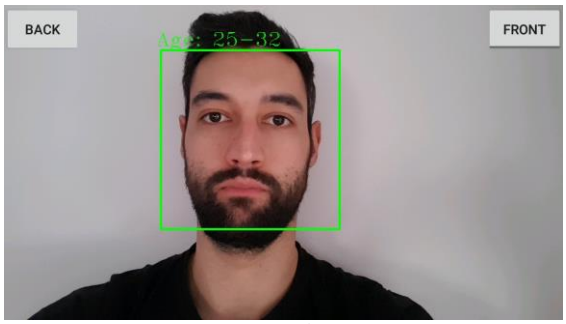

Figure 6. The result of age recognition

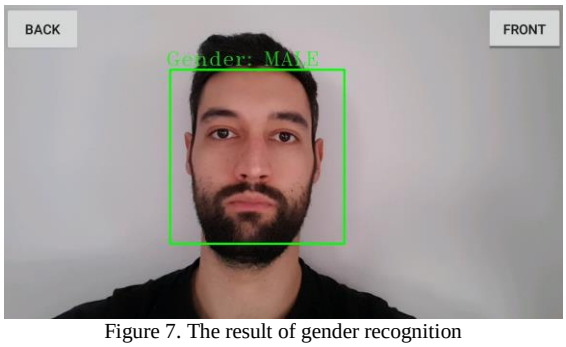

Figure 7. The result of gender recognition

processing is performed to optimize resources and performance required for computational training of face recognition algorithm. The face image is saved into the directory FacePics of the Pictures directory using the OpenCV read and write image module, Imgcodecs.

After capturing facial images, next actions are image processing for training face recognition model, creating a face recognition model, face recognition model training with facial images and corresponding facial labels and saving trained face recognition model to device memory. Each saved image in the FacePics directory is loaded into a grayscale and is saved in the Mat object. The label of each image is actually the number of the image. The processing of the input image is followed, and finally, each image is saved in the MatVector object with the corresponding label being written to the Mat object.

The mobile application uses the LBPH face recognition model that is created using a static FaceRecognizer class located in the OpenCV face analysis module, Face. After creating a face recognition model, it is possible to use its methods. One of the methods is a train() method that as a parameter requires a set of images to be used to train the model and the corresponding labels of these images. After training a face recognition model, the model is saved in the device memory of the mobile device by the write() method. The result is a file in XML format that contains all of the extracted features of the face images over which the training was performed. The file is saved in the directory FacePics.

After face recognition model training has been completed, by pressing the Recognize button on the mobile device display, the face recognition activity will launch. When the face recognition activity is started, in the background is loaded trained face recognition model in XML format. Trained face recognition model is used to recognize detected faces on a mobile device display. Recognition shown in Figure 9 is performed automatically on the mobile device display if only one face is in a camera frame. Prior to performing the recognition method, preliminary image processing is required. Face recognition is performed by the method predict() of static class FaceRecognizer. In the method predict(), as the parameters are, the image over which the face recognition is executed, list of image labels, and the probability of matching the detected face with the face

```
//Method for capturing photos
public static void takePhoto(int photoNumber,
                             Mat rgbaMat,
                             CascadeClassifier faceDetector)
throws Exception {
    File facePicsPath = new File(String.valueOf(ROOT));
    if (facePicsPath.exists() && !facePicsPath.isDirectory())
        facePicsPath.delete();
    if (!facePicsPath.exists())
        facePicsPath.mkdirs();

    Mat grayMat = new Mat();
    //Converting RGBA to GRAY
    Imgproc.cvtColor(rgbaMat, grayMat, Imgproc.COLOR_RGBA2GRAY);
    MatOfRect detectedFaces = new MatOfRect();
    faceDetector.detectMultiScale(grayMat, detectedFaces);
    Rect[] detectedFacesArray = detectedFaces.toArray();
    for (Rect face : detectedFacesArray) {
        Mat capturedFace = new Mat(grayMat, face);
        //Resizing to 92x112
        Imgproc.resize(capturedFace, capturedFace,
                       new Size(IMG_WIDTH, IMG_HEIGHT));
        //Histogram equalizing
        Imgproc.equalizeHist(capturedFace, capturedFace);
        if (photoNumber <= PHOTOS_TRAIN_QTY) {
            File savePhoto = new File(facePicsPath,
                                      String.format("%d.png",
                                                    photoNumber));
            savePhoto.createNewFile();
            //Saving photos to directory FacePics
            Imgcodecs.imwrite(savePhoto.getAbsolutePath(),
                              capturedFace);
            Log.i(TAG, "PIC PATH: " + savePhoto.getAbsolutePath());
        }
    }
}
```
Figure 8. Method for capturing photos

```
//If one face is detected, face prediction is executed
if (facesArray.length == 1) {
    try {
    //Conversion from OpenCV Mat to JavaCV Mat
    opencv_core.Mat javaCvMat = new opencv_core.Mat((Pointer) null)
    {{address = mGray.getNativeObjAddr();}};
    //Picture resizing
    resize(javaCvMat, javaCvMat,
           new opencv_core.Size(Methods.IMG_WIDTH,
                                Methods.IMG_HEIGHT));
    //Histogram equalizing
    equalizeHist(javaCvMat, javaCvMat);
    IntPointer label = new IntPointer(1);
    DoublePointer confidence = new DoublePointer(1);
    mLBPHFaceRecognizer.predict(javaCvMat, label, confidence);
    int predictedLabel = label.get(0);
    double acceptanceLevel = confidence.get(0);
    String name;
    Log.d(TAG, "Prediction completed, predictedLabel: "
          + predictedLabel + ", acceptanceLevel: "
          + acceptanceLevel);
        if (predictedLabel == -1 || acceptanceLevel >= THRESHOLD) {
            name = "-";
        } else {
            name = Integer.toString(predictedLabel);
        }
        //The result of face recognition
        for (Rect face : facesArray) {
            int posX = (int) Math.max(face.tl().x - 10, 0);
            int posY = (int) Math.max(face.tl().y - 10, 0);
            Imgproc.putText(mRgba, "Closest picture: num." +
                            name, new Point(posX, posY),
            Core.FONT_HERSHEY_TRIPLEX, 1.5,
                            new Scalar(0, 255, 0, 255));
        }
    }catch (Exception e) {
        Log.d(TAG, e.getLocalizedMessage(), e);
    }
}
```
Figure 9. Performing face recognition

from the FacePics directory. The face recognition model uses the closest neighbor recognition method.

In order to identify the number of the closest recognized image, the detected face must meet certain conditions of trained face recognition model. There are two conditions; the first condition is that the detected face on the mobile device display has face features which are compared to face features found in the trained face recognition model, and the second condition is that the probability of the detected face does not exceed the programmed threshold value (130.0). A face recognition results may be negative, if one or both of the conditions are not met, or positive, showing the number of the closest recognized face image from the FacePics directory. The negative and postitive results are shown respectively in Figure 10 and 11.

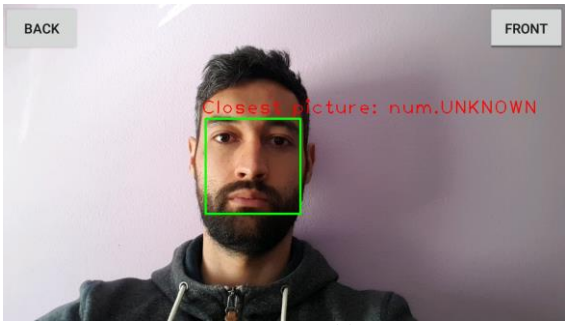

Figure 10. Negative output of face recognition

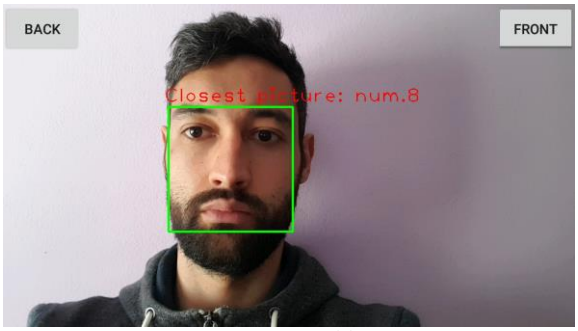

Figure 11. Positive output of face recognition

VI. CONCLUSION

This paper in detail explains the development of a gender, age and face recognition system on an Android mobile device. The overall software solution for face detection and recognition in the mobile application is achieved with the help of the OpenCV library which provides a numerous functionalities for developing computer vision aplications. A LBP face features classifier was used for face detection and LBPH model was used for face recognition purposes. Gender and age recognition was achieved by populating a deep neural network that allows the use of recognition functions without capturing the images and training gender and age recognition models. Although recognition algorithms successfully perform job of face recognition, they are affected by various conditions such as illumination, pose of the person, facial expressions, face coverage, camera features as well as the performance of the mobile device itself. It is shown that in spite of all the above mentioned issues, it is possible to implement the recognition system on the Android mobile device.

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Query Optimization in Relational Database Systems

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Abstract - Query optimization is an important component in relational systems and has gained great importance since the '80s. Sometimes, the reason for a slow query response time is the system load, but the more common one is that the query is written in a way that can not be performed efficiently. Query optimization requires a series of actions and procedures to get the desired result. The aim of this paper is to present and describe some of the more familiar and prominent methods and techniques of query optimization in relational database systems.

Keywords: query optimization, relational system, optimizer, join, select, SQL, subquery, relation/table, function, database

I. INTRODUCTION

Relational database system is a traditional way to store, browse, and organize transactional data [1]. The main focus is on data - inserting new data, modifying or deleting already existing data and querying that data. Creating queries to get answers to the questions we have about the data stored in a database is probably the most important issue for a database user [7]. Database query optimization has gained great importance, because it is very important to reduce the size, memory consumption, and the time it takes to process any queries. This improves the performance of the database itself [1].

With query optimization, we can achieve greater performance growth than with hardware optimization, server configuration, or operating system upgrade [2]. In order to improve the performance of a query, the person who writes queries, whether it is a programmer or database administrator, should understand the queries optimizer and the techniques which are an efficient way of executing queries [8]. This paper focuses on an overview of methods and techniques for relational databases optimization. Relational databases are still the most commonly used databases (mainly for transactional data, but not exclusively) in which data is defined so that it can be accessed in many different ways and can easily be reorganized [1,7].

II. QUERY OPTIMIZER

A. Query

A query is an expression that describes which data will be returned from the database. End users (through a direct query) receive the desired information about the structure or content of the database. In addition, queries in the database management system are used for internally verifying access rights, maintaining integrity constraints, and synchronizing simultaneous access [1]. For example, one of the simpler queries is the overview of the names and surnames of all the students and their points on the quiz, provided that only students who have passed the quiz are present, i.e. students who have more than 2 points:

SELECT name, surname, points FROM Students WHERE points>2;

B. Optimization

Query optimization refers to the process of selecting a strategy for successful and efficient query execution and is one of the most important tasks of any relational database management system (RDBMS). Accordingly, shaping and writing a query is required so that less resources are used. It is desirable to perform a small number of operations and to conserve the memory space to a minimum. This is the most important part of the query optimization process [1,10]. The goal of the optimization process should be to either maximize the output for a certain number of resources or to minimize resource utilization for a particular output. The query optimization attempts to reduce the response time for a particular query and its costs. The total cost would result in the sum of the costs of data transfered from the place where they are stored to the places where the calculation is made and the results are displayed, the cost of loading the data pages from the secondary warehouse into the main memory, and immediately the cost of occupying the secondary warehouse and the cost of using the central processor [1].

C. Query processing

On the server side, when the query is executed on the relational database, it passes through a series of steps (suppose that the query is in SQL). Parsing is first process that is performed. The query is analyzed, verified whether it is well formatted and then it is validated. If everything is okay, query is ready to be executed so that the most efficient access plan is determined, and if it is wrong, an error occurs. The query is then forwarded to the optimizer where the initial query is split into a brand new, more efficient code, but equivalent to the first one. Which means that the results of the optimized query are almost always the same as the results of the initial query. A new, more efficient query is executed faster. In the code generator or interpreter, the relational system follows a number of steps based on instructions received from the optimizer to make the query. Invokes the corresponding functions in the query processor which is the last point in query execution and its result is displayed [7,11].

II. TECHNIQUES AND METHODS OF OPTIMIZATION

Different authors have presented different techniques and methods of query optimization. Each of them is unique and

effective in its own way. Further on are some more common and interesting.

A. General Tips for Optimizing Queries

Some of the general tips when writing in standard SQL programming language are writing key words in capital letters, also each SQL statement is desirable to write in a new line and to put a space between the words. In addition, when we search for specific data in the database, the query can be written in several ways. Of course, if you're going to try out more than one form of query formulation, we would conclude that the query optimizer gives different query execution plans, regardless of whether the output result remains the same. Therefore, when writing a query we need to keep in mind, if possible, to formulate a query so that we get the best execution plan and the execution time as little as possible (with query visual less important to the optimization process).

In order to achieve the best performance of the query we should comply with some recommendations. It would be desirable to work with small data sets that reduce resource usage, which can be achieved, for example, by using the WHERE clause. It reduces the number of rows so we can use the index more efficiently. We can also instantly link to more efficient use of indexes that speed up query execution. It is also necessary to avoid queries that use too much resources, for example by avoiding conversion of one type of data to another. It is also important to reduce the duration of transactions by grouping multiple queries into one transaction [2,8,11].

Some of the other general tips for query optimization are [8]:

1. It is recommended to use column names in the select operation in relation to "*"
2. If possible, avoid using the HAVING clause in select operations
3. Try using UNION ALL instead of UNION
4. Avoid using OR in join conditions
5. Try changing the query with nested loops by transforming it into join operators

B. System-R Optimizer

Single Query Optimization Algorithms explore queries one by one, find the optimal solution and execute it. They mostly use dynamic programming techniques and are commonly used in commercial optimizers such as System-R Optimizer [10].

System-R Optimizer is developed by IBM and is one of the first database management systems that has used advanced query optimization techniques. It was also one of the first systems that implemented the SQL programming language for data management in relational systems. Many principles of the System-R algorithm can still be found in some modern database management systems. System-R significantly improved the state of query optimization in relational systems.

In this section we will present a simplified version of select-project-join queries. The queries in the model consists of three operations: SELECT, PROJECT and JOIN.

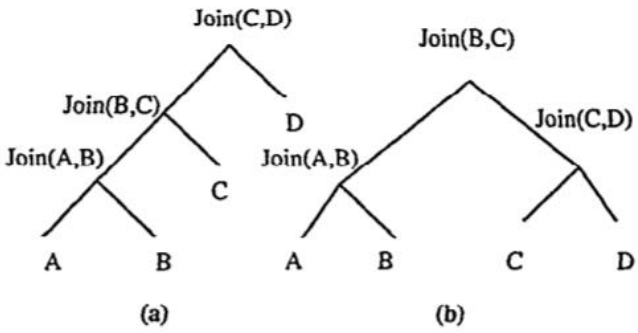

Figure 1. (a) Linear and (b) bushy JOIN [3]

The SELECT query filters a data set for the specified status, PROJECT reduces the "width" of data, takes into consideration certain attributes, and JOIN merges two relations based on the join condition. The class of queries includes conjunctive queries, which are studied in database theory. In the context of the select-project-join query search space (explained in [3]), for the System-R optimizer consists of the operating trees corresponding to the join operation.

Example - JOIN(JOIN(JOIN(A,B), C), D).

Such sequences are logically equivalent because of the associative and commutative joining properties. So when we have to join two relations like A and B, we can use A as an external relation and make A to B or vice versa B to A. Depending on the structural properties, one version may be more efficient than the other. Similarly, associativity allows us to arbitrarily choose the order we want to make a join.

The problem that arises is a huge search space. One of the reasons is that the operations have properties that we explained a bit earlier and allow different tree representations. Finally, the costs are estimated for any version of the tree in the search space. It also estimates the size of the data streams for each exit of each operator. The Cost Model uses different assumptions and criteria (such as a cost estimator for using a central processor to execute any query operator) to calculate and join the following data down-to-top, for all executing operators:

1. the size of the data streams represented by the output of the operating node
2. each sequence of data sets created or uninterrupted by the output of the operating node data
3. estimated cost of operator execution

The System-R Optimizer algorithm shows two important techniques: dynamic programming and interesting orders. Dynamic programming is based on the assumption that the cost model meets the principle of optimality. System-R,

considering the query, identified the sequence of data sets that are potentially relevant to query execution. Hence the very name of the technique, interesting orders, used in modern optimizers.

Despite the good approach of the System-R Optimizer, it can not easily extend the framework to include other logical transformations besides joining that expand the search space. This has led to the development of various new optimization architectures involving the same techniques as System-R [3,7].

C. Systematic, Heuristic and Semantic Query Optimization

Systematic query optimization occurs when the relational system contains optimization algorithms used to optimize each query. The system then estimates the price of each query execution plan and then selects the best one. The best cost plan chosen is not universal because it depends on the data limitations that are in the database. So when joining the two relations, it makes sense to merge primary with foreign key because it is unique and after the merge we do not get another key, so there is no loop in the system and the whole table is not reviewed. Some of the costs that are contemplated by systematic optimization include storage costs, calculation costs, and communication costs. How much each of these costs are important depends on the type of database. In large databases, the emphasis is on reducing storage and memory usage costs, and in small data storages the emphasis is on reducing the cost of the calculation [10].

Heuristic query optimization is used to reduce resource utilization, but at the same time to preserve the form and output content of a particular query. The main purpose of this method is to optimize the memory and minimize the amount of processing that takes place on data without affecting the output. Heuristic optimization is a cheaper optimization method and has several rules by which the optimizer can do better query optimization. Using the following rules in most cases can improve performance:

1. Perform the selection procedure as soon as possible - this reduces the resources needed to process a column as well as the memory that the column occupies.
2. Perform the projection process as soon as possible - this reduces the memory that the whole relation takes along with the amount of resources needed to process a single line.
3. Use binary operations to rearrange the query so that the restrictive selection and the join operation execute first.
4. Calculate frequent expressions once - if the expression appears multiple times and is not too large, it is stored in the memory so that when it is needed again then it is used again (if it is too large, it is kept on the disk) [10,12].

Semantic query optimization is a process of determining a set of semantic transformations resulting in a semantic equivalent query with lower execution costs. This method is a combination of the previous two, systematic and heuristic. The limitations listed in the database schema can be used to modify the heuristic rules. Certain two queries are semantic equivalent if their output is the same for a single database [10,12].

D. Optimizing queries using the ants colony algorithm

Kolaei and Ahmadzadeh [6] used a slightly different approach to query optimization in relational systems. The main reason for describing it in such a detail in this paper is because it is, in our opinion, interesting and innovative way of solving problems with query optimization. By using ants colony algorithm, they optimized the execution of the join operator. This algorithm has adaptive properties such that it can be applied to many other problems [6].

Using Figure 2 we will first explain how the algorithm works. The picture shows how ants adapt to find the source of food. In order to find food, ants as they move off the nests to other places release pheromones. We can see at the beginning in case b) when time t = 0, the number of ants moving on two different paths is the same, while in the next time t = 1, in case c), that number is no longer the same. A larger number of ants began to move through the shorter path, or way to the food location. The track in the middle, C is the shortest path and less pheromone has evaporated over time, so other ants will begin to move along that path. An experiment on the ants shows that despite the existence of several paths of different lengths to the source of food, after some time, most ants will choose a shorter path. This ratio increases as the difference between the tracks increases. Such a simple idea is applicable in order to find the appropriate solutions in optimization issues [6].

Traveling Salesman Problem (TSP) is a classic problem in the field of operational research and many problems can be formulated and solved on the basis of this problem. In this problem, we have n cities and paths between each of these cities, and each path it has its own cost of crossing. The goal is to pass all the cities and return to the city from which the traveler is going, so that the total cost of travel is as small as possible. Ants colony algorithm has been used to solve this problem. Cities are points of intersection, and the paths between the cities are distance, as in the previous explanation where the ants move to the destination [6].

Therefore, the main task A.A. Kolaei i M. Ahmadzadeh set was turning the problem of joining the relations into Traveling Salesman Problem and solving it by an ants colony algorithm. The only difference between these two problems is that in the case of a Traveling Salesman Problem, the person returns to the starting city, while in another problem that is not the case [6].

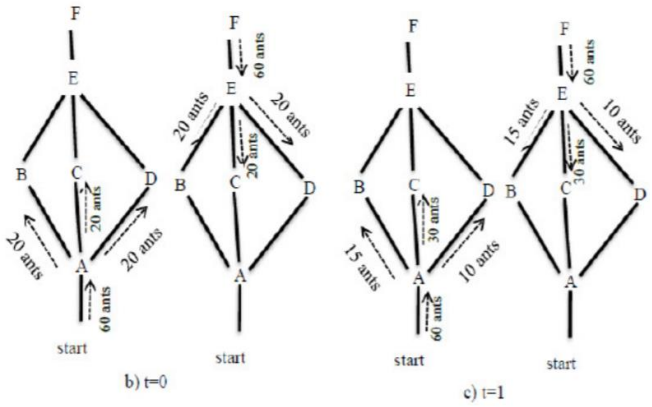

Figure 2. The way the ants move to find a source of food and leave a trace of pheromone(downloaded from [6])

The problem was transformed into a Traveling Salesman model very easily by having each table in the database representing the city, and each link of the table was the distance between the two cities. At the beginning of the algorithm, each ant (the number of ants is equal to the number of tables in the database) is randomly assigned to each table, and then for joining this table with other tables, it is necessary to check whether the join is at all possible, or if there is a link between them. After that, the table that has the minimum time required for the join operation will be considered as the following table (city). In order to achieve the result, in each step, the cost of joining two tables, as the cost of the way between the two cities, adds to the costs of the previous joining (the total cost is generated). At each step of the algorithm, the process is updated by changing the amount of pheromone until a better path is found that can be used in the next step and so until the best path is found, i.e. the one with the lowest cost of joining [6].

Approach to this algorithm has shown good results compared to other approaches. Because other approaches check almost all ways that exist to execute queries, while in this experiment if the ants find a better solution for joining tables, they will notify the existence of that solution to the other ant to use it to find the best solution in the next steps. Therefore, any other possibly useless solutions that are ineffective for query execution (joining multiple tables) will not be executed and processing time on the central processor is saved. Specifically, this is proved when another experiment was performed with a smaller number of ants. However, this reduces the precision of the results, but with the use of more powerful processors or multiprocessor systems the execution time will be acceptable. The main reason for the effectiveness of this method is the parallelism of ants. The ants work in parallel with each other, and updating is done after each step taken [6].

E. Optimizing nested queries

A nested query is a query within which another query is located. This second query can appear in the FROM clause, WHERE or HAVING clause, which is called a subquery. The query that contains the subquery is called main query or external query [9].

The issues that M. Singh is dealing with are queries with subqueries that are not aggregated and queries that have redundancies which results in unnecessary repetition of data. If there is an aggregate function in the SELECT clause (eg min, max, avg, sum) then the subquery is agregate and if it does not exist then it is not. An aggregate subquery that contains the aggregate function always returnes a single value as a result. Such queries are often used in data storage systems and decision support systems. It is important to note that these queries have a large redundancy because the main query and subquery share common tables and terms. Non-aggregate subquery is linked to the main query by one of the operators: EXISTS, NOT EXISTS, IN, NOT IN, SOME / ANY and ALL. The result of such a query is a set of some values or an empty result[9].

A proposal for an efficient and uniform estimation of queries with non-aggregate subqueries is a Nested Relational Approach. The basic idea of the approach is very simple and is based on Nested Relational Algebra. First remove the nested query from top to bottom using existing techniques, and then calculate the join predicate (the join predicate is the predicate linking the subquery and the main query) from bottom to top. The next is required that the result of the subquery is a set and a comparison between a value and a set of values. Since such operations are not supported by a relational algebra, the use of Nested Relational Algebra is suggested. The algorithm consists of three steps [9]:

1. Each block query is reduced to one relation by performing all operations in the WHERE clause (except for join predicate).
2. Tree expression is created.
3. The following is computing and processing query graphs to get the final query execution plan.

Redundancy is present because of the SQL query structure itself. The issue of redundancy is directly attacked, identifying common tables and conditions for queries and subqueries, and solving and executing the common part only once, and then the following are calculated aggregates and terms that involve one pass through the common part[9].

III. RELATED WORK IN QUERY OPTIMIZATION IN RELATIONAL SYSTEMS

Many authors have so far presented different query optimization techniques. The following table, whose idea derives from M. Khan, M.N.A. Khan [4] and S. Gupta, G. S. Tandel, U. Pandey [5], shows some of the research in the field of this topic. The table consists of the ordinal number, year, author's name, title or topic of research, and the advantages and disadvantages.

Chaudhuri discussed in his paper the search space, the cost estimation technique, the effective algorithm, and the optimizer to generate the best query execution plan [3,4].

Bruno, Chaudhuri and Ramamurthy have explored ways to improve the plan chosen by the optimizer using query hints. Through suggestions, the optimizer can continue to improve the plan until the best one is formed. Authors have suggested Phints to capture possible suggestions for optimizer to improve query execution plan [4, 17].

Table 1. OVERVIEW OF RELATED WORK

Num	Authors	Year	Title of the article	Advantages	Disadvantages
1.	Chaudhur[3]	1998	An overview of Query Optimization in Relational Systems	Choosing the best plan to execute querie.	There is no discussion of memory problems related to query optimization.
2.	Bruno, Chaudhuri, Ramamurthy[17]	2009	Power Hints for Query Optimization	A better query plan.	Suggestions are a complex method for achieving a better plan.
3.	Bellamokanda, Ahmed, Witkowski, Amor, Zait, Lin[13]	2009	Enhanced Subquery Optimizations in Oracle	Improved query execution time.	The simulation results are achieved by using a parallel central processor and other hardware that can be affected if the degree of parallelism becomes low.
4.	Chande, Sinha [14]	2011	Genetic optimization for the join ordering problem of database Queries	Better query execution time for the appropriate join operator.	The proposed algorithm is a bit expensive for more than 20 join operators.
5.	Sun, Wang[15]	2011	Paging Query Optimization of Massive Data in Oracle 10g Database	The proposed solution has a great impact on performance through the efficient use of server and client resources.	The work is mainly focused on the Oracle user guide.
6.	Herodotou, Borisov, Babu[16]	2011	Query Optimization Techniques for Partitioned Tables	Quick query processing, an effective data-loading mechanism, and maintaining statistics.	Uncertainty about the type of partition according to which the proposed technique can better execute.

Bellamokanda, Ahmed, Witkowski, Amor, Zait, and Lin presented different query transformation techniques in the Oracle relational database. Some of Oracle's transformation techniques are grouping, merging views, star transformations, moving of nested subqueries, merging subqueries techniques. These techniques recognize and solve the problem of redundancy in the query structure and change queries into a potentially more optimal state. In general, removal of subqueries using window functions and null-aware anti-join (NAAJ in Oracle 11g) methods improves query execution time. Oracle's query transformation uses Cost Based approach or Heuristic approach for choosing the optimal query execution plan. In addition, Oracle uses the PARTITION BY or ORDER BY key to sort data for computing functions. In merging subqueries technique, two queries are merged into one subquery and used to reduce multiple access to the data table and multiple join operations. Subquery merging serves as a filter on the main query tables. The null-aware anti-join method is used for null values in anti-join operations. Anti-joining is just the opposite of INNER joining, so any SQL relational comparison with zero always results in the same value as zero, the reason for the existence of the strategy, and this method is valid [4,13].

Chande and Sinha focused on the problem of join ordering in relations that is processed during query execution in the relational database. Genetic Algorithm (GA) was used to make an effective solution to this problem. Queries for genetic query optimizer were performed in different environments for comparison purposes. The execution time for all quiries is compared with the proposed genetic optimizer. A genetic query optimizer was compared with MySQL, DB2 and PostgreSQL systems. The results show that this method is a good approach to optimize complex queries and generates better results than standard database management systems [4,14].

Sun and Wang have proposed a paging query solution over large data sets to improve query efficiency and overall efficiency. By this method, all data that meets the query conditions are first placed in the server memory, and then only part of the data is forwarded to the client who requests it. This method is the opposite of the traditional paging query method in which all the data is stored in the client memory. Which is obviously not an effective way to handle large data because it can lead to "suppression" of the client's system resources. The authors of this method optimized paging queries by avoiding scanning of entire tables in all subqueries. The proposed method has a great impact on performance by effectively utilizing server and client resources, in particular to reduce client resource spending [4,15].

Herodotou, Borisov and Babu presented techniques to optimally select the best query execution plan by focusing on optimizing SQL queries that are implemented over partitioned tables. Partitioned table is a process in which a table is divided into smaller parts that can be accessed, stored in, and maintained independently of each other. Partitioned tables provide many benefits to database systems such as quick query

processing, efficient data load, data backup. Especially how query optimization is not a simple task for large amounts of data. So authors have suggested partition-aware optimization techniques for a PostgreSQL optimizer that generates plans better than instant optimizer for queries executed over partitioned tables [4,16].

I. CONCLUSION

The various techniques and methods described in this paper show that there are many traditional and innovative ways to optimize a query. With methods such as System-R Optimizer, Systematic, Heuristic and Semantic optimizations, general and easy-to-understand tips are provided so that the user can initially write and form queries to improve query performance. There is also a more complex technique of optimizing nested loops and an interesting method of optimization using the ants colony algorithm that efficiently executes a query in the database in a useful and effective manner. The paper also analyzes some other query optimization techniques in relational systems presented by different authors, leading to optimization benefits compared to non-optimized query. The main contribution of this paper is an overview of various techniques and methods for a query optimization in a relational databases.

Query Optimization has a great impact on the performance of the database management system and is constantly evolving with new sophisticated techniques and methods. Optimization can also be achieved by introducing little effort and practice to follow the rules.

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Overview and Comparison of Several Relational Database Modelling Metodologies and Notations

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Abstract – The purpose of this work is to introduce and compare several relational database modelling methodologies and notations and to show their application through an example. The concepts, methodologies and notations are defined and described in order to compare them mutually. Moreover, a database model is shown for all five notations: IDEF1X, Crow's foot, Chen, UML, and MIRIS.

Keywords: data modelling, database, methodology, notation, IDEF1X, Crow's foot, Chen, UML, MIRIS, entity, relationship, cardinality

I. INTRODUCTION

Information technology is developing very fast, with information systems being more and more complex and the demands getting bigger. The importance of relational databases has increased with the development of hardware, the appearance of the Internet, electronic stores, business intelligence, mobile communications, etc. Today, relational databases are at the root of information systems and one of the main components of software engineering.

The first step in creating a relational database is collecting the necessary data and its analysis, which is followed by semantic modelling or, in other words, building a conceptual model. The third step is logical modelling – that is, transforming the conceptual model into a relational model. The final step is the physical implementation of the relational database.

The semantic or conceptual modelling is a process that visually represents a data model using certain methods. The method "entity-relationships" (ER) is a graphical representation of a conceptual structure of a problem domain being modeled [21]. ER is a semantically rich data-modelling method because it deals with human-friendly concepts [2]. Concepts that are used in ER diagrams are: entity, weak entity, association, weak association, attribute and relations. An entity is an object that exists and is distinguishable from other objects. Weak entity is an entity that cannot be uniquely identified by its attributes alone, therefore, it must use a foreign key in conjunction with its attributes to create a primary key. The foreign key is typically a primary key of an entity it is related to [22]. An association defines a relationship between two entities based on common attributes. The association allows entity objects to access the data of other entity objects through a persistent reference [23]. An attribute is a characteristic or trait of an entity type that describes the entity [24].

Various notations and methodologies for relational database modelling are used daily, but this work will deal with the IDEF1X, Crow's foot, Chen, UML and MIRIS notation.

As for the paper organization, section 2 gives an overview and a relational database model example of each notation that is mentioned in the introduction. Section 3 shows a graphic comparison of the notations and describes the main differences between them. Also, that section describes a subjective comparison of notations based on criteria that is defined one chapter before. Section 4 holds a conclusion.

II. RESEARCH METHODOLOGY

In the continuation of this work, there will be a description of the methodologies and notations in order to make the later comparisons as clear as possible. A relational database model has been built for each notation using the Microsoft Visio tool [3] so that the differences between them would be additionally highlighted.

Microsoft Visio supports all those notations, except MIRIS but because it contains template for Chen notation and other general symbols it is, also, simple to draw database model in MIRIS notation. Besides, according to Capterra.com Microsoft Visio is ranked high with an overall grade of 4.5 from 5 [25] and it is free for students within the Academy program.

Figure 1 shows a graphic comparison of the notations based on the elements: entity type, weak entity, association, weak association, attribute, generalization, primary key, foreign key, and various cardinalities. The figure distinctly shows that the notations IDEF1X, Crow's foot and UML are similar and so are Chen and MIRIS.

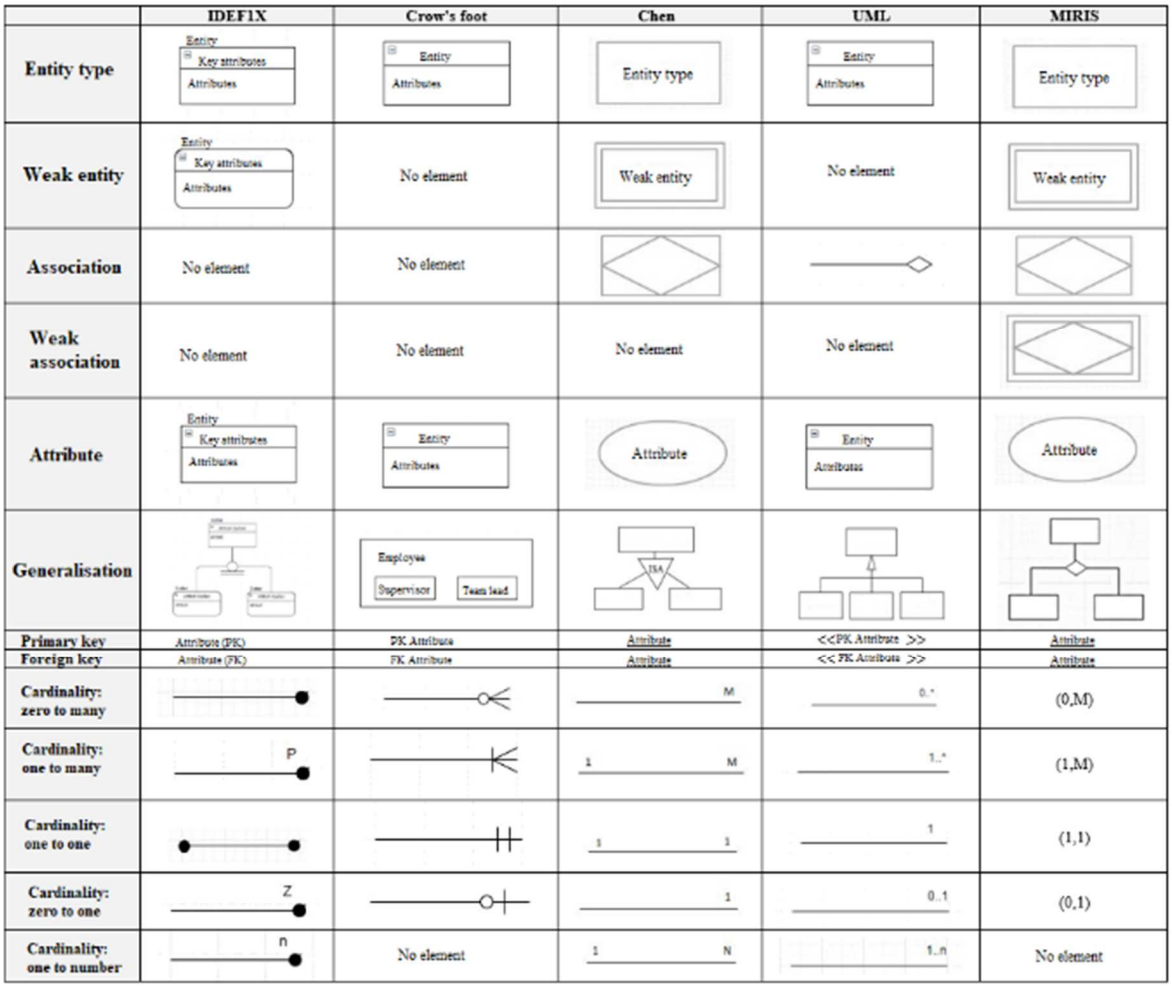

Figure 1. The comparison of notations according to chosen elements

The most of concepts from Figure 1 are used in model. Entities Chef, Ingredient and Recipe are strong entities, Item is weak entity which depends on Recipe entity, and Cooking is associative entity. All entities have attributes and relations that are used between entities have different cardinalities. Because of simplicity of the model, only the hierarchical relations (generalization and categorization) are not shown.

After building all the relational database models, concepts of each notation were compared, initially descriptive, and later in the table. The last section is intended for subjective comparison and grading based on defined criteria.

A. *IDEF1X (Integration DEFinition for information modeling)*

IDEF1X [4] is a relational database designing method. It is based on the ER approach for semantic data-modelling developed by Chen [5] in 1976. It contains many concepts which can be found in ER models such as: entity, attributes and relationships between entities.

Entities are represented using rectangles with curved or non-curved corners. Entities with non-curved corners can exist without any other entity – that is, they do not depend on any other entity in the model. Weak entities have curved corners and they are dependent on another entity in the model. The name of the entity appears outside the rectangle while the attributes are listed on the inside. The attribute name must be unique in the whole model and the meaning of the name must be consistent. Each attribute can belong to only one entity (one-owner rule) and each attribute has to have a value (no-null rule). Moreover, no attribute may have more than one value (no-repeat rule). Some attributes are also keys. Each entity must have at least one key and that key is written in the first part of the rectangle separated by a horizontal line from the rest of that entity's attributes.

Like entities, relationships can be dependent or independent. The dependent relationships are marked with a full line and they are used when that entity depends on another entity and its primary key is comprised of that other entity's primary key. Independent relationships are marked with a dotted line and used for connecting entities whose primary key does not depend on another entity. If there are no markings on the relationship, that relationship is read as exactly one. If the symbol present on the relationship is in the shape of a rhombus, that relationship is read as zero or one, and if the symbol is in the shape of a full circle, then that relationship is read as zero or more. There can be the letter Z above the full circle (zero or one), the letter P (one or more) or the letter n (exactly n).

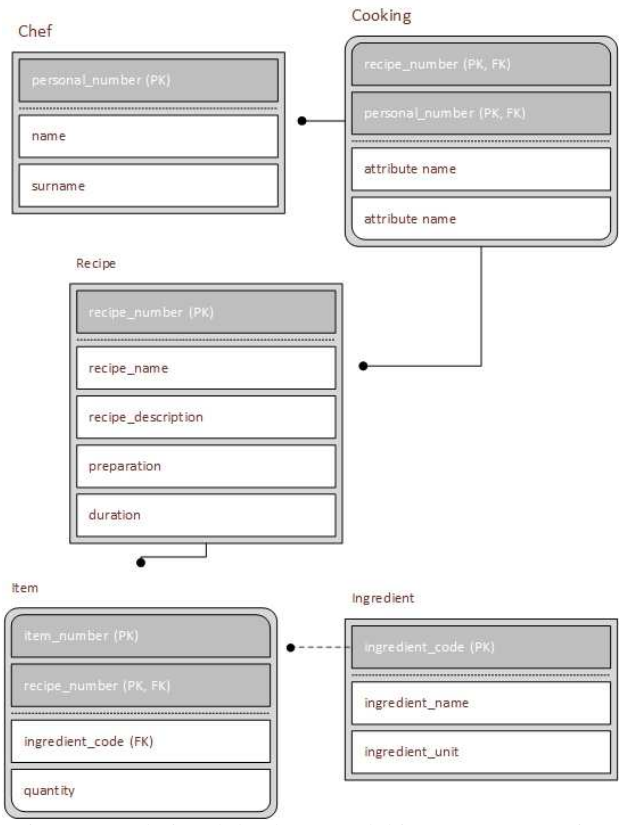

Figure 1. Relational database model in IDEF1X notation

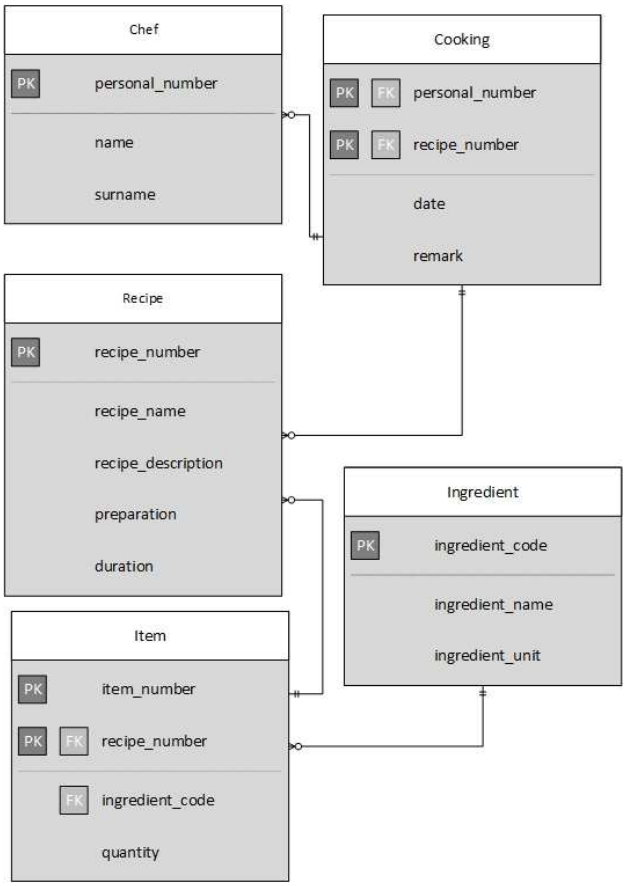

Figure 2. Relational database model in Crow's foot notation

B. Crow's foot (Information Engineering)

Crow's foot notation is one of the more popular notations for relational database modelling, maybe even the most popular. The most recognizable characteristic of this notation are the graphic symbols that mark the "more" (one or more) side of the relationship. These graphic symbols look similar to a crow's foot, which got the notation its name.

In this notation, entities are represented with a rectangle and the entity's name is in the upper part of the rectangle. It is recommendable that the name of the entity is singular (buyer) instead of plural (buyers). The attributes are listed in the rectangle, below the entity's name. The first of the attributes is the primary key and it is, in most of the tools, underlined. Entities are connected using relationships. Each relationship is assigned a name that describes the function of the relationship. The relationships can be one-sided and many-sided. The one-sided relationships show the minimum number of times that an entity can be connected to another entity (zero or one). Those relationships are marked with a normal line that has a short vertical line near the entity. Many-sided relationships show the maximum number of times that an entity can be connected to another entity (one or more). Those relationships are marked with the signs > (more) and < (less) near the entity as shown at figure 2. The relationship can be optional, and it is then marked with a circle.

C. Chen

The Chen notation was named after Peter Chen. In 1976, Peter Chen published a work in which he describes the "entity-relationships" model [9]. He was the creator of the concept of "entity-relationships" in information system modelling. This notation is used even today, primarily in scientific works, and is considered a more detailed way of showing the "entity-relationships" model.

In Chen's notation, the entity is represented with a rectangle containing the name of that entity. There are three different types of entities: the strong entity, the weak entity, and the associative entity. The symbol for the weak entity is a dual-lined rectangle. The associative entity describes the relationship between two entities as one of them being a component of the other. The symbol for the associative entity is a rectangle containing a rhombus.

The attributes in this notation are marked with an ellipse which contains the name of that attribute. All the attributes of a certain entity are connected to the entity with a straight line. The attribute can be a primary key, a partial primary key, a multivalued, or a derived attribute. The partial primary key is used with weak entities and its name is underlined with a dotted line. The multivalued attribute is an attribute that can have more than one value (e.g. hobby) and it is marked with a dual line around the attribute. The derived attribute is derived from other attributes and it

doesn't have to be physically saved in the database. Such attribute is marked with an ellipse with a dotted line.

The relationships of this notation are shown with a line that has a rhombus with the relationship's name in the middle and its cardinality on the ends. The symbols for cardinality are: 1, N and M, with N and M standing for "many".

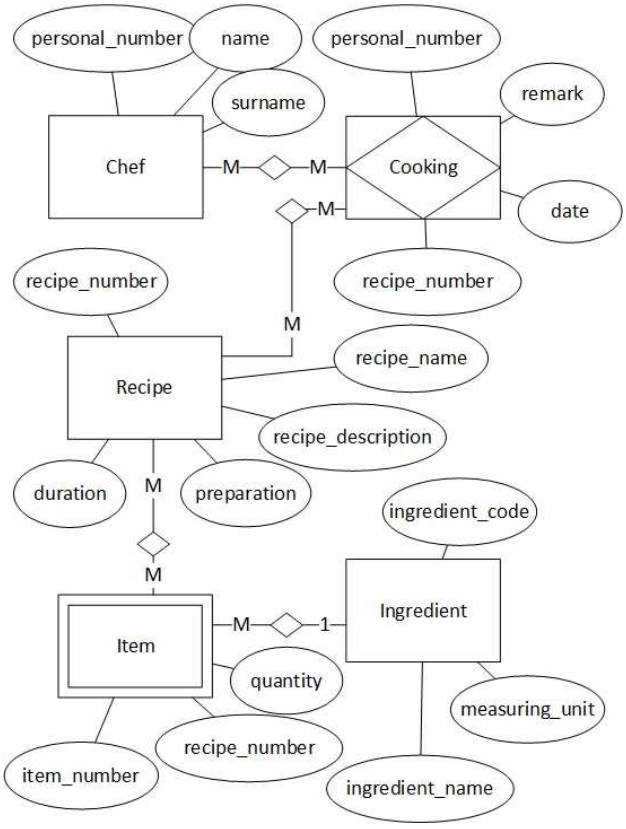

Figure 3. Relational database model in Chen notation

D. UML (Unified Modeling Language)

UML is a standard language used to determine, visualize, and document artefacts of software systems, as well as for business modelling and other non-software systems. It is accepted as a standard by the Object Management Group (OMG), and the software community has accepted it as a primary notation for object and component modelling. [7] In UML, entities are represented using a rectangle with their name and attributes written inside the rectangle. The primary key is marked by letters <<PK>>, and the foreign key by letters <<FK>> written before the name of the attribute. The relationships are full lines with the description of the relationship and the cardinality at the ends of the line. The cardinality is marked by 0..1 (zero or one), 1 (exactly one), 0..* (zero or many), 1..* (one or many), n..m (the exact range of n to m).

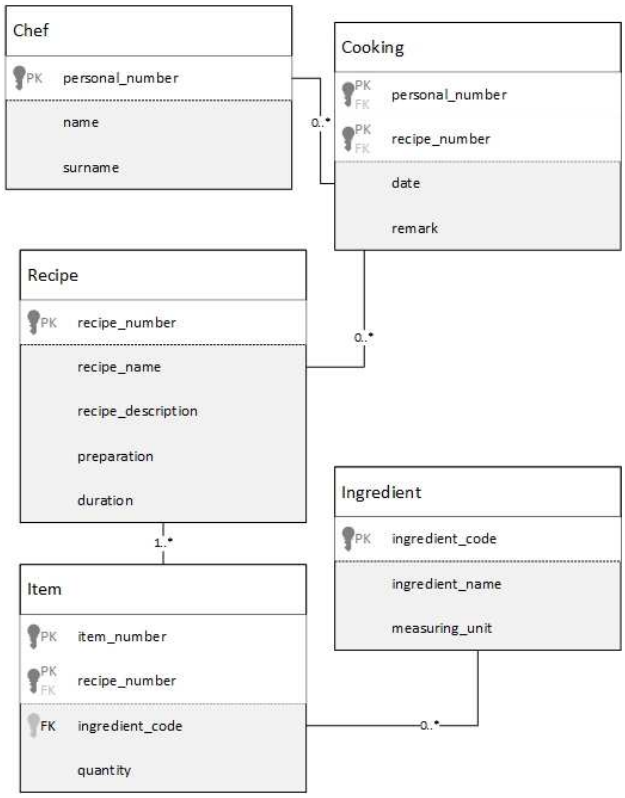

Figure 4. Relational database model in UML notation

E. MIRIS (Metodologija za Razvoj Informacijskog Sustava – Methodology for the Development of the Information System)

The MIRIS methodology is a collection of methods and instructions with the collective goal of designing and building an information system. The life-cycle phases are divided into two groups: the logical shaping (information system designing) and the physical shaping (information system building) [2]. The logical shaping consists of the phases of strategic planning, the main design and the detailed design, while the physical shaping consists of the programming support implementation phases: its introduction, application and maintenance.

When it comes to notations, the MIRIS methodology is almost the same as the Chen notation. Entities are rectangular - shaped and attributes are represented by an ellipse. The relationships are indicated with a full line, showing the cardinality on either side. The types of cardinality are: (0,M), (1,M), (1,1), (0,1).

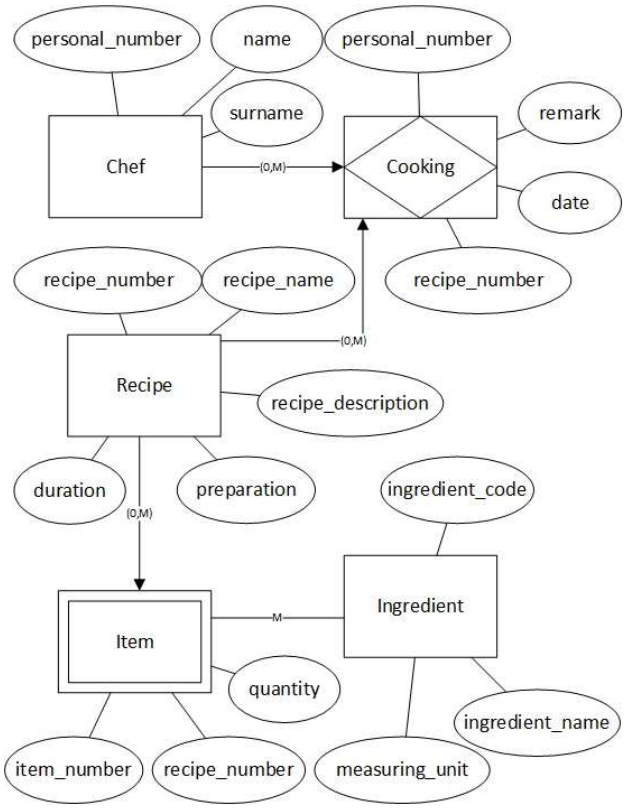

Figure 5. Relational database model in MIRIS notation

III. RESEARCH RESULTS

In all the notations, entities are represented by rectangles. The IDEF1X notation is the only one that has the entity name outside the rectangle, while all the other entities have the entity name inside the rectangle. There is no distinctive way to represent a weak entity in Crow's foot and UML and in IDEF1X, the weak entity is the same as the strong entity except that it has curved corners. Chen and MIRIS represent the weak entity with a double-lined rectangle and they are the only notations with a distinctive representation for association, which is represented the same way in both notations: a rhombus inside the rectangle. The attributes of these notations are written inside ellipses around the entity itself, which makes it less straightforward than it is in the other notations which all have the attributes listed inside the entity rectangle. Association in UML is represented by a rhombus on the relationship. Weak association is an element that only MIRIS distinguishes and that is the main difference between the MIRIS and Chen notation. When it comes to primary and foreign keys, there are no major differences between the notations. Attributes that are keys in Chen and MIRIS notations are underlined (full line for primary keys and dotted line for foreign keys), while the other notations simply have the letters PK (primary key) or FK (foreign key) to mark the keys.

The biggest differences between the notations are the cardinality of relationships. IDEF1X represents the cardinality with a circle next to the corresponding letter, Crow's foot uses symbols which are similar to a crow's foot and the other three notations mark the relationships in a classic way, with a line that has a number, a letter or an asterisk as a way of showing cardinality. In the IDEF1X notation, the cardinality is not obvious. The letters which stand as a representation of cardinality are not noticeable and in some tools for building relational database models, they are not even supported. When it comes to cardinality, MIRIS has exceeded the other notations with its intuitiveness and simplicity of representation.

Table 1 shows the comparison and the assessment of the notations based on speed of drawing, intuitiveness, simplicity and support in relational database modelling tools. The maximum score for each criteria for one notation is 5 because every criteria, except support, is tested by 5 individuals. Five persons have drawn models in the given time. For each person who finished with drawing model in given time there is one point for speed of drawing. The same persons evaluated intuitiveness and simplicity. After drawing they chose "yes" or "no" for intuitiveness and simplicity for every notation. The number of "yes" is grade for those criteria. Regarding to support, support is tested in 3 different modeling tools: MS Visio [3], Draw.io [26], Creately [27]. Those tools support IDEF1X, Crow's foot and Chen notation. UML is supported, in some tools through UML Class diagram, and that is why it has one point less than maximum. MIRIS is not supported in any of listed tools but it can be easily drawn with modification of Chen notation.

TABLE I. COMPARISON OF THE NOTATIONS

Tool name / criteria	**IDEF1X**	**Crow's foot**	**Chen**	**UML**	**MIRIS**
Speed of drawing	5	4	3	5	3
Intuitiveness	4	2	4	4	4
Simplicity	5	2	3	4	3
Support	5	5	5	4	2
Sum	**19**	**13**	**15**	**17**	**12**

When it comes to speed of drawing, Chen and MIRIS notations are the slowest, unlike IDEF1X notation. Drawing the ellipse for each attribute in a model greatly slows down the process of drawing and makes it less straightforward and simple. Some entities can have more than ten attributes, because of that the models drawn in those notations are too crowded and look unprofessional. The cardinality in Crow's foot is different than any other notation. It uses symbols which are similar to a crow's foot versus other notations that mark the relationship in a classic way. For that reason, drawing models in Crow's foot is complicated and better to be used by the professionals not beginners. The UML notation is quite intuitive and easy to draw, but UML is intended for a much wider field and because of that, some of the elements are left undefined.

IV. Conclusion

In this article, five notations of database modelling have been compared: IDEF1X, Crow's foot, Chen, UML, and MIRIS. Before comparation was made, description, detailed overview and database model for every notation has been presented. All the models were built in the same tool so the differences between them would be easy to spot, but also that the simplicity, intuitiveness and speed of drawing each model could be subjectively compared.

Notations were compared based on the concepts presented in figure 1. Although, that figure shows that the notations IDEF1X, Crow's foot and UML or Chen and MIRIS are similar, grades in table 1 for similar notations are different. It is important to note that grades in table 1 are given based on a subjective judgement.

According to the criteria and grades defined in table 1 the first choice would be the IDEF1X notation. This notation achieved the highest grade with the overall score of 19 from a maximum of 20. It is intuitive, simple to use and supported in nearly every database modelling tool. The second place is given to UML notation. Because UML is intended for a much wider field, some of the elements are left undefined. In this case that is a minus, but on other hand more people are familiar with that notation and database modelling tools. With one point less, on the third place, is the Chen notation. This notation is not that simple and fast to draw and that is the only negative thing about it. The last place is shared by Crow's foot and MIRIS notation. According to subjective opinion, because of the very low overall score, those notations are not recommended.

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Development of 2D Game with Construct 2

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***Abstract* - Developing a computer game presents a big challenge, since creating a single product requires much more knowledge and experience in different areas than just programming. However, the question is how to bring your work to life in hours and days instead of weeks and months. Using the Construct 2 drag and drop method, we are able to implement visual materials into our game, and the principle of programming is reduced to the events option, which helps us to assign actions through selected graphics icons. Application instant preview allows fast prototyping and iterative development which enables testing during the entire creation process, making it much easier to detect and resolve problems. It gave us flexibility and the ability to see how the prototype of each version actually responds to certain actions, conditions, and events. As a final point, with a good organization and understanding of powerful event system, flexible behaviours, stunning visual effects and capabilities provided by the Construct application package, it is possible to do any conceivable 2D project.**

Keywords - Game Development, Construct 2, Game Optimization, GUI, Interactive Review, 2D Project, Procedural Mode

I. INTRODUCTION

In the 21st century, computer games are one of the most popular form of entertainment. Games have entered into every aspect of everyday life and they do not have the age limitations. The development of this form of entertainment is very demanding because the multimedia shape includes integration and adaptation of videos, animation, 3D, text, audio and motionless picture. The development of multimedia computer game is a very complex job which requires the team of experts who have the understanding of theory and practical methods used during the development and who know how to use professional tools for the development of the multimedia games. The motivation for the game creation came from the detailed research and analysis of the so-called "old-school" 2D games which marked many childhoods. Throughout this paper, we will discuss the production of 2D platform game intended for one player. The name of the game is "Funky Student", and the groundwork of production is based on the usage of Construct 2 architecture. The particularity of Construct 2 environment is in its adaptability to various platforms, such as browsers that support HTML5 and operational systems like Linux and Windows as well as the interactive compilation of the game at any moment, which enables realistic overview of the game functionality to the programmer. Graphic user interface is conceived with the principle of adventure platform game „Super Mario".

The remainder of the paper is structured as follows. The second section will briefly introduce Construct 2, present comparison and features of the competitive 2D game engines and explain which games motivated us to start our own project in that respect. The essential part of the paper is the third section in which the whole process of game development is thoroughly explained. Conclusions are drawn in the last section.

II. BACKGROUND TO OUR WORK

A. Construct 2 enivronment

Construct 2 is a very simple commercial application for the creation and design of two-dimension games developed in early 2011. In Construct 2, the classic coding is replaced with dragging and dropping game objects. Games developed in Construct 2 are implemented in HTML5 and Javascript languages. Several commercial computer games were developed with Construct 2, some of which are available on Steam [2] such as Airscape: The Fall of Gravity, and The Next Penelope [1].

B. Comparison with the competitive 2D game engines

Adobe product called Adobe Flash Pro (Adobe Animate) is the industry's leading animation toolset which lets us create apps, ads and amazing multimedia content that moves across any screen. It allows us to draw art assets in the engine using vector art and also animate it in-engine using key frames which is very convenient and simple to use. Programming the animations is relatively easy as well. Flash uses the Action Script 3 programming language which is similar in syntax to JavaScript or C#. Flash is still widely used in game development these days. It has a free 30-day trial option, but once the trial is finished we must buy a license, unlike Construct 2, where we can work with a free version as long as we like..

Game Maker Studio was originaly released by Yo Yo games in 1999 under the name Animo. It was originally made for creating 2D animations but quickly moved on to being a very robust 2D game development tool. Overall this engine is known as an introduction to game dev tool or a hobbyist tool. Games made in Game Maker Studio are generally made using pre-defined events. Example of pre-defined event will be: "when we select create new event we can then select "When Left Button is pressed" and then select a pre-defined action like "Move Left" [7]. This means when the Left is pressed the assigned character moves left. This makes it easy for people to make simple games without knowing how to program. The following

Figure 1. summarises the features of each of the tools covered and provides a simple comparison of the tools.



Figure 1. 2D game engine comparision

C. *Current similar games*

The idea of the game is generally perceived as a so-called platform way of playing where the user controls the main character and the levels represent platforms which contain various objects such as enemies, key to unlock the "door" in order to pass to the next level and alike. The basic approach to the 2D platform game is easily related with a well-known game "Super Mario". Also, the principles, the interface and the access to other 2D games contributed to the plan itself and the development of the game. On that list are games such as Icy Tower, Flappy Bird and Angry Birds, which have represented the "addictive era" of 2D games with its simplicity and adjustable user interface.

III. PROCESS OF DEVELOPING THE 2D GAME

Before the actual development of the game, during the pre-production part, it was necessary to come up with the concept of the game itself and to design its components. The game itself is conceived so that the main player is located in the 2D platform where its goal is to collect three signatures in order to successfully finish the level and open the door of the university to pass to the next level. The task is made more challenging because of the different enemies which are located on various positions in levels. Moreover, there are gems on the platforms which serve as guides through the level. The player has the power we can relate with the popular game "Super Mario" where he can destroy the object of the enemy with his jump, or more precisely, the fall. The game has three levels accompanied with special sounds which accentuate particular action and with the background music which gives the additional charm.

A. *The look of the layout*

Layouts represent levels in the game. The reference of the motifs in the background are characteristics related to the city of Pula as shown in Figure 1. The second and third layout were generated according to a conceived initiative. All the content and objects we enter into an active scene will automatically be connected to the active layout.

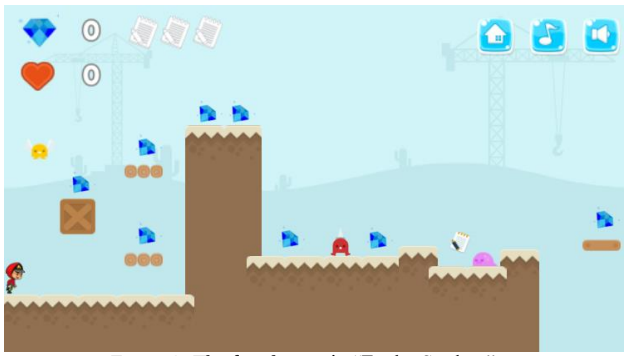

Figure 2. The first layout in "Funky Student" game

B. *Layers*

Layouts consist of layers which enable us to classify the imported materials in groups. When importing materials and objects, it is important to do the process of sorting by the layers as shown in Figure 3. This process is done in specified window for layers thus contributing to the easier workflow, better organisation and visibility of the project itself.

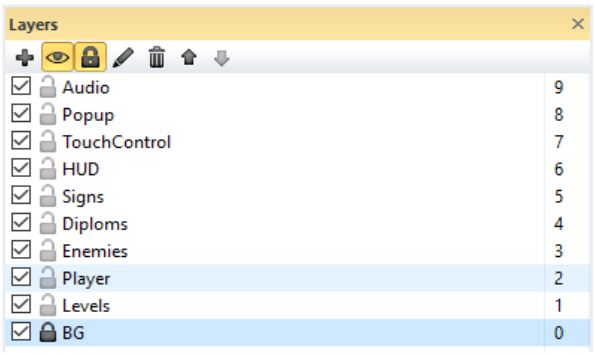

Figure 3. Different layers created in "Funky Student" game

C. *Event sheet and events*

Every layout has its event sheet in which all the steps related to the addition of the events, addition of actions and other events as depicted in Figure 4. Events are the main characteristics of the Construct 2 that facilitate game development. They eliminate the need for complicated scripting in programming languages with fixed syntax and overcoming obstacles when developing a game by careful studying the enormous quantity of content in help, tutorials, and guides. To understand what is the best way to solve a certain problem, Construct 2 offers us the programming with the help of logical blocks of the system. In other words, events are collective blocks. The basic concept of

events is that conditions filter the cases which fulfil the state, and then the actions are done only for those cases.



Figure 4. Example of event structure

D. *Behaviours*

Behaviours give predefined functionality to object types. Construct 2 includes 26 behaviours, some of which are shown in Figure 5. One example of behaviour can be "solid behaviour" which makes other behaviours react to the object as if it were an impassable.

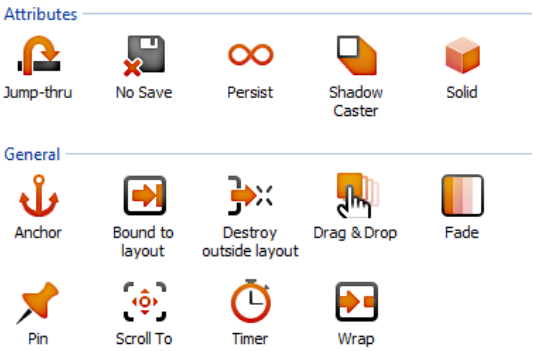

Figure 5. Behaviours in Contruct 2 environment

E. *Effects*

Effects change the visual appearance of the object. They can be added in the *Effects* dialog box. Effects can be added to the layers and layouts, although the effects which are blended to the background cannot be used in the layout. They are sometimes categorised as shaders or WebGL shaders, only because that technology enables the appearance of those effects. Construct 2 has over 70 different effects which can be used in its library, and some of them are shown in Figure 6.

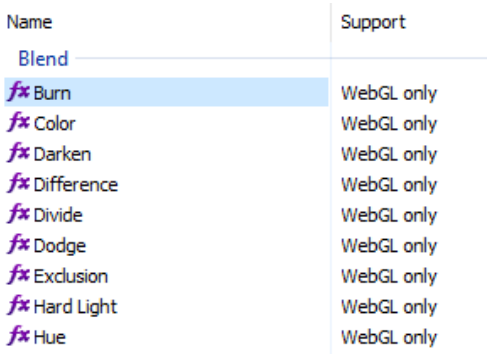

Figure 6. Effects in Contruct 2 environment

F. *Families*

In Construct 2, families are groups of objects. All kinds of objects in the family have to be from the same plug-in (for example all *Sprite* objects and not the combination *Sprite* and *Tiled Background* objects). Families help us to avoid the repetition of events, as depicted in Figure 7.

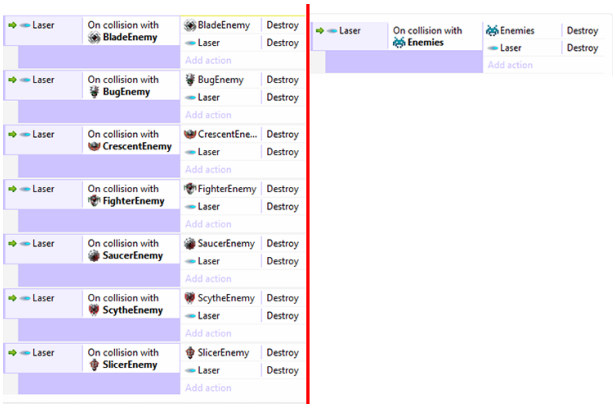

Figure 7. Example of using vs. not using the family principle

G. *Plug-ins*

Plug-ins determine the type of objects. Construct 2 contains a specific window for the plugin list. Some of the plugins are shown in the Figure 8. For example, *Sprite* is one type of the objects while video, keyboard, and button are completely different types of objects.

There are three main kinds of plug-ins:

- Visual plug-ins (e.g. Sprite) occur in appearance and they draw something on the screen.
- Hidden plug-ins (e.g. Array) are set on certain layouts, but are not drawn on the screen.

- Project plug-ins (e.g. mouse, audio) are added to the whole project and can be added only once.

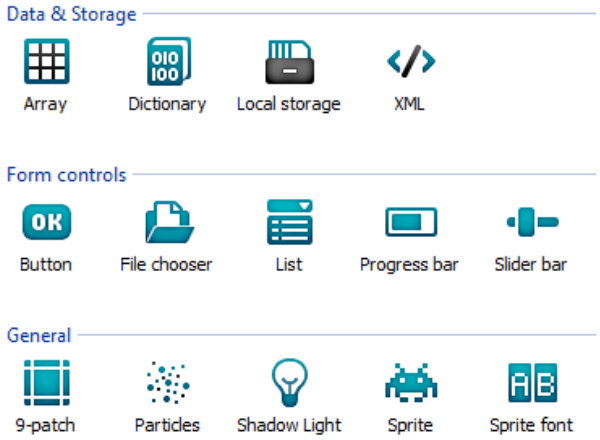

Figure 8. Plug-ins in Contruct 2 environment

H. *Objects*

Object is the representation of certain idea. Mentally, when you imagine a certain idea, it can be something like a book or a ball. Although you know very well how a book looks like, you also know there are many unique books. Every instance of any object in Construct 2 assigns a unique value known as UID (Unique ID) [1]. As a visual representation of objects inside of the game, all the objects (and one animation of each) are shown in Figure 9.



Figure 9. Objects of the "Funky Student" game

I. *Object types*

One of the main elements of the game design in Construct 2 are object types. They define the class of some object. For example, we have types of objects "Player" and "Enemy" which come from the same (*Sprite*) plug-in. They have different animation and will behave differently with the help of events although they come from *Sprite* object.

J. *Object types instances*

Object types instances allow to each object (e.g. enemy) to save its own life value. In short, the variable is a value that can be changed (or vary) and is stored separately for each instance.

K. *Main character*

It is necessary to specify in advance what a certain object will be used for. Since we talk about the main character, it is necessary to specify in advance its movements, namely *rig* animations, which prove to be very helpful in animation of movements, assignment of events and player action, as presented in Figure 10. It is a *drag and drop* process of the set of animation pictures in the *Sprite* object. In that manner, we create the initial animation in which we need to specify collision on each of imported pictures. There are five animations for the main character: walk, stand, jump, fall and dead. In order to be able to move through the platforms, it is necessary to assign "jump and run" style of movements to the player, which is done with behaviour *Platform*, that enables the object to move left, right and the possibility to jump.

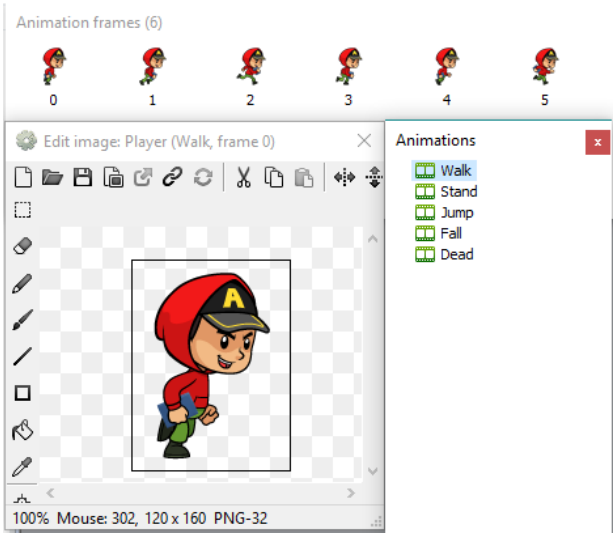

Figure 10. The main character animation

L. *Enemies*

By employing events, we can control movement of enemies through the work space independently of the main character or adjust their movements depending on main character. The process of creating the enemy is equal to the one creating the main character. Figure 11 shows events for simple automatic movement of the enemy that will during the realisation of the Solid behaviour, in this case the wall, do the rotation for 180 or -180 degrees on the x axis and keep moving.

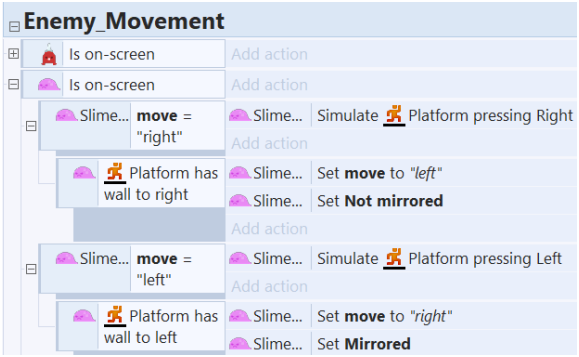

Figure 11. Events related to the movement of the enemy

M. Destruction of enemies

It is common to all the enemies that in the case of "TRUE" collision with the main character (player) they are destroyed, as shown on an event tree in Figure 12. During the "FALSE" collision, one life is taken away from the player and the *Flash* behaviour is initiated which gives the object the possibility to flash in a way that it rapidly turns on and off the visibility of that object. Events for "FALSE" collision are shown in Figure 13. Finally, the sound record is initiated which demonstrates the collision, or rather "FALSE" collision with the enemy. In order to destroy the enemy, the player must jump and fall on the enemy to do the destruction of the enemy object.

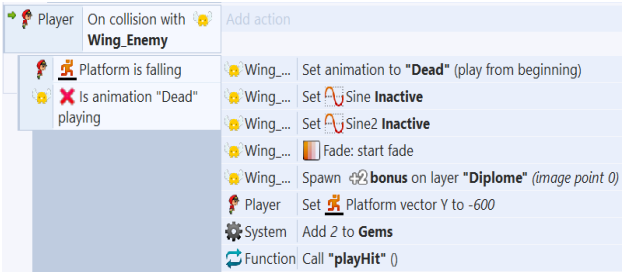

Figure 12. Event representation of "true" collision of the player with the enemy

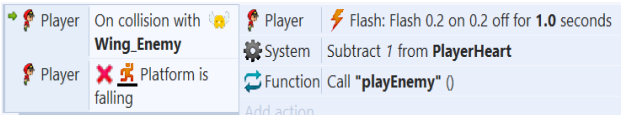

Figure 13. Event representation of "false" collision of the player with the enemy

N. Global variables

Global variables store their values between layouts. Events from any layout can access to any global variable, even if it was created on the other event sheet which is not turned on.

In this project there are parts which follow each other and change in time. Those are global variables related to turning on and off the background music and special effects, as well as the variables connected to relations, namely the state of the game (e.g. win or lose) and numerical variables which refer to lives of players and the sum of gems through levels. All stated global variables inside the game are presented in Figure 14.

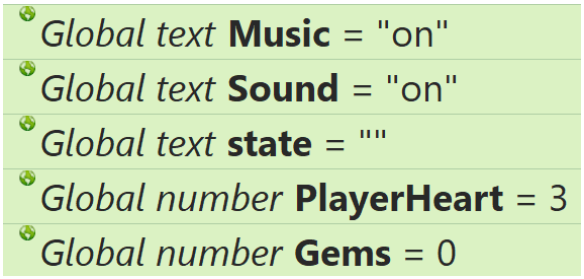

Figure 14. Global variables in "Funky Student" game

O. HUD

The word HUD (head-up display) represents the insight into the player's progress, things (s)he currently possesses (e.g. lives) and things (s)he collects (e.g. signatures and gems) as shown in Figure 15. It is necessary to create a special layer for HUD in order to fix and keep its position on every level. It is most commonly created from textual-numerical object connected to some variable. In this project, HUD is used so that the player can get insight in his/hers lives, gems and signatures.

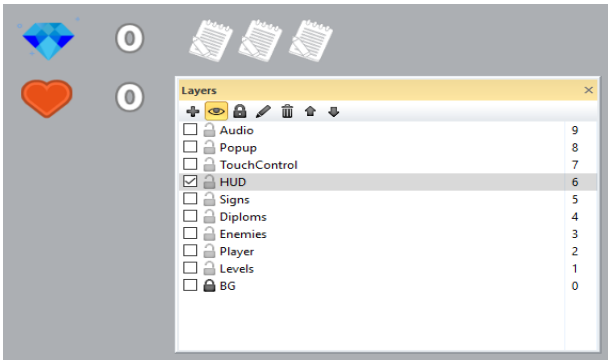

Figure 15. The HUD display

P. Passing the level

The ultimate goal of the player is to finish the game, which is achieved by passing from one level to another. Each level is specific and has different structure of platforms and enemies. As presented in event sheet that is depicted in Figure 16, the process of passing the level is as follows: when the player collects three signatures, the system will start the action of changing the animation on the "university door" and the colour of the flag from red to green which will result in visual simulation of the door opening.

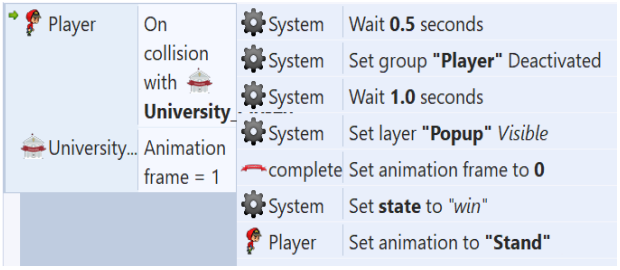

Figure 16. Event sheet related to level passing

Q. Main menu

The last phase in the game development is design of the main menu. As shown in Figure 17, the main menu is here to present the game home screen to the player and introduce him/her the basic controls. During any moment of the gameplay, main menu can be reached by pressing the escape (ESC) button or by clicking on the home button.



Figure 17. Game's main menu

R. Bussines plan, target group and game distribution

The first step is to identify and understand the target group. During the aforementioned, it is necessary to take into the consideration the following factors: geographical location, economic factors, and age of target players [4].

The game "Funky Student" is aimed at younger users (but not necessarily) and is based on the free to play method (F2P), where the game would basically be free, but it would have monetization options. The price of the game and the price of additional features in the game should be maximally optimised with the consumer boundaries of the target group. A price which is too low or too high will directly influence the monetization potential of the game. It is also necessary to investigate all the available options of distribution platforms for the game. The most common way of distribution of the multimedia computer game is the digital one.

Digital distribution of not only accessories, but also the entire multimedia computer games has become the most common way of buying games. Online distributors usually take around 30% of income, and if they take less, it usually means lesser penetration to the market. The choice of the platform and the canal of distribution will play an important role in the overall incomes from the game. Services such as Steam with impressive base of 35 million active players has as much as 80% of digital distribution of games on PC platform according to estimations for 2018. Since nearly any game can be published on that service, it is ideal for small development teams who would never have their game published by the traditional publishers. It can be said that Steam lead to the increase of Indie games which do not require big investments in the development and teams of just several people are enough for their making [6].

IV. Conclusion

The process of making a computer game is a complex one. Depending on the type of the game, it is necessary to choose the right event hierarchy, namely the processes which need to be followed and maximally optimised to decrease the influence of bugs and unwanted actions. Drawing on old-school 2D games, objects (main character, enemies, platforms, gems, signatures) have been created whose actions (events) are added in the Construct 2 environment. When the user successfully completes a particular level, the university doors open. For this part of the game, the reference is made with the action of exam taking. Construct 2 introduces the game designer with the making of user interface in interesting and dynamic manner. Events govern the objects which are means the game backbone is made from. The environment is accessible and easy to use, with an interface which is susceptible to various expansions/accessories from the third party plug-ins as well as plug-ins programmed in JavaScript. By importing prepared objects, one gets a template of the game with three levels and user interface. In order to achieve that game looks good and photo-realistic and at the same time to have realistic simulations, one would usually need to invest a lot of time, effort, and have expertise in in various fields and environments. Construct 2 enables anyone to create a game in easy and straightforward fashion. The aforementioned feature of Construct 2 attracts the interest of many programmers, especially the younger generations who are just discovering the world of programming. In that respect, the Construct 2 environment would be an excellent representative in the world of interesting and instructive ways of programming.

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Network and Service Performance Case Study in a High School Equipped in the Scope of the Pilot Project *e-Schools*

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***Summary* – The Croatian Academic and Research Network (CARNet) is currently coordinating a program referred to as *e*-Schools, aimed to strengthen the capacities of elementary and secondary education by introducing ICT into the school system. The aim of this paper is to analyze the network infrastructure deployed in the *e-Schools pilot project,* focusing on one target high school in the city of Varaždin as a case study to help develop an insightful methodology in the future performance analysis of the infrastructure deployed in schools. A small-scale analysis of the school network infrastructure was carried out, with an additional examination of Quality of Experience (QoE) across three scenarios that simulate the usual behavior of students and teachers, while also observing the behavior of the network infrastructure through Meraki dashboard system. Based on our findings, we concluded that students are generally satisfied with the installed network infrastructure. However, there are some problems that occur (e.g., speed problems and Internet connection problems), which need to be investigated in more detail and resolved, so as to maximize end user QoE. The presented lessons learned will help develop appropriate test methodology to be applied to schools taking part in the e-Schools program for detailed performance evaluation purposes.**

Keywords – network performance; network services; project e-Schools; Quality of Experience

I. INTRODUCTION

Given the speed of digitalization, the growth of the amount of digital content and the increasing involvement of young people in the digital world and new technologies, there is an increasing development gap in the equipment and the digital maturity of schools from urban and rural areas. For this very reason, but also for bringing primary and secondary education in the Republic of Croatia closer to the level of more developed European countries, the Croatian Academic and Research Network – CARNet, launched the project "*e-Schools: Establishing a System for Developing Digitally Mature Schools (pilot project)*" [1]. One of the main activities of this project is the establishment of an adequate network infrastructure offering sufficient capacity and access to digital services in educational institutions.

The aim of this paper is to help establish a proper methodology of the network infrastructure performance analysis to evaluate the realization of this activity based on both subjective and objective measurements of network performance and services in high schools equipped within the e-Schools pilot project.

A. E-Schools program

The e-Schools program, under the name "*e-Schools: A comprehensive informatization of school operation processes and teaching processes aimed at the creation of digitally mature schools for the 21st century*", consists of two phases [1]:

- A pilot project, which runs from March 1st 2015 to August 31st 2018;
- The second phase of the project, which will be carried out from 2019 to 2022, based on the results of the evaluation of the activities of the pilot project.

The implementation of the entire program is operationally separated into two programs funded from different funds:

- Project A – Operational Programme Competitiveness and Cohesion 2014 – 2020 (OPCC), funded by the European Regional Development Fund;
- Project B – Operational Programme Efficient Human Resources 2014 – 2020, funded by the European Social Fund.

B. E-Schools pilot project

The purpose of the pilot project is to *"...pilot the organizational, technological and educational concepts of introducing ICT into educational and business processes in selected schools for the period of two years and, based on that experience, develop a strategy for the implementation of digitally mature schools throughout the system of primary and secondary education in the Republic of Croatia in the period from 2019 to 2022*" [1].

The pilot phase of the e-Schools project has included 101 primary and 50 secondary schools (10% of all schools in Croatia). When selecting the schools to take part in the pilot project, the main factors were the motivation and willingness of the schools to participate, but also the uniform allocation of schools across the country.

The total value of the pilot project is HRK 306.853.184 HRK, out of which HRK 260.825.207

comes from the European Union funds, while national co-financing amounts to HRK 46.027.977.

This paper will primarily address the success of the implementation of an adequate ICT infrastructure in one of the selected schools. This key activity comprises of the following [2]:

- Designing and building wireless networks in schools,
- providing necessary equipment to classrooms and educating teaching and non-teaching staff,
- establishing fully equipped regional educational centers,
- upgrading CARNet data centers, and
- upgrading the CARNet network.

Participating schools are additionally equipped with an interactive classroom, including tablets. Additionally, teachers are provided with tablets, hybrid computers and/or laptops. As a part of the project, five regional educational centers were established and equipped with the state-of-the-art technology.

To use the equipment effectively and successfully, but also to consume the digital content without any disturbances, a stable and a high-quality network infrastructure is required.

In the small-scale experiment conducted within the scope of this paper, subjective and objective performance analysis of the network was conducted so as to help develop an insightful methodology in the future performance analysis of the network infrastructure deployed in schools participating in the pilot project.

C. *Technical requirements and analysis of initial interviews*

Since most participating schools lacked an acceptable network cabling system and the characteristics of the passive network infrastructure did not meet the requirements from the project documentation, a completely new cabling installation and implementation of a passive network infrastructure were needed. Schools that already met the required quality standards continued to use the existing infrastructure [3].

Requirements which an existing or newly constructed infrastructure must meet are:

- Stability and quality of a passive network infrastructure,
- undisturbed connectivity of the user to the network,
- simple administration, maintenance and upgrade,
- sufficient LAN connection capacity, and
- wireless network speed with an average of 30 Mbps

While 151 schools participated in the scope of the e-Schools pilot project, there is a lack of a systematic methodology for evaluating both network and service performance following completion of the pilot. We therefore plan to use lessons learned in the scope of this paper to introduce such a methodology, which will be then used to evaluate the network and service performance in high schools taking part in the pilot project. Findings in this paper were based on a case study involving one of the schools participating in the pilot project, *Prva gimnazija Varaždin*. As a first step, initial interviews were conducted with the school principal, the computer science professor, and one of the students. Conducted interviews showed that all three correspondents were generally satisfied with the deployed wireless network, but sometimes experience some issues, which may require further attention.

The school principal claims that "*…the school has over 270 laptops, 40 tablets, 11 smartboards and 20 PCs. All of them are connected to the Internet during the work day, either over wired or a wireless connection. It is very important to mention that all teachers and students also connect to the wireless network with their own phones, laptops and tablets.*". She is generally satisfied with the wireless network, but there are some situations where the connection breaks and then quickly resets again. However, she considers this as normal, as over 500 different devices are connected to the wireless network at the same time.

The computer science professor uses a lot of network services during his lectures, including WWW, e-mail, social media, cloud computing, Moodle, Office 365, Kahoot, and Plickers. He has noticed that "*…some areas of the school have very weak signal. Additionally, connection often breaks. However, such events don't occur often, only a few times per month.*".

Network services that the interviewed student is using most often include Kahoot, chemistry and biology simulations, video streaming and searching the Web for articles. He has noticed that he sometimes has trouble with connecting to the *eduroam* network. Additionally, he claims that a slow response can sometimes be experienced when using the network. Generally, he is satisfied with the network.

II. ACTIVE NETWORK EQUIPMENT AND ARCHITECTURE IMPLEMENTED AS A PART OF THE E-SCHOOLS PILOT PROJECT

The architecture of the infrastructure implemented in the scope of the e-Schools pilot project can be divided as following:

- *Cloud networking* architecture,
- *Meraki dashboard* architecture, and
- LAN/WAN network architecture

A. *Cloud networking architecture*

Cloud networking is a term that describes the access to the network equipment over a centralized service provider using a Wide Area Network (WAN) or other Internet-based access technologies [5]. It is based on cloud computing, where resources from a centralized node can be shared to all clients over a computer network. The advantage of cloud networking is that the network can be remotely managed over a centralized and unified system. Thus, physical location of the equipment being managed is not important.

The system consists of a central data center and the network equipment that communicates with it. Such communication is performed over the cloud, using an encrypted connection, through which additional configuration and upgrades of the equipment are possible. Additionally, network equipment can provide the central

data center with statistical data regarding its operation, if such a feature is available on a certain piece of equipment.

The Meraki dashboard system, which is a part of the infrastructure implemented as a part of the e-Schools pilot project, is based on cloud networking technology.

B. *Meraki dashboard architecture*

The Meraki dashboard system enables organizational division into different administrative units [3], which is especially useful for managing computer networks of different schools participating in the e-Schools pilot project. The overall architecture of the system is divided into three levels:

- *Managed Service Provider* level – the level at which the main administrator can manage the networks of all the schools involved in the project,
- organization level – school administrators have direct access only to the network of their own school, and
- network level – the lowest administrative unit, each school can have one or more defined networks. This is used when, for example, several dislocated buildings belong to the same school.

Figure 1 shows the visualization of the Meraki dashboard architecture.

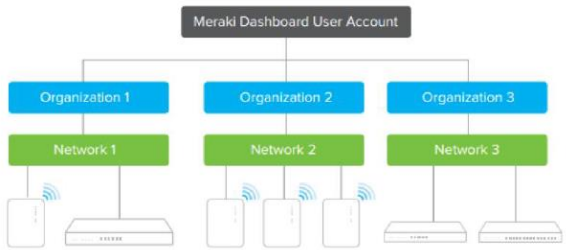

Figure 1. Meraki dashboard architecture [3]

The Meraki dashboard system allows control over the entire network infrastructure, including the following:

- Installation of upgrades, applications and software solutions
- management of security settings,
- checking and monitoring the status of connected devices, including diagnosis and troubleshooting,
- data management,
- automatic configuration of WiFi and VPN settings
- insights into online traffic analytics and information about all wireless access points.

C. *LAN/WAN network architecture*

As a part of the infrastructure implemented in the e-Schools pilot project, an integrated system *Meraki MX* is implemented [4]. Based on its characteristics, it belongs to the UTM (*Unified Threat Management*) devices family, which provides standard firewall functions, along with the possibilities of filtering the content, detection of unwanted users and antivirus protection [6]. Additionally, such devices offer users to be identified by a username, instead of the IP address.

When setting up a wireless network in schools, it was important to ensure the following [3]:

- The ability to monitor and maintain network security,
- the ability to detect and resolve inappropriate behavior,
- access to the network for many users, and
- simplicity from the administrator side, but also from the users' side.

To achieve simple management of the network by the administrator, the Meraki system contains many automatized features that maintain the stability of the network, such as transferring traffic to other wireless access points, when many users are connected to the network at the same time.

In every school, three different wireless networks are set up, with the following SSIDs (*Service Set Identifiers*): *eSkole*, *eduroam* and *guest*.

All traffic within the implemented network infrastructure is filtered on the CARNet central filtering system for inappropriate content [3]. However, given the fact that multiple types of users are accessing the network, including students, teaching staff, school staff and guests, there is a possibility to set up additional limitations and filtering options within the Meraki dashboard system.

III. CASE STUDY: NETWORK AND SERVICE PERFORMANCE – METHODOLOGY

A. *Quality of Experience*

Focusing on end user perceived quality, the term Quality of Experience (QoE) has been defined as [7] *"…the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state.*".

In the context of communication services, QoE can be influenced by various factors, such as service quality, content, network quality, device quality, application quality and the context in which the service is used. Given that it is impossible to determine universal criteria for measuring QoE, test methodologies (including measurement metrics, tested influence factors, and participant demographics) are tailored for different target service and context scenarios.

The most common form of evaluating the QoE is quantifying users' experience with a rating scale, where

each grade represents a certain level of satisfaction, along with providing a space for descriptive expression of their own satisfaction or dissatisfaction with the service.

As a part of the case study described in this paper, QoE was evaluated with the help of descriptive answers and grades that users provided for various examined service scenarios.

B. Methodology

Using the previously described features of the Meraki dashboard system, which allows network equipment management and monitoring of the complete network infrastructure of the school equipped within the pilot project, a small-scale analysis of the school network infrastructure was carried out at Prva gimnazija Varaždin high school, with an additional examination of Quality of Experience (QoE) on a small sample of students.

For all the activities that have been carried out, including access to the documentation of the pilot project and the controlled access to the Meraki dashboard system with the presence of an e-technician, permission was obtained from CARNet, the project coordinator.

The experiment was carried out in two main phases:

1. General inspection of the network infrastructure based on the students' overall satisfaction and the historical data stored in the Meraki dashboard system, and
2. evaluation of QoE in three service scenarios that simulate the usual behavior of students and teachers, while observing the network behavior in the Meraki dashboard system.

With the aim of understanding the performance of the network infrastructure implemented within the e-Schools pilot project, general data on the day-to-day behavior of the network has been observed, including the number of connected clients, generated traffic and access point health. This data was observed on June 7th, 2018, for the past day, week and the last 30 days.

A total of 41 high school students participated in our tests. The age of the participants varied between 15 and 18 years. The students were divided into two adjacent classrooms, with 26 students in the first classroom (access point VZ-PRVAGIMNA-AP-TO09) and 15 students in the second classroom (access point VZ-PRVAGIMNA-AP-TO17). Each student was assigned to one computer. All computers were connected to the SSID *eSkole* beforehand. In the beginning, students gave their general opinion and observations regarding the school's network infrastructure.

All students participated in 3 different test scenarios, each of them being 15 minutes long:

1. Basic Internet browsing – students were given the task of browsing the Internet for 15 minutes, including searching for various terms via the Google Search engine, opening various websites and browsing through them. The aim of this scenario was to simulate the execution of the most common tasks during a class, which include browsing the Internet, making presentations, and filling in worksheets. Students were instructed to avoid playing any multimedia content, such as audio and video.
2. Playing an interactive quiz using the Kahoot platform – students were instructed to play a quiz about basic computer science concepts, created using the Kahoot platform. The duration of the quiz was 15 minutes.
3. Video streaming – students were instructed to open Twitch, select the first live video on the home page and watch it for 15 minutes.

After each scenario has finished, students were given 5 minutes to provide quality ratings for that scenario using Google Forms. The total duration of this experiment, including the preparation of the computers, execution of three scenarios and filling out the evaluation form, was 90 minutes.

The evaluation form contained the same questions for each scenario and included both quantitative (5-point scale, 1 – Very bad, 5 – Excellent) and descriptive components (students could enter their observations in the text box). Students were asked to:

1. Rate how seamless it was to carry out the task,
2. rate their total satisfaction with the quality of the execution of the task,
3. state if they would continue carrying out the task in the same conditions, and
4. describe the problems that occurred, if any.

Throughout the testing period, monitoring of the traffic and network infrastructure on the two access points was performed through the Meraki dashboard system. It is important to state that the rest of the school was normally using the network during this experiment. For this reason, the number of connected users on access points varies slightly during the experiment and is overall greater than the number of students participating in the test itself. This was due to the inability to disrupt the regular activities of the school, as the experiment took place during a regular working day.

IV. CASE STUDY: NETWORK AND SERVICE PERFORMANCE – RESULTS

A. General inspection of the network infrastructure

From the observations made, it was apparent that all 65 wireless access points were working and were properly connected to the network. Most wireless access points worked normally in the past 7 days, with an average of 26% of unsuccessful attempts to connect. However, 7 wireless access points had an average of unsuccessful attempts to connect above 26%. Average packet transfer time between the original sender (e.g. Google server) and the recipient (the user) was found to be 21 milliseconds.

On average, there were around 500 devices connected over the course of the day, including devices used by teachers, students, guests and other school staff. For one day, the average generated traffic amounts were found to

be between 80 and 90 GB, out of which video streaming and multimedia had the largest share. During one working week (Monday to Friday), the average generated traffic was observed to be between 400 and 500 GB. For one month, the total generated traffic was measured to be approx. 2TB.

B. *First scenario – basic Internet browsing*

The captured network traffic on the two access points, while students were carrying out the task of browsing the Internet varies between 10 Mb/s and 35 Mb/s on access point VZ-PRVAGIMNA-AP-TO17 and between 3 Mb/s and 16 Mbs/s on the access point VZ-PRVAGIMNA-AP-TO09. During the time the network traffic was captured, there was a period of several seconds where the traffic suddenly falls to zero. This coincides with the reaction of the students at that time, who reported difficulties while trying to browse the Internet. After this period, the system becomes stable again and the students continued carrying out the task without any disturbances. Although the reason for this outage needs to be further explored, it can be assumed that, at this point, too many students wanted to access demanding web content, which the infrastructure itself could not bear.

C. *Second scenario – playing an interactive quiz using the Kahoot platform*

The captured network traffic on the two access points while students were playing an interactive quiz using the Kahoot platform shows that the average amount of traffic recorded is significantly lower when compared to the first scenario, varying between 0 Mb/s and 8 Mb/s for the access point VZ-PRVAGIMNA-AP-TO17 and between 0 Mb/s and 12 Mb/s for the access point VZ-PRVAGIMNA-AP-TO09. During the second scenario, the traffic on access point VZ-PRVAGIMNA-AP-TO17 got close to zero a couple of times, which was also noticed by the students themselves, who complained about the delay of the quiz compared to their colleagues.

D. *Third scenario – Video streaming*

The captured network traffic on the two access points while the students watched streaming video games on the Twitch platform, which is based on HTTP adaptive streaming of the video content, shows that the generated traffic is considerably higher in relation to the previous two scenarios, and the download volume is generally between 16 and 32 Mb/s for the access point VZ-PRVAGIMNA-AP-TO17 and between 20 and 30 Mb/s for the access point VZ-PRVAGIMNA-AP-TO09.

During the third scenario, students did not report any significant problems, which coincides with findings from the captured network traffic.

E. *Quality of Experience assessment*

When asked about the general satisfaction regarding the implemented network infrastructure at Prva gimnazija Varaždin high school, 90.3% of students graded their satisfaction with the grade 3 or above. Some of the issues that they mentioned include low speed of the network, connection problems, presence of latency and a weak signal.

During the first scenario, 87.7% of students graded the seamlessness of carrying out the task with a grade 3 or above, out of which 28 students gave the grade 4 or 5. When asked about overall QoE (question no.2), 90.2% of students gave the grade 3 or above. Out of all the students, 87.8% would continue to browse the Internet in the same conditions. In the descriptive section of the assessment form, students mentioned connection problems and low speed of the network.

During the second scenario, 90.2% of students graded the seamlessness of carrying out the task with a grade 3 or above, out of which 23 students gave the grade 4 or 5. When asked about the QoE, 90.2% of students gave the grade 3 or above. Out of all the students, 80.4% would continue to play the quiz in the same conditions. In the descriptive section of the assessment form, students mentioned connection problems and the presence of latency during the quiz.

During the third scenario, 92.6% of students graded the seamlessness of carrying out the task with a grade 3 or above, out of which 24 students gave the grade 4 or 5. When asked about the QoE, 85.4% of students gave the grade 3 or above. Out of all the students, 75.6% would continue to watch the video stream in the same conditions. In the descriptive section of the assessment form, students mentioned low speed of the network and the presence of the latency in the video stream.

Figure 2 compares the distribution of QoE ratings across all three scenarios.

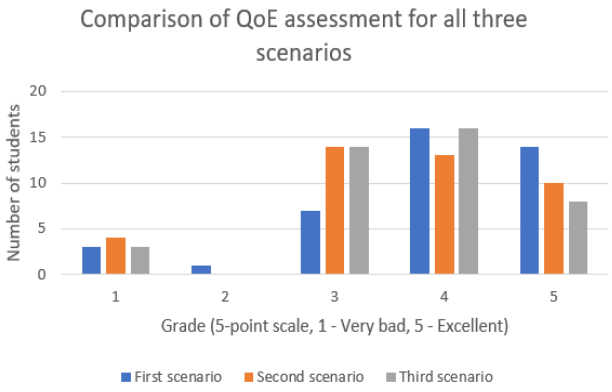

Figure 2. Distribution of QoE ratings across all three scenarios

F. *Discussion and future work*

Certain network problems were apparent during the observation of the traffic and behavior of wireless access points. In the scope of this experiment, the root causes of observed problems were not identified and should be further investigated in future work. These problems were further confirmed when examining subjective ratings provided by the students. Some wireless access points had more unsuccessful connection attempts than the others. It is interesting to note that most such wireless access points are in the older part of the school building.

Although the experiment was carried out with approximately 20 students in each classroom, the number of connected clients ranged between 40 and 50. This is due to the possibility that some other students from nearby classrooms connected to the same access point without being present in the classroom itself. The test methodology that will be developed for the purposes of detailed performance evaluation of the network infrastructure in schools taking part in the e-Schools program needs to ensure that the experiments and measurements are carried out in a controlled environment.

Some of the most frequent issues students mentioned include connection and network speed problems. These two main lessons learned show that there is a need for further examination, evaluation and improvement of the infrastructure deployed in schools. While our focus has been on monitoring and assessing performance, a key step to be investigated in further work is systematic analysis of the root causes of potential problems, and suggestions for methods to alleviate these problems. These findings could indeed help the advancement of the project itself.

With respect to the three tested service scenarios, they differ in terms of quality of service requirements. Hence, it is important to understand the relationship between network level performance measurements and application-level user perceived quality indicators (e.g. page load time, video freezes, etc.). The concept of adaptive streaming, used when streaming over the Twitch platform (and also used by popular streaming services such as YouTube), allows the service to adapt to the network conditions to prevent freezes (stalling), initial delays, and low video quality. On the other hand, while playing the quiz on the Kahoot platform, minimal delay is very important, as the players may experience an unfair position otherwise, which reduces their assessment of the QoE.

V. CONCLUSIONS

After the lessons learned with the help of the case study presented in this paper, it can be concluded that there is a need for the development of a more detailed and insightful methodology for the performance analysis of the infrastructure deployed in schools. The proposed methodology should ensure a controlled environment with a larger sample of students and more scenarios.

Based on a small-scale analysis of the school network infrastructure implemented in Prva gimnazija Varaždin high school, it can be concluded that the infrastructure is satisfactory for most users, with some emerging problems whose root causes are yet to be identified. The measurements and data obtained through the Meraki dashboard system were in line with the subjective assessment of the QoE of the students.

The aim of this paper is fulfilled, given that the foundation for further development of methodology to evaluate network infrastructure in schools has been obtained. In future work, we aim to conduct an in-depth evaluation of the network infrastructure implemented in schools within the e-Schools pilot project. Currently, the e-Schools program is moving into the second phase of the project, which includes 60% of all schools in Croatia. Therefore, future work can also include a detailed evaluation of the network infrastructure implemented in the second phase of the project, and a comparison with the evaluation of the network infrastructure implemented during the pilot project phase.

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An Overview of Clustering Models with an Application to Document Clustering

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***Abstract* - This paper presents an overview of selected clustering models and shows an application of K-Means algorithm to document clustering. In the introductory part, the definitions of basic concepts and common characteristics of clustering models are described. Then an overview of clustering models is given. The methods of clustering, basic characteristics, visualization and possible input data for each algorithm are presented. The authors also explain the assessment of each algorithm taking into consideration measures such as *Rand index, homogeneity, completeness, V-measure* and *Silhouette coefficient.* Furthermore, the paper describes the application of the *K-Means* algorithm to document clustering showing the final result and elaborating the procedures applied when clustering the documents.**

Keywords – clustering, clustering algorithms, K-Means, Mean-shift, hierarchical clustering, DBSCAN, Birch, clustering evaluation

I. INTRODUCTION

Clustering [1] is a machine learning technique that performs grouping over statistical data. Similar objects are classified into different groups, i.e. the dataset is divided into subgroups that share common features. Given a dataset, clustering algorithms classify each data point into a specific group. Clustering presents a method of unsupervised learning. A lot of clustering algorithms use a predefined number of clusters. Another a priori part of information are constraints which might be used by some algorithms. Clustering is a common technique for statistical data analysis.

Clustering can be used in a variety of scientific areas, for example in biology in the field of genetics, then in various researches such as division of the population in consumer segments or demanders to better understand their relationships. Of course, it can be applied in other areas as well, and facilitate the work that is demanding because of the larger datasets.

According to the way they group samples, clustering algorithms can be divided into hierarchical and non-hierarchical algorithms. Hierarchical types are based on the idea that the objects are more attached to those objects closer to them than to those that are further. Thus, clusters are formed by a measure of similarity between new elements and other predetermined clusters. In non-hierarchical types, each object is placed in exactly one of the disjunct clusters. The most known such algorithm is *K-Means*.

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This paper presents chosen cluster algorithms and their main characteristics. It also gives an overview of clustering performance evaluation and shows an example of the application of clustering to document clustering.

The paper is organized as follows: in the next section an overview of chosen cluster algorithms is presented; in section III characteristics of the measures for clustering performance evaluation are given; in section IV an example of application of clustering to document clustering is shown; main conclusions are given in the final section.

II. AN OVERVIEW OF CLUSTERING MODELS

There are numerous clustering algorithms. The choice of a suitable clustering algorithm and of a suitable measure for their evaluation depends on the clustering objects and the clustering task. In this chapter the main ideas behind the chosen clustering algorithms are briefly explained. The main focus is put on the K-means algorithm, which is used in the experiment presented in the paper.

A. K-Means

The K-Means algorithm [2] clusters the data by separating samples into *n* groups of equal variance. This algorithm requires a certain number of clusters. It works well with a large number of samples.

The *K-Means* algorithm divides a set of samples into separate clusters, each described by the mean of the samples in the cluster. The means are usually referred to as cluster „centroids".

The aim of the *K-Means* algorithm is to select the centroid that minimizes the inertia, or within-cluster sum of the squared criterion.

The algorithm has three steps. The first step is selecting the initial centroids, with the most basic method being to select samples from the dataset. After initialization, the loop with two steps follows. The first step assigns each sample to its nearest centroid. The second step creates new centroids by taking the mean value of all the samples that are assigned to each previous centroid. The differences between the old and the new

centroids are computed, and the algorithm repeats until the centroids do not change significantly.

B. *Mini Batch K-Means*

The *Mini Batch K-Means* [3] is a variant of the *K-Means* algorithm that uses mini-series to reduce the time of computing while still trying to optimize the same objective function. Mini-series are subsets of input data.

The algorithm iterates between two steps. In the first step, the samples are randomly selected from the dataset to form mini-series. They are then assigned to the nearest centroid. In the second step, the centroids are updated per sample by taking the streaming average of the sample and all previous samples assigned to that centroid. These steps are repeated until convergence or predetermined number of iterations is reached.

This algorithm converges faster than *K-Means*, but the quality of results is lower. The difference in quality can be quite small, as shown in Figure 1.

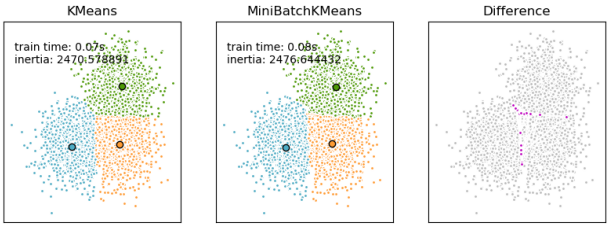

Figure 1. Difference between *K-Means* and *Mini Batch K-Means*[1]

C. *Affinity Propagation*

Affinity Propagation [4] creates clusters by sending messages between pairs of samples until convergence. The dataset is described by a small number of exemplars which are the most representative of other samples. The messages represent the suitability for one sample to serve as a representative of the other, which is updated in response to the values from other pairs. This updating happens iteratively until convergence, when final exemplars are chosen, and final clustering is given, as shown in Figure 2.

This algorithm selects the number of clusters based on the submitted data. Its main drawback is its complexity, so it is more appropriate for small to medium size datasets.

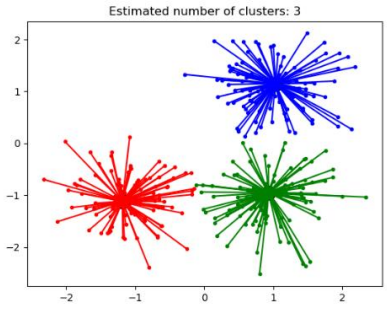

Figure 2. *Affinity Propagation*[2]

[1] Source: http://scikit-learn.org/stable/_images/sphx_glr_plot_mini_batch_kmeans_0011.png

D. *Mean Shift*

Mean shift is a centroid based algorithm [5], and it works by updating candidates for centroids to be the average point within a given region. The candidates are filtered to eliminate near-duplicates to create the final set of centroids.

The algorithm automatically sets the number of clusters. The drawback is that it requires multiple searches for the closest neighbors during the execution of the algorithm. Although the convergence is guaranteed, the algorithm stops when the centroid change is small.

Labeling a new sample is performed by finding the nearest centroid for a given sample as shown in Figure 3.

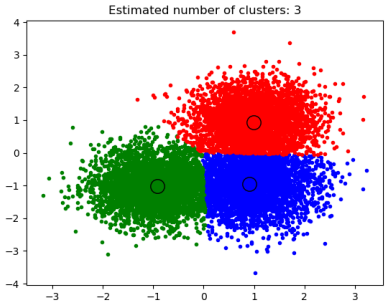

Figure 3. *Mean Shift*[3]

E. *Spectral Clustering*

Spectral clustering [6] incorporates a small dimension of affinity matrix between samples, followed by *K-Means* in a small dimensional space. It is particularly effective if the affinity matrix is rare. This clustering requires the number of clusters as input. It works well for a small number of clusters but it is not recommended when using many clusters.

To perform a spectral clustering there are 3 main steps: create a similarity graph between N objects to cluster, compute the first k eigenvectors of its Laplacian matrix to define a feature vector for each object, run k-means on these features to separate objects into k classes.

This criterion is especially interesting when it comes to images: the vertices of the graph are pixels; the edges of the similarity graph represent the function of the gradient of the image as shown in Figure 4.

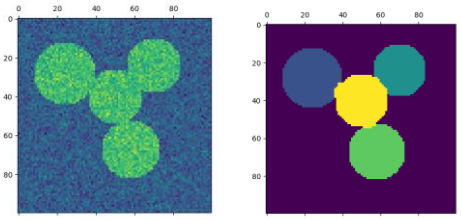

Figure 4. *Spectral clustering*[4]

[2] Source: http://scikit-learn.org/stable/_images/sphx_glr_plot_affinity_propagation_0011.png
[3] Source: http://scikit-learn.org/stable/_images/sphx_glr_plot_mean_shift_0011.png

F. Hierarchical Clustering

Hierarchical clustering [7] is a general family of clustering algorithms that builds nested clusters by merging or splitting them successively. It is represented as a tree where the tree root is the unique cluster that gathers all the samples, and the leaves are single sample clusters.

The agglomeration clustering performs a hierarchical clustering using bottom-up approach. This clustering can also be performed on a large number of samples, but it is computer-expensive when no restrictions are added between samples. The restrictions can be added so that only adjacent clusters can merge as shown in Figure 5 This avoids forming clusters that extend across overlapping folds of the roll and makes the algorithm faster.

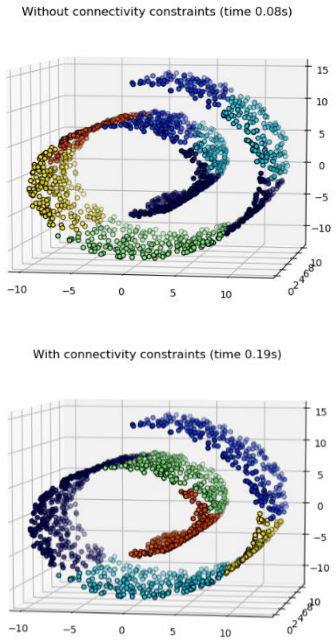

Figure 5. An example of *Agglomerative Clustering* before and after adding restrictions[5]

G. DBSCAN

DBSCAN algorithm [8] views clusters as areas of high density separated by areas of low density. Because of this, the clusters found by *DBSCAN* can be of any shape. The central component of *DBSCAN* is the concept of core samples. The cluster is a set of core samples, each close to each other and a set of non-core samples that are close to a core sample, but they are not core samples themselves. The density is regulated by two parameters.

In Figure 6, the color indicates cluster membership, with large circles indicating core samples found by the algorithm. Smaller circles are non-core samples that are still part of a cluster. Moreover, untypical values (outliers) are shown by black points.

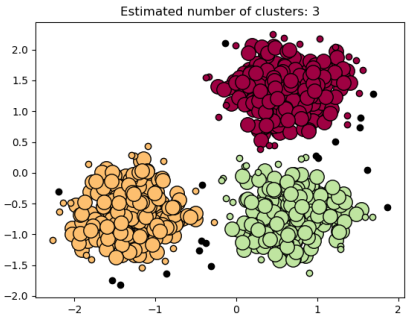

Figure 6. *DBSCAN*[6]

H. Birch

Birch algorithm [9] builds a tree called the Characteristic Feature Tree for the given data. The data is essentially lossy compressed to a set of Characteristic Feature Nodes. These nodes contain a number of subclusters called the Characteristic Feature subclusters that can have nodes as children. There are two parameters. One parameter limits the number of subclusters in a node and another limits the distance between the entering sample and the existing subclusters.

The algorithm can be viewed as a data reduction method because it reduces the input data to a set of subclusters.

I. A Comparison of Different Clustering Algorithms

The main advantage of *K-Means* algorithm is its simplicity and speed which allows it to run on large datasets. It never gives the same result with every new iteration of the algorithm. If *n_features* are greater than twenty, it's usually better to use *MiniBatch K-Means*. If the number of data instances needs to be reduced, or if a large number of subclusters are required either as a pre-processing step or otherwise, *Birch* is much more useful than *MiniBatch K-Means*. *Birch* does not scale well with the very large dimensional data. *DBSCAN* deals with different cluster forms so the groups of points are closely related and then the clusters extend in any direction where the near points are located. The main disadvantage of *Affinity Propagation* is its complexity, but it is suitable for clustering of smaller sets of data. The advantage of *Mean Shift* is the fact that it only needs one parameter but it is computer expensive. *Spectral clustering* is elegant and mathematically well-grounded, but datasets with noise create a problem because the performance may suddenly change from good to terrible.

[4] Source: http://scikit-learn.org/stable/_images/sphx_glr_plot_segmentation_toy_0011.png http://scikit-learn.org/stable/_images/sphx_glr_plot_segmentation_toy_0021.png

[5] Source: http://scikit-learn.org/stable/_images/sphx_glr_plot_ward_structured_vs_unstructured_0011.png http://scikit-learn.org/stable/_images/sphx_glr_plot_ward_structured_vs_unstructured_0021.png

[6] Source: http://scikit-learn.org/stable/_images/sphx_glr_plot_dbscan_0011.png

III. CLUSTERING PERFORMANCE EVALUATION

There are numerous possibilities for evaluating a clustering against a gold standard. A clustering evaluation refers to using a reliable measure for the assessment and comparison of clustering experiments and results [10]. The descriptions of best known measures for clustering performance evaluation are given below.

A. Rand Index

Rand index defines an evaluation measure for a general clustering problem on the basis of agreement versus disagreement between object pairs in clustering [10]. By this measure, not only the points that are present in the cluster are important for the definition of the cluster, but also those that are not present.

Given the knowledge of the ground truth class assignments and clustering algorithm assignments of the same samples, the adjusted Rand index is a function that measures the similarity of the two assignments, as well as mutual information that measures the agreement of the two assignments. Their solutions are symmetrical because the argument substitution does not change the result [11].

The adjusted Rand index has a value close to 0.0 for random labelling independently of the number of clusters and samples. Its range is between -1.0 and 1.0. The main disadvantage of the adjusted Rand index is the fact that it requires knowledge of the ground truth classes.

If C is a ground truth class assignment and K the clustering, then the unadjusted Rand index is given by (1).

$$RI = \frac{a+b}{C_2^{n_{samples}}} \tag{1}$$

The letter a stands for the number of pairs of elements that are in the same set in C and in the same set in K, b is the number of pairs of elements that are in different sets in C and in different sets in K, and $C_2^{n_{samples}}$ is the total number of possible pairs in the dataset.

B. Homogeneity and Completeness

Given the knowledge of the ground truth class assignments of the samples, it is possible to define homogeneity where each cluster contains only members of a single class and completeness where all members of a given class are assigned to the same cluster. V-measure is their harmonic mean [12].

The measures homogeneity and completeness of a clustering solution are in opposition which means that increasing the homogeneity of a clustering solution results in decreasing its completeness. V-measure measures how successfully the criteria of homogeneity and completeness have been satisfied since it is computed as the harmonic mean of distinct homogeneity and completeness scores.

The advantages of the measures are limited range of scores and intuitive interpretation (clustering with bad V-measure can be qualitatively analyzed in terms of homogeneity and completeness to better feel what 'kind' of mistakes are done by the assignments). The main disadvantages are the requirement for knowledge of the ground truth classes and dependence on the number of samples, clusters and ground truth classes. A completely random labeling will not always yield the same values for homogeneity, completeness and hence V-measure. This means that random labeling will not yield zero scores especially when the number of clusters is large.

Homogeneity and completeness scores are formally given by (2) and (3).

$$h = 1 - \frac{H(C|K)}{H(C)} \tag{2}$$

$$c = 1 - \frac{H(K|C)}{H(K)} \tag{3}$$

$H(C|K)$ is the conditional entropy of these classes given the cluster assignments and $H(C)$ is the entropy of the classes given by (4) and (5).

$$H(C|K) = -\sum_{c=1}^{|C|}\sum_{k=1}^{|K|}\frac{n_{c,k}}{n} \times log\left(\frac{n_{c,k}}{n_k}\right) \tag{4}$$

$$H(C) = -\sum_{c=1}^{|C|}\frac{n_c}{n} \times log\left(\frac{n_c}{n}\right) \tag{5}$$

The letter n represents the total number of samples, n_c and n_k the number of samples belonging to class c and cluster k, respectively, and finally $n_{c,k}$ the number of samples from class c assigned to cluster k.

V-measure is given by (6).

$$v = 2 \times \frac{h \times c}{h + c} \tag{6}$$

C. Silhouette Coefficient

If the exact classification sample is not known, the estimation must be performed using the model itself. The Silhouette Coefficient is an example of such an estimation that is defined for each sample and consists of two parameters. The Silhouette Coefficient s for a single sample is given in (7).

$$s = \frac{b-a}{\max(a,b)} \tag{7}$$

The first parameter a is the mean distance between the sample and all the other in the same class, and the second parameter b is the mean distance between the sample and all the other points in the next closest cluster [13].

The advantage of the measure is the limited range of scores between -1 for incorrect clustering and +1 for highly dense clustering. The disadvantage is the fact that the coefficient is generally higher for convex clusters than other concepts of clusters.

IV. APPLICATION OF THE K-MEANS ALGORITHM DOCUMENT CLUSTERING

In this section an application of the K-means algorithm to document clustering on a toy example is shown. There

are several steps that need to be conducted in the clustering procedure.

Nine texts with the titles “Techno”, “Dance”, “Rock”, “Left-wing”, “Right-wing”, “Barack Obama”, “Christianity”, “Buddhism” and “Islam” were obtained from the Internet. Our goal is to use the K-Means algorithm to group these texts into three genres - music, politics and religion.

The first step in the document clustering procedure is usually tokenization. Tokenization is the process of parsing text data into smaller units (tokens) such as words and phrases. Among tokens, there are also punctuation marks and all other characters in the text. In the following illustrations we use the sentence "*Buddhism [1][2] is the world's fourth-largest religion [3][4] with over 520 million followers, or over 7% of the global population, known as Buddhists.*" Table I shows that sentence after tokenization. Each of the elements of the list represents a token.

The next step includes eliminating all punctuation and other unimportant characters that are not essential to clustering. In the example above those characters are brackets, numbers, the sign “%”, etc. They are usually removed before further analysis and only words are kept. Table II shows the above given tokenized sentence with “words_only”.

The third step is stemming and lemmatization where different tokens can transfer similar information (for example words *“walk”, “walked”, “walks”, “walking”* all have the same base form – *“walk”*. We can avoid repeatedly calculating similar information by reducing all tokens to its base form using different stemming and lemmatization dictionaries. Table III shows the above given tokenized sentence with “words_only” after stemming. It can be seen that some words have changed, e.g. *“population”* has become *“popul”* and *“buddhists” “buddhist”*.

All the steps above represent pre-processing of the text data. When the data is prepared, we can continue to generate the features for clustering model training. For document clustering, one of the most common ways of generating features for a document is to calculate the term frequencies of all its tokens (tf-idf). These frequencies can usually give some indication of the topic of the document. Table IV gives program execution time and the value of the obtained tf-idf.

The final step represents clustering different documents based on the features we have generated. Table V shows K-Means algorithm document clustering,

TABLE I. AN EXAMPLE OF A TOKENIZED SENTENCE

```
['Buddhism', '[', '1', ']', '[', '2', ']', 'is', 'the', 'world', "'s", 'fourth-largest', 'religion', '[', '3', ']', '[', '4', ']', 'with', 'over', '520', 'million', 'followers', ',', 'or', 'over', '7', '%', 'of', 'the', 'global', 'population', ',', 'known', 'as', 'Buddhists', '.']
```

TABLE II. AN EXAMPLE OF A TOKENIZED SENTENCE WITH “WORDS ONLY”

```
['buddhism', 'is', 'the', 'world', "'s", 'fourth-largest', 'religion', 'with', 'over', 'million', 'followers', 'or', 'over', 'of', 'the', 'global', 'population', 'known', 'as', 'buddhists']
```

TABLE III. AN EXAMPLE OF A TOKENIZED SENTENCE WITH “WORDS ONLY” AFTER STEMMING

```
['buddhism', 'is', 'the', 'world', "'s", 'fourth-largest', 'religion', 'with', 'over', 'million', 'follow', 'or', 'over', 'of', 'the', 'global', 'popul', 'known', 'as', 'buddhist']
```

TABLE IV. PROGRAM EXECUTION TIME AND TF-IDF

```
Wall time: 157 ms
(9, 392)
392
```

TABLE V. K-MEANS ALGORITHM DOCUMENT CLUSTERING

```
Wall time: 40 ms
[2, 2, 2, 0, 0, 0, 1, 1, 1]

   rank         title  cluster     genre
2     1        Techno        2     Music
2     2         Dance        2     Music
2     3          Rock        2     Music
0     4     Left-wing        0  Politics
0     5    Right-wing        0  Politics
0     6  Barack Obama        0  Politics
1     7  Christianity        1  Religion
1     8      Buddhism        1  Religion
1     9         Islam        1  Religion


Top terms per cluster:


Cluster 0 words: b'right', b'left',
b'supports', b'act', b'term', b'social',

Cluster 0 titles: Left-wing, Right-wing,
Barack Obama,


Cluster 1 words: b'islamic', b'teaching',
b'practices', b'asia', b'religion',
b'world',

Cluster 1 titles: Christianity, Buddhism,
Islam,


Cluster 2 words: b'music', b'rock',
b'dance', b'dance', b'styles', b'producer',

Cluster 2 titles: Techno, Dance, Rock,
```

i.e. the final results of the clustering are shown – the time it takes to complete the program, the cluster indexes, the table with titles, clusters and genres, and the words (features) based on which the algorithm grouped the text into genres.

The Rand index on the toy example presented in this section equals 1, i.e. all the document class assignments are in line with their ground truth class assignments.

V. CONCLUSION

Clustering is used in a variety of scientific areas for statistical data analysis. It is a technique that divides datasets into subgroups that share common features. There are numerous clustering algorithms and the methods for their evaluation. In this paper an overview of the chosen clustering algorithms and the measures for their evaluation are given. An example of the application of clustering to document clustering is shown as well.

The performance of these algorithms can be evaluated by various measures. Each evaluation measure has its advantages and disadvantages. In this paper basic characteristics, main advantages and disadvantages of measures Rand index, homogeneity, completeness, V-measure and silhouette coefficient are described.

We chose *K-Means* algorithm as one of the best known clustering algorithms in order to illustrate the application of clustering to document clustering on a toy example.

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New Frontiers in Document Classification with Applications to Medical Context

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***Abstract* - This paper surveys on the recent trends of supervised document classification methods with a special focus on the medical context. In particular, the semantic document classification is considered, where some relevant general purpose algorithms are described. Then, relevant methods for semantic classification of medical documents are in the focus. The considered algorithms are categorised according to the adopted document representation or classifier. Finally, advancement of the state-of-the-art is proposed and described in the medical domain.**

Keywords - document; classification; semantic analysis; categorisation; medical analytics

I. INTRODUCTION

The supervised classification of text documents has the task of assigning one or more categories to the document in order to improve its management, comprehension and archiving. In particular, in the supervised classification, a model trained by a set of training documents is constructed, in order to categorize the test documents with unknown class label. This categorization may concern the type of document, e.g. letter, newspaper, article, etc., the language of the document [1], [2], the author who wrote the document, a semantic class to which the document or a part of its text belongs. The classes to which the documents belong are in most cases predefined. In relation to the type of classifier, the latter can also return a score that indicates the degree of reliability of the performed classification [3].

The accuracy of the document classification depends on the robustness and reliability of the used classifier, but also on the model used to represent the document.

In this regard, different models of text representation have been introduced in the literature. They include [4]: Vector Space Model (VSM) in which each document is represented as a vector keeping a weight for each term in the document (a well-known weighting scheme is TF-IDF where the weight of a term increases with the frequency inside the document and the rarity inside the collection), Boolean Retrieval Model in which for each word it is indicated whether or not it is present in the document, Latent Semantic Analysis (LSA) and Indexing (LSI) which use the Singular Value Decomposition (SVD) to reduce the original document-term matrix to an approximation of much lower rank that retains as much information of the original matrix as possible, Latent Dirichlet Allocation (LDA) for which a document is a random combination of topics on latent space that are modeled as word distributions, word-to-vector (Word2Vec) which is characterized by a vector for each word so that closer vectors correspond to semantically similar words, and document-to-vector (Doc2Vec) consisting of vectors built on paragraph of text.

As for classifiers, some well known methods have been successfully applied to the problem of supervised document classification. They include [5]: Support Vector Machine (SVM), artificial neural networks and deep learning, Naive Bayes classifier, evolutionary algorithms, Bayesian classifier, genetic programming, rule-based classifier, classifier based on ensemble learning.

In recent years, the semantic classification of documents or text fragments has assumed a role of primary importance in various areas including medicine and bioinformatics, cultural heritage preservation, and commerce and finance. This is mainly related to the ambiguity of topics, words and phrases occurring in the text documents. Accordingly, a representation and categorization that takes into account their intrinsic meaning is important and needed. On the other hand, the inclusion of semantic information in the text classification would make it possible to categorize documents and fragments with a higher level of accuracy. It is especially true when the required categories go beyond simple syntactic characteristics of the text. In the medical context, semantic document classification can be essential in different cases, which include: (i) Question Answering systems which support the diagnosis process, (ii) modeling and identifying key problems in medical notes of complex cases, (iii) making easier the understanding of medical terms, (iv) data and knowledge extraction from specific medical subdomain document groups, (v) better understanding of electronic medical records semantics for reducing errors and time in diagnosis, (vi) supporting consumers in managing their personal medical information, and (vii) capturing the semantics for managing security issues in electronic medical records. Consequently, surveying on recently introduced works about semantic classification of documents or fragments is relevant for the advancement of the state-of-the-art.

This paper is mainly focused on the analysis of some relevant works that have been introduced in the literature of semantic document classification in recent years. They include: (1) general purpose methods for classifying

documents, and (2) systems specifically developed for the semantic categorization of medical documents.

The paper is organised as follows. Section II describes the different state-of-the-art methods for general purpose, and for medical domain-specific semantic classification. Section III makes proposal of advancements in semantic classification of medical texts. Finally, Section IV draws conclusions.

II. SEMANTIC DOCUMENT CLASSIFICATION

A. General Purpose Classification

In the following, the general purpose methods for semantic classification of documents are categorised as: (1) methods that use Bag of Words (BoW) and Bag of Concepts (BoC) models, (2) methods based on LSA, (3) methods which employ the Word2Vec representation, (4) semantic network-based approaches, and (5) methods of combined typology. It is worth noting that neural network models (Convolutional Neural Networks - CNN, Gated Recurrent Unit - GRU and Long Short-term Memory - LSTM) are currently pretty much the state-of-the-art in document classification for most domains.

1) BoW and BoC-based models

These methods explore some extensions of the traditional BoW-based model including relational semantic information as background knowledge, such as relations between terms, i.e. ontologies, and relationships between documents, i.e. web links and citations for articles, and other semantic features in order to improve the classification of documents. Firstly, methods extending the BoW model are described. Then, more advanced methods extending the BoC representation are considered.

In the context of BoW, Nyberg et al. [6] integrated background knowledge on the relationships between words and documents into the classification process. The proposed method is tested on 7'252 documents of the National Finnish Archive divided into categories, described using the metadata model SÄHKE. The results obtained by the experiment show that the accuracy of the classification improves when the background knowledge on the relationships between words and documents is integrated into the classification process.

An extension of BoW is also proposed by Mirowski et al. [7] for the classification of temporal sequences of documents (with timestamps). The algorithm is based on a non-linear and multi-level semantic representation model with an auto-encoder that progressively learns BoW representations at the paragraph or document level. The temporal information of the sequence of documents is incorporated into the latent representations. Model training is performed using an approximate gradient-based MAP inference method. The algorithm is able to classify documents or regress their labels. The results obtained by the algorithm on the NIPS and State of the Union datasets, the Reuters collection and financial news are promising compared to other classification methods of the state-of-the-art.

By contrast, Rujiang and Junhua [8] use a system based on ontologies and Natural Language Processing (NLP) for the semantic indexing of texts instead of the traditional BoW approach. Thus, the BoC matrix is constructed to replace the BoW matrix. In order to build this matrix, specific methods have been developed to create correspondence between keywords and concepts within the ontology. Finally, the authors adopt the SVM method for the classification of the document representation. The results obtained by the experiment show that the new semantic representation of the documents is able to improve classification performance.

An extension of BoC is proposed by Albitar et al. [9] using other semantic features that could further improve the classification performance of documents. In particular, the authors propose two improvement techniques to be applied on the vector representation derived from the BoC: (1) the semantic kernel method, and (2) the vector enrichment method. The semantic kernel method consists in the generation of a semantic proximity matrix that contains the pair similarity among the BoC concepts and is applied before training. The vector enrichment method also uses the proximity matrix to extend the BoC model and is applied before the prediction. The experiment consists in evaluating the proposed enrichment techniques using the supervised Rocchio classifier, the UMLS ontology and the Ohsumed corpus.

2) LSA-based approaches

These approaches use LSA-based metods to determine the dependencies and semantic correlations between words within the document. The classification is made based on these dependencies and correlations. Firstly, works based on LSA are described. Then, proposed extensions are considered.

In this context, Kuralenok and Nekrest'yanov [10] propose a new method that uses LSA based on a given set of topics. The experiment is performed on the Text REtrieval Conference (TREC) dataset. It shows that the introduced approach is very promising with sustained calculation times.

The LSA is also used by DL [11] for classifying documents into classes of emotions. After a preprocessing phase in which the stop words are removed and the word stemming is performed, the frequency matrix of the terms is constructed. It contains the frequency of unique words in the text and is used as a vector space model to find the correlation between words. Then, the LSA method is applied, which includes a phase of SVD and a phase of reduction of the dimensionality of the system. The LSA method uses the training dataset for learning in order to generate a low-dimensional singular value matrix. The similarity of the test dataset with the training dataset is then calculated. The emotion of a particular example in the test dataset corresponds to that of the most similar example in the training set.

By contrast, Liu et al. [12] highlight the limitations of LSI's method of text classification. In particular, since this method is not supervised, when applied to the training set, it ignores the belonging of the texts to the classes and only focuses on the representation. Although some LSI

supervised methods have been introduced in the literature, they show somewhat limited improvements compared to the traditional LSI approach. In order to overcome these limitations, the authors present the Local Relevancy Weighted LSI method. It associates each document in the training set with a relevance score based on a topic. The local region is only generated by documents whose relevance score exceeds a given threshold. Finally, the local region is subjected to SVD in order to generate a local semantic space. The results obtained by the experiment show that the proposed approach achieves better performance than previously introduced LSI methods.

3) Word2Vec model

These methods represent the words of a document as low-dimensional vectors. This ensures that semantically similar words correspond to neighboring vectors in a semantic space of words. Accordingly, two works are presented. The first one is relevant since it considers the distribution of word vectors in the class or in the whole document instead of averaging the word vectors as document representation. The second one tests the efficacy of semantic embeddings over BoW to improve the performance of the multi-label classification of text documents.

Accordingly, Xing et al. [13] model distributions of word vectors in documents as their representation. Specifically, the authors use two types of models: (1) Gaussian Mixture Model (GMM), and (2) Semantic Space Allocation, in which a document is modeled as a posteriori probability on the elements of a global GMM in the space of word vectors. Results obtained by the application of the method on the textual dataset Sohu show its superiority compared to other methods of document classification.

Also, Berger [14] experiments, with the use of a CNN and a recurrent network equipped with GRU and Word2Vec, pre-trained embeddings in order to classify large collections of documents with different labels. The results obtained by the experiment show that both CNN and GRU networks are able to obtain better classification performance compared to Binary Relevance models with BoW document features on datasets with over 2 million documents and 1000 classification labels.

4) Semantic network-based approaches

These approaches exploit the use of semantic networks and graph-based models for the representation of documents or their fragments. Next, two works representing the two sub-categories are presented.

In particular, Ginter et al. [15] explore the use of a semantic network to improve the representation of documents with their hyperonyms that is used to classify them in a supervised way. In particular, the weights on the edges of the semantic network characterize the contribution of hyperonyms to the similarity of documents in the new feature representation. Thus, a descending gradient method is used to determine the optimal set of weights on the edges of the semantic network. This method uses the misclassifications obtained by the *k*-nearest neighbour method to update the weights of the network in successive iterations, which modify the similarity of documents according to their belonging to the classes. The experiment consists in classifying indexed PubMed documents with the MeSH biomedical ontology. In particular, the proposed method is tested on 10 randomly selected datasets with 7 training set dimensions. The obtained results show that the proposed method achieves better results than the traditional BoW approach and the representation based on density of the hyperonyms.

Also, Amelio and Pizzuti [16] introduce a graph-based method to determine the opinions of Twitter users regarding political parties and their exponents during the 2014 European elections for a period of three months. This classification is carried out by an analysis of the text of the tweets. In particular, it is based on the extraction and analysis of significant hashtags that represent the names of politicians and parties. Thus, an analysis of users' opinions is provided and discussed. It reveals that the positive sentiment of the users towards the leaders is higher than that towards the party. The study shows the potential of Twitter in revealing the opinions and feelings of users in different social and political contexts.

5) Combined approaches

These methods describe combined approaches which include different characteristics of the previous categories. Also, two works are presented, which are specifically designed for the commercial context.

In particular, Bloehdorn and Hotho [17] extend the traditional term stem-based approach for the representation and classification of documents. The basic knowledge is modeled as an ontology and the terms extracted from this ontology are integrated into the term stem representation. Classification is performed using boosting techniques, in particular the AdaBoost algorithm. The experiment is conducted on three datasets: Reuters-21578, OHSUMED and FAODOC. The obtained results show an improvement in the classification performance at the lexical and conceptual level when the semantic features are added to the traditional representation of the documents.

In contrast, Yang et al. [18] use the SVM to classify short documents whose feature representation combines the lexical and semantic contribution. Specifically, the method starts from learning a series of topics from a basic knowledge base. Thus, each word of the short text is associated with a given topic using a Gibbs sampling method. The mapping between words and topics is weighted based on the degree of consistency of the word with the given topic. At that point, each document is represented based on the mapped topics. The experiment consists in applying the method on the GoogleSnippet and Ohsumed datasets using Wikipedia as a base of knowledge. The results obtained by the experiment demonstrate the superiority of this document representation compared to other methods present in the literature.

An extension of the traditional Naive Bayes classification method is proposed by Jing et al. [19] which include semantic information for the classification of

documents. In particular, semantic features are extracted from each document using a log-bilinear document modeling algorithm. In this way, every word is associated with a semantic vector. Subsequently, Principal Component Analysis (PCA) is applied to the semantic space of the word-generated vectors in order to select semantic features for the document. The model is learned from the semantic features of the documents in the training set. In testing, the semantic classifier incorporates the features of traditional Naive Bayes and the semantic features to perform the classification of documents. The results of an experiment carried out on 20 datasets News-groups and WebKB demonstrate the superiority of the new semantic classifier compared to the traditional one.

In the commercial context, Tang et al. [20] introduce a new approach to classify the level of feeling in product reviews. In particular, the authors propose a neural network model called User Product Neural Network (UPNN) that integrates to the semantic information of the text, also information about users who express the feeling, and about the products that are evaluated. The system receives as input the text of the document, the user who wrote it and the product that is described in the document. The vector space model is used to represent users and products, revealing patterns on user preferences and product quality. The output of the system corresponds to a label that indicates the polarity of the sentiment associated with the document. The results of the experiment conducted on 3 datasets of product review documents show that UPNN achieves better performance than its competitors in sentiment analysis.

Also, Dave et al. [21] present an approach to classify product reviews based on opinion (positive, negative). In the first phase, training and test data sets are constructed from structured revisions. Thus, a classifier is proposed that uses information retrieval methods to extract appropriate features and scoring methods to classify the review opinion as positive or negative. The results obtained by the proposed method are in some cases better than those obtained by traditional machine learning algorithms. Secondly, the classifier is used for categorizing review phrases from the web, a more complex scope due to noise and ambiguity.

B. Medical Document Classification

In the following, the methods for semantic document classification in the medical context are categorised according to the adopted classifier as: (1) methods based on statistics, (2) methods based on knowledge, (3) other methods.

1) Statistical methods

Statistical methods use deep learning (CNN and shallow networks), SVM and Naive Bayes classifiers for the text categorisation.

In the SVM context, Garla and Brandt [22] propose a method to improve the classification performance of clinical documents that exploits the domain knowledge contained in the Unified Medical Language System (UMLS). In particular, the identification and evaluation of the features is improved through new techniques of information theory that exploit the taxonomic modeling of UMLS. In addition, the authors introduce a measure of semantic similarity that maps the clinical document into a feature space in order to refine the classification by SVM. The experiment consists in evaluating the proposed method on the 2008 Integrating Informatics with Biology and the challenge of obesity Bedside (I2B2). The results show how the method is able to improve the performance of the best machine learning algorithms in the I2B2 2008 challenge in case they are extended with the same method, and of other machine learning methods for classification of clinical documents. Also, starting from the medical text, Niu et al. [23] propose an approach to classify the polarity of a clinical outcome. This polarity is expressed as positive, negative or neutral. In particular, classification is performed at the sentence level using an SVM. The authors use different representations of features for text modeling: unigrams, bigrams, change phrases, negatives and categories. Different combinations of features are experimented with the classifier and their performances are evaluated. The results obtained by the experiment show that a combination of linguistic and specific domain characteristics obtain the best performances in the recognition of the polarity of the medical text.

In the deep learning context, Yang et al. [24] introduce a multi-layer CNN-based system for the extraction of high-level semantic features from electronic medical records in order to automatically diagnose the patient's health status. This method is able to self-learn the semantic characteristics of interest directly from the text and carry out the automatic diagnosis. In particular, CNN is able to map the words of the document in a continuous space of vectors, in such a way that similar words from the semantic point of view (therefore with similar meaning) will be close in this space. This reduces the risk of semantic ambiguity and improves performance compared to the use of traditional knowledge bases. The method is tested on a dataset of 18'590 copies of real electronic medical records. The results of the experiment show that the system is able to obtain an accuracy and recall value of more than 95%. Also, Hughes et al. [25] introduce a semantic method based on CNN for the classification of portions of text at the level of sentences that considers the semantics derived from a corpus of medical texts. In particular, CNN is used to model the features of medical documents. Network training is performed considering a large corpus that includes a broad classification of health information. The proposed method is compared with three other methods of the state-of-the-art, i.e. Sentence Embeddings, Mean Word Embeddings and Word Embeddings with BoW. The results of the experiment show that the proposed method outperforms the other classification methods by a percentage of accuracy at least equal to 15%.

Combining CNN, SVM and shallow neural networks, Weng et al. [26] present a method to categorize clinical notes in medical sub-domains, such as pediatrics or neurology. In particular, the method uses an NLP pipeline based on machine learning techniques and generates classifiers of medical sub-domains according to the content of the clinical note. The pipeline, composed of a clinical system of NLP, the Clinical Text Analysis and

Knowledge Extraction System (cTAKES), the UMLS Metathesaurus, Semantic Network and the learning algorithms, is used for the generation of the features and the creation of the classification algorithms of the medical sub-domains in various data representations and learning algorithms. The experiment is conducted on two datasets of clinical notes from the Integrating Data for Analysis, Anonymization, and Sharing (iDASH) and the Massachusetts General Hospital (MGH). From the analysis of the obtained results, the proposed method achieves good categorization performance of the clinical notes in the medical sub-domains.

Abacha and Zweigenbaum [27] solve the Medical Entity Recognition (MER) problem using SVM and Conditional Random Fields (CRFs). MER consists in finding and delimiting sentences in the text that refer to medical entities, and in determining the semantic class of the found entities. In this regard, the authors consider three different approaches to solve this problem: (1) a purely semantic method, (2) a second approach that includes a first phase in which sentences composed of names are extracted, which are then classified with SVM in a second phase, and (3) a third approach using machine learning techniques based on CRFs to which the semantic method is then applied. The results of the experiment conducted on the corpus of clinical documents of the I2B2/VA2010 challenge show that hybrid approaches obtain the best performances compared to approaches where only machine learning techniques or knowledge-based methods are used.

Another method for semantic classification of medical texts (Medline repository) based on statistical techniques is proposed by Prakash G et al. [28]. This consists in determining the semantic representation for the medical abstracts present in Medline. The first phase consists of a refinement pre-processing of the abstract and NLP, removal of the stop words, classification of non-informative and informative terms from the medical point of view using a Naive Bayes-based approach. At the end, the semantic representation of the informative terms is given which is important for determining the metathesaurus concept for medical terms.

2) Knowledge-based methods

These works include rule-based classifiers.

In this context, Solt et al. [29] propose a context-aware rule-based method for the specific semantic categorization of the pathology from summaries of clinical discharges. Semantic labels are assigned to these documents, which correspond to say if a given disease is present, is not present, or is questionable in the document. The method begins with a pre-processing phase to remove misleading elements from the text. Therefore, from the text, segments of positive, negative or uncertain context are extracted. In the end, the semantic labeling of the document is assigned based on the result of a set of binary classifiers. The experiment is conducted on the I2B2 Obesity Challenge documents and reveals the superiority of the rule-based classifier compared to other machine learning methods in the case of limited training data and sparse semantic labels.

3) Other methods

Two works using Multiple Criteria Decision Analysis (MCDA) and clustering are described.

In particular, Lakiotaki et al. [30] introduce an approach to classify medical documents in: (1) professional (for experts), and (2) non-professional. Each document is represented as a vector of terms whose degree of importance in participating in the classification of the document is assessed by including MCDA. Term vectors are generated using the AMTEx method, a technique for indexing medical documents that is particularly suited to large collections of documents. The experiment consists in the categorization of a subset of the Medline documents, the main bibliographic database of the U.S. National Library of Medicine, and comparison with MetaMap Transfer and the MeSH method, respectively used for automatic classification of biomedical documents and indexing of documents through domain experts. The results obtained by the proposed method are superior in terms of compact and essential representation of the significant sentences extracted from the document and, consequently, in terms of the classification performance.

Also, Amato et al. [31] semantically categorize portions of medical records based on the level of security. Then, they use this categorization to classify other resources and select the appropriate security rules. First, the record text is segmented for the extraction of lexical items. At this stage, normalization follows, which brings variants of the same lexical expression in the same way. Thus, morpho-syntactic analysis is performed in order to extract categories of words. Finally, the relevant terms are selected based on the frequency of the terms and their distribution within the corpus. They are then grouped into synsets in order to find groups of terms with semantic affinity. This classification is used to highlight the resources present in the medical record to which the correct safety rules are associated based on its type and the actors involved. The system is very promising and useful for solving data security issues.

III. ADVANCEMENTS IN MEDICAL DOMAIN

In the previous section, different methods have been described for identification of the patient's health status and pathology from electronic medical records, and the polarity of clinical outcomes as positive, negative or neutral. It is worth noting that the proposed methods are based on rule-based strategies, CNN systems and other supervised classifiers, which are not possible to efficiently retrain as soon as new text data becomes available. This represents a clear limitation, since electronic medical records and clinical notes are often subjected to "on-the-fly" changes by the physicians according to the current patient's health status.

To overcome this limitation, new methods for real-time semantic classification of text fragments from electronic medical records and clinical notes are especially encouraged. The main idea consists in "online" semantic labeling of the text for identification of the patient's health status while the physician is taking note on the electronic medical record. In the starting phase, the

semantic labeling is carried out using the current text contextualised to the data of patient's history. Changing or adding new text by the physician can lead to real-time modification of the semantic labeling which can be shown as output of the procedure.

Design, testing and evaluation of the real-time method for semantic document classification will be the object of our future investigation.

IV. Conclusion

This paper surveyed on some relevant works introduced in recent years in the literature of semantic text and document classification. Approaches based on tree-kernels, which are also relevant in semantic document classification, are missing in this discussion since they deserve a wider description and analysis. They will be presented further in a dedicate location.

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Exploring Aspects of Polyglot High-Performance Virtual Machine GraalVM

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***Abstract* - Contemporary software often becomes vastly complex, and we are required to use a variety of technologies and different programming languages for its development. As interoperability between programming languages could cause high overhead resulting in a performance loss, it is important to examine how a current polyglot virtual machine with a compiler written in a high-level object-oriented language deals with it. OpenJDK's Project Metropolis presented the GraalVM, an open-source, high-performance polyglot virtual machine, mostly written in Java. This paper presents GraalVM's architecture and its features; furthermore, examining how it resolves common interoperability and performance problems. GraalVM makes software ecosystem productive when combining various programming languages, for example, Java, JavaScript, C/C++, Python, Ruby, R, and others. The vital part of GraalVM is the Graal compiler written in Java, which allows developers to maintain and optimize code faster, simpler, and more efficient, in comparison to traditional compilers in C/C++ languages. Graal can be used as a just-in-time (JIT) or as static, ahead-of-time (AOT) compiler. Graal is an aggressively optimizing compiler implementing common compiler optimizations, with emphasis on outstanding inlining and escape analysis algorithms. This paper compares Graal with some of the best-specialized competitors, and presents our results tested within an academic environment.**

Keywords – GraalVM; Graal; polyglot virtual machine; Java Virtual Machine; Java; programming languages; cross-language interoperability

I. INTRODUCTION

Process Virtual Machines (or Application Virtual Machines), designed to run as regular applications within an operating system (OS), provide a platform-independent programming environment and allow any compatible program execution, regardless of the platform, the OS, and the underlying hardware [1]. As high-level object-oriented programming (OOP) languages became more popular, new Virtual Machines (VMs) were implemented with an interpreter in order to deal with high-level abstraction from the details of the platform and OS. Many OOP implementations appeared using Process VMs; however, the popularity was enhanced with the rise of Java Virtual Machine (JVM) and .NET Framework's Common Language Runtime (CLR), which had the ability to automate important areas of program execution, such as memory management and garbage collection.

Nowadays, many different scripting and OOP languages are being used to create applications which run within VMs to solve various specific computing problems in a way to balance between simplicity and high performance. Moreover, in some cases we need to combine different languages to achieve an optimal solution for a given problem. We assembled a list of the most popular languages (Table I) which presents that no language overrules the others in popularity, and within the past years the difference between them decreased even more.

Cross-Language Interoperability [2] enables reuse of existing libraries in other languages but often requires additional steps, i.e., paying a high serialization cost. In that case program data needs to be marshaled and converted into an adequate format and communicated using some type of an interface. Afterward, it needs to be deserialized to use it in other languages, which comes with a performance cost.

Programming languages that are primarily used for high-performance purposes are being additionally specifically optimized to run in high-performance mode. However, that is most often not the case with the most popular general-purpose programming languages, which without such additions do not perform well in high-performance cases. Therefore, it is sometimes necessary to combine different languages in a cross-language interoperability manner to achieve the optimal results. When combining various languages, it is desired to use the same set of tools for configuration, debugging, and profiling to achieve interoperability, but at this moment that is rarely the case.

TABLE I. THE MOST POPULAR PROGRAMMING LANGUAGES[1][2] IN JANUARY 2019 [3][4]

Language	TIOBE Index	PYPL Index	IEEE Spectrum Ranking	Google Trends Average
Java	16.904%	21.42%	97.5	42
C	13.337%	6.31%*	96.7	11
Python	8.294%	25.95%	100	12
C++	8.158%	6.31%[a]	99.7	11
VB .NET	6.459%	1.13%	45.1	11
JavaScript	3.302%	8.26%	82.6	20
C#	3.284%	7.62%	89.4	12[b]
PHP	2.680%	7.37%	84.9	16
Objective-C	1.781%	3.15%	50.5	1
R	1.331%	4.04%	82.9	n/a

a. A shared percentage for both C and C++ programming languages
b. Search term as a word, not as a programming language (not available)

[1] TIOBE Index, https://www.tiobe.com/tiobe-index/

[2] Google Trends, https://trends.google.com/

For the purpose of this research, we tested the performance of the current JVM and associated compilers, and compared it with GraalVM[3], a contemporary virtual machine with polyglot programming capabilities. In addition, we added a set of tests to determine the polyglot abilities of GraalVM, and presented architecture and different aspects of GraalVM, as well as preliminary results of conducted tests on induced features.

A. About GraalVM

One of the projects to circumvent the problems mentioned above and support wider and better cross-language interoperability on the JVM is OpenJDK's Graal Project[4], which evolved out of the Maxine VM project [5], featured as the next-generation modular architecture platform written in Java, compatible with modern Java IDEs and standard JDK [6].

As a part of the project, GraalVM was introduced, presenting a high-performance universal polyglot virtual machine that is able to run different programming languages with a minimal loss in performance. GraalVM enables usage of other programming languages with almost zero overhead interoperability when using external libraries.

GraalVM works efficiently with polyglot applications, thus allowing developers to choose the most appropriate language to deal with the problem without having to compromise performance [7]. GraalVM is designed to execute programs within the JVM using a Just-In-Time (JIT) compiler, but also using Ahead-Of-Time (AOT) compilation for creating native images or embedded into both managed and native applications. Polyglot capabilities can be extended by embedding GraalVM into different runtime platforms, for example, relational databases which can directly use programming languages.

Languages that GraalVM currently supports include:

- JVM-based languages – Java, Scala, Kotlin, Groovy, Clojure
- Interpreted languages – JavaScript, Python, R, Ruby
- Native languages – C, C++, Rust, Swift, Fortran

GraalVM is an open source project, mostly written in Java and supported by Oracle and its affiliates. The most important components of the GraalVM project are the Just-In-Time (JIT) compiler, also named Graal, and a framework used for implementation of other programming languages named Truffle.

II. GraalVM Architecture

A. Graal Project background

Graal compiler from the OpenJDK Graal project started in 2012, as a part of the Maxine VM project, with a goal to create an advanced compiler in high-level OOP language, in this case, Java [8]. A starting concept was to design a dynamic compiler that produces high-quality code, simplifies development, and lowers the abstraction when using low-level languages, without compromising on compile times and memory usage. Future development was reassigned as Project Metropolis[5], which objective is to present advanced Java-On-Java implementation techniques for the HotSpot VM replacement.

B. The Java HotSpot™ Virtual Machine

The Java HotSpot VM is an implementation of the JVM, originally developed by Sun Microsystems, later acquired by Oracle, which became default JVM in Java 1.3. It is a high-performance VM that connects to the lowest stack of GraalVM architecture (Fig. 1); however, by itself, it can be used only for languages that target the JVM itself. This VM was designed in a way to seek frequently executed methods or "hot spots" in the code for JIT compiling optimization.

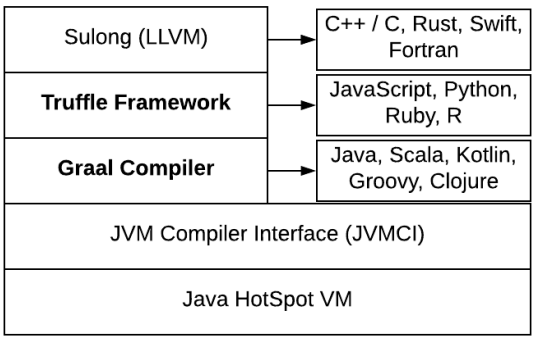

Figure 1. GraalVM Architecture

The HotSpot VM contains two JIT compilers which both compile bytecode to optimized machine code [9]:

- The server compiler also called *opto* or C2
- The client compiler also called C1

The server compiler creates highly optimized compiled code, mostly intended for long-running server applications since it uses a bottom-up tree rewriting component and a program dependence graph. The client compiler is based on a control flow graph so it can quickly generate compiled code and is mostly a better fit for desktop applications. C1 is tuned for quick loading and makes use of interpretation, as, on the other hand, C2 has slower loading with more precise and better optimizations which result in higher performance [9]. In addition, HotSpot VM uses two different interpreters, the C++ interpreter and the template interpreter, and contains memory management that performs garbage collection.

C. JVM Compiler Interface

The JVM Compiler Interface[6] (JVMCI) allows to implement a custom optimizing JIT compiler written in Java, which can be used in JVM as a dynamic compiler. In GraalVM architecture it is placed above the Hotspot VM (Fig. 1) and connected to the Graal compiler. JVMCI provides the possibility to use a compiler written in Java,

[3] GraalVM, https://www.graalvm.org/
[4] Graal Project, http://openjdk.java.net/projects/graal/
[5] Project Metropolis, https://openjdk.java.net/projects/metropolis/
[6] JEP 243: Java-Level JVM Compiler Interface, http://openjdk.java.net/jeps/243

which is easier to manage and improve than existing compilers written in C or C++.

D. Graal, the JIT compiler

An important part of GraalVM is Graal, a high-performance compiler, mainly used for JIT compilation, but also static, AOT compiler. As GraalVM has a modular architecture, a compiler is separated from VM, and Graal replaces C1 and C2 compilers used in HotSpot. This architecture provides the ability to reuse all VM components that don't interfere with compilation process, such as an interpreter, GC, Java Native Interface (JNI), class loading, and others [9].

Since compilation is a complex process, within GraalVM it is separated into two parts (Fig. 2), first of which is a source-specific, where most high-level optimizations are performed. This part includes a front end and platform-independent optimization phase named Graal Intermediate Representation (Graal IR). The second, target-specific part represented as Back End, is responsible for the translation of high-level Graal IR into low-level IR (LIR).

The front end is in control for turning Source representation as bytecode into Graal IR, using Truffle framework or Graphbuilder. Graphbuilder parses an array of bytes as JVM bytecode into a Graal graph and combines profiling feedback from interpreter [9]. On the other hand, if we are using Truffle framework [10], Graal recognizes this and aggressively optimizes its interpreter, allowing us to develop runtime for different programming languages.

After bytecode is interpreted into high–level intermediate representation Graal IR, the optimization process can begin. This is the generic part of compilation where all, platform-independent optimizations are performed. Graal IR is a complex hybrid structure which controls flow and data dependencies, which consists of two directed acyclic graphs and splits it optimization process into three tiers: High Tier, Mid Tier, and Low Tier. Tiers are deconstructed into independent phases, and at the end of each tier, a preparation named lowering phase deconstructs operations, preparing them for the next tier.

High Tier focuses on high-level optimizations, where common compiler optimizations are used, but the emphasis is on Graal's outstanding method inlining and partial escape analysis. Graal performs Late Inlining by parsing methods independently and combining them in a later compilation process. Thus, it is possible to cache the results of bytecode parsing to make better inlining decisions. Partial escape analysis verifies if an allocated object can be used outside of allocating thread or method. The object is being allocated on current thread's stack, or directly pushed to registers in order to avoid allocation [11]. Mid Tier mainly deals with memory optimizations, and Low Tier does the final clean up, small optimizations, and graph preparation for low-level representation conversion [9].

Finally, Back End, which deals with the translation of Graal IR into LIR, performs register allocation and forwards byte-code instructions to the processor.

E. The Truffle Language Implementation Framework

Developing an interpreter for a programming language should be more efficient than creating a high-performance compiler from scratch. Truffle [7] is an open-source framework for creating self-optimizing interpreters, for implementation of programming languages. Truffle uses an abstract syntax tree (AST) concept to implement a specific version of an interpreter by modifying it during the interpretation process to incorporate type feedback. This is achieved by using information of a guest programming language and a given program [12].

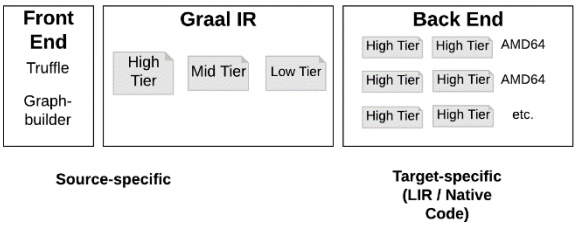

Figure 2. Compilation Process within GraalVM

As data is running through the program, several techniques could be used for optimization by specialization, such as inlining and constant folding. Graal incorporates logic for different types of optimizations, which are bundled in the Partial Evaluation technique; thus, Truffle uses Graal to create a Partial Evaluator.

The optimization process (Fig. 3) presents AST interpreter as the starting point of Truffle, by itself a technique that isn't sufficiently optimized. In the beginning, AST interpreter is populated by uninitialized nodes ("U"). When executed, uninitialized nodes are replaced by type-specific nodes, such as for Integer ("I"), Double ("D"), or String ("S"). These nodes are a specialized thread-safe replacement dynamically optimized by Truffle.

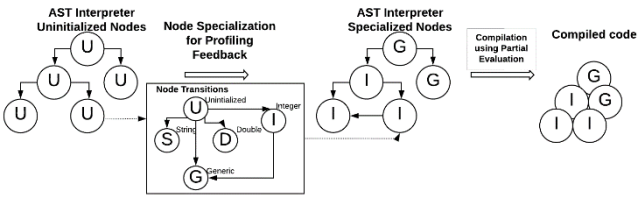

Figure 3. Truffle Optimization Process

Each specialized node has its guard for verification of the validity of the specialization node on each execution. If a guard recognizes node specialization as a failure, then that node will be replaced with a generic version ("G"), which can resolve any possible case, but only a few replacements are allowed for each node. Node Transitions inset could end with completely generic implementation if needed. When nodes in AST are stabilized, Graal compiles the interpreter using partial evaluation and dynamically optimizes it, which produces highly specialized machine code, noted as "Compiled code" [12].

Another possible event is dynamic deoptimization which is triggered by guard failure in optimized machine

[7] The Truffle Language Implementation Framework, https://github.com/oracle/graal/tree/master/truffle

code. Compiled code is transferred back to AST Interpreter and speculatively optimized more aggressively, i.e., recompiled using partial evaluation.

At runtime, using Truffle, same interoperability protocols are being used by all interpreters. In addition, Truffle virtualizes languages implementation, and this means that from Truffle's perspective there is no significant difference between languages. Therefore, ultimately, all runtime-based tools such as debuggers, profilers, and dynamic analyzers, can be used as polyglot.

F. Native images and Substrate VM

GraalVM allows Ahead-Of-Time (AOT) compilation of applications to native images. Substrate VM[8] (SVM) is an embeddable VM with integrated native development tools, written in Java and optimized to execute Truffle compatible languages. It has features any VM would have but precompiled by Graal. Java application is being precompiled together with SVM, resulting in a native image of an entire application. Internally, this is a binary that has VM packaged together with the Java program. Usage of native images can have significant performance benefits in certain situations, when JVM is not required to run, load, and initialize classes, resulting in a fast startup and low footprint. Such executables do not express with peak performance, but a fast startup and low runtime overhead could make a significant difference in a contemporary cloud or serverless production environment.

G. Embeddable

GraalVM extends its polyglot capabilities by being able to embed itself into different runtime platforms. Taken as a binary, GraalVM can be put into a Java VM, as standalone or embedded into a database. Possible implementations include MySQL and Oracle databases, Apache Spark, NGINX, and others. For example, in an experimental build of Oracle database, GraalVM runtime was integrated [13], which resulted in much simpler business logic, by enabling users to call a JavaScript function directly from SQL query directly. The advantages of embeddability introduce the ability to push business logic straight into the database by skipping intermediate steps. In addition, programming languages, modules, and libraries of a software ecosystem that user may work with are supported and can be in further development of applications.

III. THE BENCHMARK AND THE RESULTS

A. The Benchmark

The DaCapo benchmark suite [9] is a tool for Java benchmarking mainly created for performance analysis of JVMs, including compiler and memory management analysis. The benchmark suite consists of open source real-world benchmark application in order to showcase an environment similar to production. As a reference guide for comparison we used a study on Java Benchmarks [14], and research on GC performance has been taken into consideration when choosing viable benchmarking tests [15]. We used a set of benchmark tests from DaCapo suite version 9.12-MR1-bach to get a wider spectrum of results.

The benchmark cases used in testing are the following:

- *h2* – execution of JDBC like in-memory benchmark, by running a large number of transactions on a banking application model
- *lusearch-fix – an* application that indexes works of Shakespeare and the King James Bible by using *lucene*
- *xalan* – an application that transforms XML documents into HTML documents
- *pmd* – an application that analyzes a number of Java classes for a range of source code problems
- *sunflow* – an application that renders a set of images using ray tracing
- *jython* – an application that interprets the *pybench* Python benchmark

Since DaCapo suite's system automatically detects a steady state where results vary with a much smaller deviation, tests need to be run in a number of iterations *N*, and benchmark takes *N*-1 iterations as a warmup, with final iteration being used as the most credible. In the same manner, a certain number of warmups is needed for the JIT compilation and GC mechanism to stabilize.

B. Testing environment configuration

Our environment configuration consists of OpenJDK 64-Bit Server VM build 11.0.2+9-Debian-3 mixed mode with same Javac version, OpenJDK 64-Bit Server VM build 10.0.2+13-Debian-1 mixed mode with same Javac version, and for GraalVM we used GraalVM Enterprise Edition (EE), GraalVM 1.0.0-rc11 build 25.192-b12-jvmci-0.53, mixed mode with Open JDK version 1.8.0_192, and GraalVM Community Edition (CE), GraalVM 1.0.0-rc11 build 25.192-b12-jvmci-0.53 mixed mode with Open JDK version 1.8.0_192. OS we were using as test environment is Linux Kali 4.17.0-kali1-amd x86_64 GNU/Linux. We have complied with GraalVM's instructions to install both CE and EE version of GraalVM, to investigate possible differences. Every benchmark application was run by GNOME Terminal version 3.28.2.

TABLE II. TEST RESULTS FOR SELECTED DACAPO BENCHMARKS WITHIN GRAAL EE, GRAAL CE, JDK 10, AND JDK 11 ENVIRONMENTS WITH TIME (IN MILLISECONDS)

Benchmarks	Graal EE	Graal CE	JDK 10	JDK 11
h2 avg	4494.95	5327.10	10821.85	9550.05
h2 stdev	613.18	336,18	618.49	515.68
lusearch avg	2683.40	2757.10	2874.50	2886.15
lusearch stdev	223.60	378.66	264.96	203.40
xalan avg	863.32	277.41	870.72	232.51
xalan stdev	863.32	277.40	870.72	232.51
pmd avg	138.23	194.61	201.95	276.76
pmd stdev	138.29	194.61	201.94	276.70
sunflow avg	5062.05	5626.25	5417.25	6151.25
sunflow stdev	630.12	536.45	274.53	307.89
jython avg	6652.86	7038.34	6433.60	6672.10
jython stdev	2325.62	2095.47	2159.1	1667.34

[8] Substrate VM, https://github.com/oracle/graal/tree/master/substratevm

[9] DaCapo Benchmarks, http://dacapobench.org/

C. Test cases

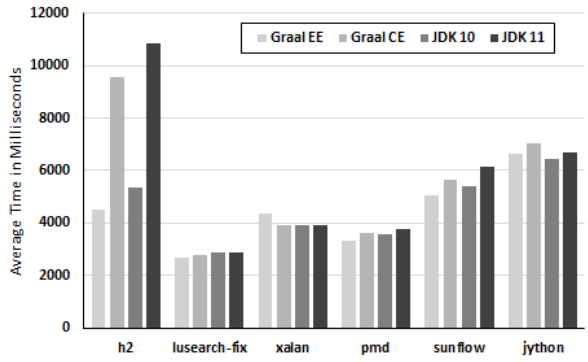

Figure 4. Preliminary average test results for selected DaCapo benchmarks on Graal EE, Graal CE, JDK 10, and JDK 11

Preliminary test results reported in Table II present stable runs with average and standard deviation test time expressed in milliseconds. All benchmarks have been warmed up before taking precise measurement since it takes time for benchmark and JIT compiler to stabilize caches. Therefore, we have mostly recorded the best performance that resulted in our environment, defined by the lowest time in milliseconds it took the test program to run. Each benchmark was performed in 30 iterations, and several initial runs were ignored, and this was repeated 4 times. The test included environments Graal EE, Graal CE, JDK 10, and JDK 11, with their respected version mentioned in the previous section. Due to limited resources in our academic environment, our preliminary results represent a smaller number of iterations tested on limited computing power.

D. Preliminary Results and Discussion

Within our test environments, preliminary results describe the following. As presented in Fig. 4, Graal EE performs the best in 4 out of 6 cases. In *xalan* and *jython* benchmark tests are the only ones where Graal EE doesn't have the best results, but it is by a small difference compared to JDK 10 benchmark result. In benchmark *xalan* JDK 10 performs 11.17% better, and in benchmark *jython* 3.4% better. On the other hand in benchmark *h2*, GraalVM is better by as much as 19.8%.

On the other hand, it is interesting how Graal CE behaves in a given environment, mostly similar to JDK 11, but particularly in *h2* benchmark test as they both result with much higher values compared to Graal EE and JDK 10, for example Graal EE completes *h2* benchmark in 47.06% faster than Graal CE. In addition, Graal EE performs the worst in *xalan* application test; however, Graal CE performs similarly to JDK 10 and JDK 11.

Considering standard deviation, Graal CE turned out to be more consistent than Graal EE and JDK 10, but the outcome from JDK 11 presents it as being the most stable. Correspondingly to our premise from the previous section Graal CE and JDK 11 perform in a similar manner. An interesting result is that in *pmd* application test both Graal CE and EE performed significantly better than JDKs. In total, JDK 11 is the most stable version with Graal CE following closely.

As our results present, using GraalVM has many advantages. In 4 out of 6 tests in which GraalVM outperforms the competition we found a similar software architectural pattern, and it is important to understand how this affects our results.

Benchmark tests *h2*, *sunflow*, and *pmd* are all multithreaded applications where our results are similar, with Graal EE being the fastest, JDK 10 and Graal CE following closely, and JDK 11 being the last. In addition, multithreaded application result within *lusearch-fix* and *xalan*, at least one of GraalVM versions is better than standard JDK. On the contrary, *jython* test as a single thread application shows the best result with JDK 10.

In addition to benchmark testing, we have also compared Graal's polyglot performance within our environment, and the preliminary results were successful. Our tests mainly include test examples conducted by the GraalVM team, such as running simple applications in different programming languages to test Graal's interoperability features. A particular example was using Java's BigInteger objects in JavaScript, and JavaScript's regular expression used in Python string matching. We have experimented with these examples in different configurations, and it worked as expected without larger wait times or any errors.

IV. Future Work

Our initial research was of a simpler scope covering basic functionality and features of GraalVM. Our preliminary test results were conducted in a limited environment thus we plan to continue this research with experiments conducted on a much larger scale. An interesting part of this project are additions in the form of stochastic performance optimizations named Genetic Improvement (GI), which could be further investigated. Additionally, our research in the current state could be extended more to cover the detailed process in creating native images and embedding process.

V. Conclusion

With the current version of GraalVM, without any additional configuration and tuning, in comparison to standard JDK, both Graal CE and Graal EE versions proved to be better in most cases. Tests in which GraalVM performed slightly worse as standard JDK can be mostly disregarded since the difference is negligible and, at this point in time, without discovering the cause. This indicates that with the next version of GraalVM we can expect further optimizations and presumably even better results. With GraalVM being recently deployed it means that it works better with modernized syntax and algorithms; thus, using contemporary software practices our performance results could be even better. Considering the size of this project and all additional features it provides we can say that performance wise, GraalVM executes praiseworthy.

GraalVM's polyglot features show interesting promises for future usage and development, furthermore, providing the Cross-Language Interoperability support for polyglot programming in many supported languages. Thus, for example, a project could be written in several programming languages without any performance overhead allowing

computing problems to be solved in the best-specialized language.

We believe the most prominent features of GraalVM project are native images and embeddability options. As contemporary software includes the use of databases, cloud and serverless services, these features could become imperative in the future of development.

GraalVM is still in development, but we have promising results with various tests and with features that work as defined, and as such we have optimistic expectation in the next few years of development.

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Analysis of Garbage Collection Algorithms and Memory Management in Java

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***Abstract* – Significant elements of the Java Virtual Machine (JVM), as a part of the Java Platform, Standard Edition (Java SE), crucial for automatic memory management are various Garbage Collection (GC) algorithms. Since implementation of the Java Development Kit (JDK) is continuously being improved, it is difficult to ignore several new Java Enhancement Proposals (JEPs) correlated to memory management in JVM. Several different garbage collectors are implemented in addition to the existing aged Serial, Parallel, and Concurrent Mark & Sweep (CMS) GC algorithms, as well as newer Garbage-First (G1) GC. The major progress since JDK 10 is making Parallel Full GC for G1, as a default multi-threaded GC when performing collections on an entire heap. Redundant overheads could appear when GC algorithms perform garbage collection too frequently, or a too large amount of memory could be allocated when garbage is not collected regularly. The goal of new algorithms' features is optimizing the overall process of releasing space so that pause times do not affect applications' performances negatively. This paper explores several garbage collectors available in JDK 11 by using selected benchmarking applications of the DaCapo suite for comparison of the number of algorithms' iterations and the duration of the collection time.**

Keywords* – *Garbage Collector; Garbage Collection Algorithm; Memory Management; Java; G1; Garbage-First; DaCapo suite; Parallel Full GC for G1

I. INTRODUCTION

Memory management, the process which regulates the allocation and release of the memory for every application, should be optimized for a specific case to run efficiently. In lower-level programming languages, e.g., C or C++ languages, memory is managed explicitly by a developer, which might consequently lead to an application more prone to errors. In contrast, the main reason how some high-level object-oriented programming (OOP) languages, such as Java, differ from those, is the capability of performing the automatic reclamation and management of memory. The important component of an abstract computing machine with execution environment for other applications, such as Process Virtual Machine, is the process of automatic memory management, achieved through garbage collection algorithms.

The primary principles of automatic memory management system within Java Virtual Machine (JVM), the embedded part of Java Runtime Environment (JRE), are provisioning and recovery of the necessary memory from objects which are no longer being referenced in the run-time memory area called the heap.

In modern software development, automatic tuning of memory release is preferred in contrast to manual handling rearrangement of memory, as it helps to decide which parts of the heap space, where created objects reside, is available for use. Instead of relying on the developer's expertise with the deep understanding of run-time data areas' architectures, garbage collection algorithms and other internal optimization of JVM's instructions [1], have been embedded as part of both runtime environment and JVM.

A. Heap Memory

The heap memory, a specific part of memory which is created on JVM's start-up is used for allocating memory to all class instances and arrays. Also, all JVM threads are able to access the objects stored at the heap and perform allocations until there is enough space. Apart from the heap, as presented in Figure 1, another important element of JVM contributes to memory management, JIT compilation controls the running application by tracing information and allows making decisions based on it with the goal of optimization of the memory [2].

B. Garbage Collection

The component of JVM responsible for automatic process of managing the memory is oftentimes referred to as garbage collection. Garbage, the heap memory that is no longer in use by the application, is recovered and reused by performing the Mark and Sweep algorithm, which is the underlying principle of garbage collection algorithms. In its simplest form, this algorithm stops all running program threads, and examines all live objects, which have a reference in any stack's frame of any application thread. Afterward, it searches through the reference tree of used objects and marks any object found as live. Every object left is considered garbage and is ready to be collected (swept) [3].

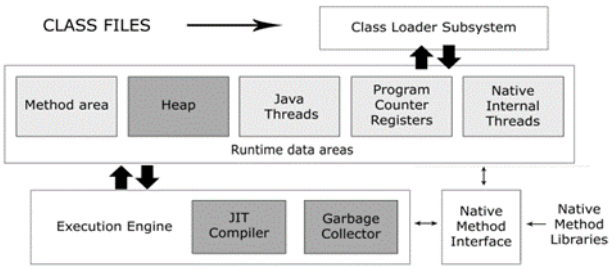

Figure 1. Crucial components of Java Virtual Machine related to memory management

A garbage collector is responsible for several tasks [4], including:

- Allocating from and giving back memory to the operating system
- Handing out that memory to the application as it requests it and determining which parts are still in use by the application
- Reclaiming the unused memory for reuse by the application

The essence of Java's garbage collection is that the runtime keeps track of objects and automatically destroys those which are no longer needed [2]. However, garbage collectors do not solve all problems related to automatic memory management. For instance, an application may continue keeping unnecessary references or new objects could be continuously allocated, and consequently out of memory error might be encountered.

Automated reclamation comes with the performance cost, which can be significantly enlarged when running applications that might require more computational resources [5]. Therefore, there is a need for the improvement of the garbage collection algorithms which allow the applications' runtimes to be optimized in a way that they are rarely interrupted by the garbage collection process [3]. Therefore, new enhancements are proposed in order to move closer to the accomplishment of this goal.

II. GARBAGE COLLECTORS (GCS)

There are many garbage collectors (GCs) that we can use in the JVM, ranging from the most commonly used older GCs, including Serial GC, Parallel and Parallel Old GC, Concurrent Mark and Sweep (CMS) GC, and Garbage-First (G1) GC, up to the latest experimental ones like Z Garbage Collector (ZGC) and Shenandoah GC.

The Parallel Old GC was the default garbage collector in JDK 7 and JDK 8 before it was substituted with G1 GC in JDK 9. The G1 GC has been improved since its official introduction and upgraded with new Parallel Full G1 GC, default in JDK 10 and onwards. Additionally, JDK 11 introduced an experimental GC named Epsilon GC, mostly for testing purposes. Moreover, the Java Zing VM's default garbage collector algorithm is upgraded Azul's C4 (Continuously Concurrent Compacting Collector) GC.

A. Current Java Garbage Collectors

Serial, Parallel, and Parallel Old GCs are all implemented as full Stop-The-World (STW) collectors, and take advantage of the Weak Generational Hypothesis, claiming that the vast majority of objects are short-lived, and others have longer life expectancy [2].

Following this hypothesis, the heap is divided into three generations: young, old, and permanent. Objects are first allocated in the young generation, and when more memory is required for the new objects, minor garbage collection is performed. Memory that is no longer used is discarded, and live objects are moved from the young generation to the old generation. Since objects are eventually moved, at some point of time it is necessary to collect garbage on the whole heap, and thus, perform full garbage collection, which might require more computational resources.

On the contrary, due to the scanning of unused objects without stopping the application running threads, the CMS and G1 GC are known as concurrent low-pause collectors. Moreover, both are able to perform full collection but occasionally tend to avoid it [6]. The application experiences fewer pauses because the duration of phases in which application threads are stopped is decreased compared to the STW GCs. G1 GC's heap is based upon the set of regions, unlike the Parallel or CMS GCs with a generational heap. Since JDK 9, the CMS GC has been deprecated, and G1 GC has become the default.

1) Parallel Full Garbage-First (PFG1) GC

In Garbage-First GC, both young and old generations are sets of regions, and most garbage collection operations can be performed per region at a time, rather than on the entire heap or an entire generation. Also, there is no need to decide which regions will be part of young or old generation in advance; thus, it is possible that, after a young generation collection, a whole region becomes a part of an old generation and vice versa [7]. Although some GCs have a generational design and finish collection relatively fast on a small portion of the heap, they inevitably have to enter a full collection at some point in time to collect the whole heap space and thus are subjected to considerable pause times.

Full garbage collection uses a compaction-based algorithm that copies all live objects into the beginning of the old space to vacate a vast continuous free memory area. Specifically, Parallel Scavenge GC (PSGC), which is compatible with Parallel Old GC, implements full GC algorithm that partitions the heap into regions which represent tasks assigned to multiple GC threads for further concurrent processing. To understand the primary principles of the full collection algorithm, PSGC's implementation might be separated in three phases [8]:

- Mark phase – GC's threads search for live objects, for instance, on-stack references or static variables from known roots which are marked as alive and their locations are recorded for later use
- Summary phase – PSGC calculates a heap summary for all live objects based on the pre-generated records, divides the heap into continuous regions of equal size (default 512KB) and summarizes objects within the same region
- Compacting phase – GC threads concurrently fetch destination regions and fill them with found live objects in corresponding source regions

Sometimes, G1 GC is unable to find a free region when trying to copy live objects from a young region or during evacuation from an old region. At such times, the collector will try to increase its usage of the heap, and if the expansion of the space is not successful, G1 will trigger its "fail-safe" mechanism in which a single thread marks, sweeps and compacts all regions constituting heap generations [7].

Since JDK 10, there have been some improvements regarding the worst-case latencies of G1 GC resulting in

development of Parallel Full GC for G1 GC[1]. The major improvement is a multi-threaded parallel mark-sweep-compact algorithm which should use the same number of threads as the young and mixed collections while performing full garbage collection.

B. Experimental and Other Garbage Collectors

In the last few years, several experimental GCs were introduced, but most of them are still under development and used only for special purposes or within a specific environment.

Epsilon GC [2] was presented with the latest JDK 11, as a garbage collector that handles memory allocations without performing any actual memory reclamation. The goal of this approach is not to introduce manual memory management features to the JVM or new heap management API, but to use it as a reference point for other GCs comparisons, when performing performance analysis for other GCs, memory or VM testing, or for last-drop latency and throughput improvements. It is a passive GC implementation with a bounded allocation limit and the low latency overhead, at the expense of memory footprint and throughput. In a way, Epsilon is not a "real" GC and is designed for testing purposes or special cases only.

As a part of their Zing JVM, Azul Systems has also created a high-performance concurrent and parallel GC named C4 (Continuously Concurrent Compacting Collector) [9], which provides consistent and contained application response times by eliminating GC pauses, thus enabling Java applications to scale up easier. Zing uses concurrent compaction with a single 64-bit word object header. However, since C4 is not a part of an open-source project like OpenJDK, and not easily comparable in our test environment, we will not consider it in this analysis.

In this research paper, we will also discuss ZGC and Shenandoah GC, although both are still considered experimental and under development.

1) Z Garbage Collector

The ZGC [3] is an experimental scalable low-latency garbage collector available in JDK 11. At the moment of writing this paper, it is only available for 64-bit Linux, which is its main platform, but other platforms could be added later. It handles heaps ranging from relatively small to very large multi-terabyte sizes, and ZGC's pause times do not increase with a heap or live-set size. Therefore, the heap can vary from GBs to TBs, and that will not have a significant impact on pause times because STW phases are limited to root scanning, and its pause times should not exceed 10ms.

Compared to G1, ZGC is also region-based, but it has a flexible sizing scheme, and has a better way to deal with object allocations; there is no generational separation of the heap. The heap is internally divided into many small regions, and we can choose to compact subset of those, typically one that contains the most garbage.

Load barriers and colored pointers are two core techniques chosen for achieving concurrency in ZGC. Pointer coloring is a core method which stores metadata in unused bits of 64-bit pointers. Because there is not enough unused space in 32-bit pointers for using pointer coloring, 32-bit platforms are currently not able to support ZGC. Metadata holds information about the object itself or about the object that it points to, and currently, it stores marking and relocation related information. By storing metadata in a pointer, we can use a load barrier when an object reference has to be loaded from the heap, which is conceptually similar to the decoding of Compressed Oops (Ordinary Object Pointers). Once a reference is loaded, the load barrier will check if the metadata bits (i.e., the colors) are "good" or "bad," and make a decision. "Bad" color means that particular action should be performed, whether that is marking, relocating, or remapping (depending on the phase of GC), and "good" color indicates that there is no need to again load the object reference from the heap [10].

Colored-pointers allow reuse of the memory before reclaimed regions are fixed during the relocation-compaction phase, which helps to keep the general heap overhead down, and therefore, an additional separate mark-compact algorithm that should handle full collections does not have to be implemented. Also, only few simple GC barriers keep the runtime overhead down and enable easier implementation, optimization, and maintenance of the GC barrier code in interpreter and JIT compilers [3].

2) Shenandoah Garbage Collector

The main reason behind Red Hat's development of an experimental Shenandoah GC [4] was to reduce the pause times by performing concurrent compaction. Shenandoah GC [11] is an open-source region-based low-pause parallel and concurrent collector, similar to ZGC, which tempts to reduce pause times by evacuating objects (compacting) concurrently with running application threads. Although GC performance depends on the heap size, with the Shenandoah the pause times are independent of the size of the heap.

The concurrent compaction is a complex task, as with moving live objects, all references to that object have to be updated to point to the new location, and to find those references the entire heap must be scanned. The object layout for Shenandoah GC adds its word on every object's header, and it is allocated only when this collector is used. This enables moving the objects without updating all references of an object, but the thread which is copying the object performs an atomic compare and swap to have it point to the new address. All future readings or writings on this object will be done on a forwarded copy via the forwarding pointer. Similar to ZGC, Shenandoah's heap is

[1] JEP 307: Parallel Full GC for G1, http://openjdk.java.net/jeps/307

[2] JEP 318: Epsilon: A No-Op Garbage Collector (Experimental) https://openjdk.java.net/jeps/318

[3] JEP 333: ZGC: A Scalable Low-Latency Garbage Collector (Experimental), https://openjdk.java.net/jeps/333

[4] JEP 189: Shenandoah: A Low-Pause-Time Garbage Collector (Experimental), https://openjdk.java.net/jeps/189

partitioned in equal sized regions, and a region may keep newly allocated objects, long-lived objects, or a mix of both, and any subset of those regions might be collected during a GC cycle, similar to G1.

III. Benchmark and Preliminary Results

A. Benchmark Suite

Benchmark suites are practical research tools, indispensable when features' quality of systems is being tested, which report descriptive results to demonstrate the advantages within a new or improved system [12]. For the purpose of this research, we have chosen the DaCapo suite [5], which consists of a set of real-world Java applications for performance and memory management analysis, with non-trivial memory loads. In general case, open source DaCapo benchmarks are mostly larger, more complex, and richer than the commonly used SPEC Java benchmarks, thus ideal for scientific evaluations [13].

For exploring characteristics of new and experimental GCs available in JDK 11, we decided to use version 9.12-bach of DaCapo benchmark suite which has also been used when our previous preliminary research was conducted, and G1 GC was being compared to garbage collectors in JDK 9 [14]. The selected set of testing applications is similar to those which were used in prior testing and includes the following tests: *fop* (a single thread application which parses XSL-FO to generate PDF), *h2* (a multi-threaded in-memory database which executes JDBC by performing transactions against a banking model), *pmd* (an application that analyzes Java source code in multiple threads), *xalan* (transforms XML documents into HTML by using multiple threads), *sunflow* (a multi-threaded rendering system for realistic images using ray tracing), and *tradebeans* (derived Daytrader benchmark with multiple numbers of threads).

B. Test Environment

Our testing environment relies on Java HotSpot™ Client VM of build 25.201-b09, mixed mode as well as Java HotSpot 64-Bit Server VM 18.9 of build 11.0.2+7-LTS, mixed mode. Moreover, OpenJDK 64-Bit Server VM of build 12-ea+29, mixed mode and sharing was included. The hosting environment which provided the testing was Windows 10 Pro OS. Regarding memory reclamation, the JVM's choice for GC in JDK 8 was Parallel GC, whereas in JDK 11 the G1 GC was selected. Additionally, other garbage collection algorithms were tested, including CMS and Serial GC.

The results were gathered by using a graphical tool, Visual VM[6], version 1.4.2, as well as its Visual GC plugin, which enables the in-depth exploration of measurements of both the number of algorithms collections and the duration of each. We repeated each test scenario within three different versions of Java. Moreover, each case consisted of five independent application runtime iterations, and both the average duration and collection count was calculated. In addition, the live set size was determined within each runtime by setting the heap size of 1GB.

[5] DaCapo Benchmarks, http://dacapobench.org/
[6] Visual VM, https://visualvm.github.io/

C. Preliminary Results

Based on the generated traces, the metrics, i.e., the number of collections as well as the duration of executions, have been extracted for chosen test cases within JDK 8 and JDK 11, as well as the OpenJDK 12 Early-Access Build.

Even though G1 GC was expected to perform better in most benchmarks, that was not always the case, and G1's advantages have not been obviously presented in the preliminary results within JDK 8. However, with an in-depth exploration of gathered data, interesting enhancements in performances of G1 and Parallel GCs might be noticeable in newer versions of Java.

In JDK 8, G1's durations of collections are longer in contrast to Parallel GC for every application excluding *tradebeans* (Figure 2). When comparing these results to Serial GC, the number of collections (Figure 3) is more similar to Parallel GC's, whereas in most cases, the execution time differs as it is increased in comparison with both G1 and Parallel GC. Besides, for other chosen applications, except for *fop* and *h2*, the CMS collector performed more collections than the other collectors in a relatively longer period than G1 and Parallel GCs.

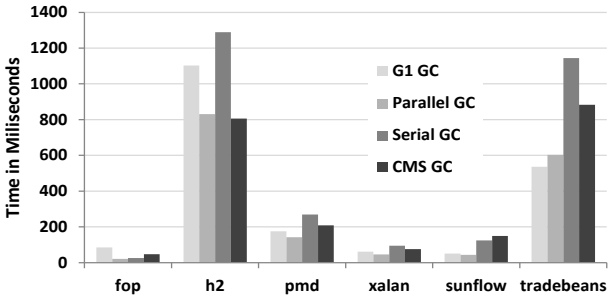

Figure 2. Comparison of durations (in milliseconds) of collections within JDK 8 for selected DaCapo benchmark applications

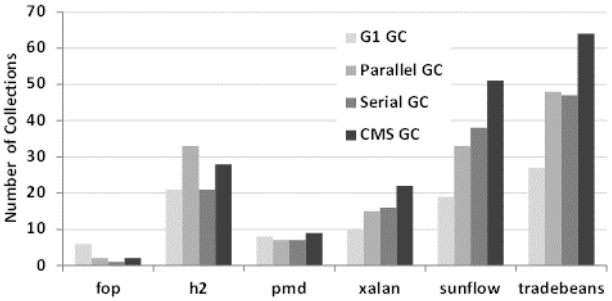

Figure 3. Comparison of number of collections within JDK 8 for selected DaCapo benchmark applications

After conducting the identical benchmark within JDK 11, the behavior of the mentioned algorithms has changed. The most interesting difference is visible in the total garbage collection time of G1's and Parallel GC's collections when G1 was faster, in fact, for *pmd* application even almost two times faster than Parallel GC (Figure 4), but in most cases Parallel GC did more collections than G1 (Figure 5). However, for the test case *h2*, the major decrease of G1's collection time within JDK 11 can be detected, i.e., new Parallel Full G1 performing similar number of collections as in JDK 8, but with recognizably reduced duration.

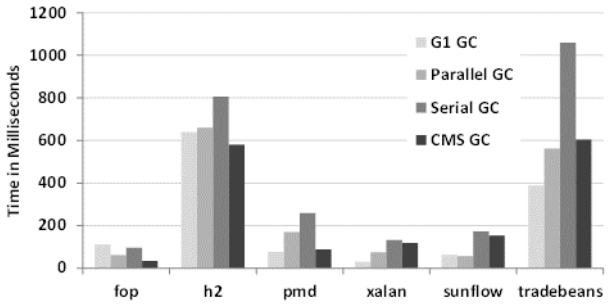

Figure 4. Comparison of durations (in milliseconds) of collections within JDK 11 for selected DaCapo benchmark applications

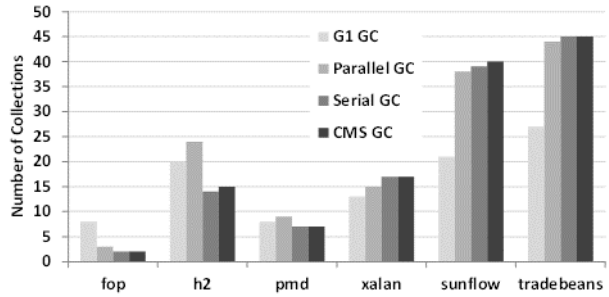

Figure 5. Comparison of number of collections within JDK 11 for selected DaCapo benchmark applications

Also, apart from G1 having outperformed Parallel GC in case of *pmd*, another interesting difference in G1's behavior can be noticed in case of *xalan* application compared to Parallel GC. G1 had 13.34% less collections, but in doubly decreased amount of time, whereas within JDK 8, the Parallel GC was certainly a better choice for *xalan*.

The observation in case of *fop* benchmark is that G1 performed more operations than Parallel GC as in all other cases, Parallel GC performed a greater number of collections, e.g., for *sunflow* application 44.74% more and as well for *tradebeans* that number is significantly increased. Furthermore, for *sunflow* benchmark, Parallel GC surpasses the G1 as it did almost two times more collections with slightly reduced execution time within JDK 8, and in JDK 11 both collections and the durations are proportional as well as increased for both collectors.

With the quite interesting outcome in case of *fop* where G1 has shown to be superior over other collectors as a result of enlarged collection count, another benchmark *luindex* was included as part of the testing because both *fop* and *luindex* are run by a single thread. *Luindex* is a single-threaded full-text searching library and has a low nursery survival rate (a measure of how closely a program follows the generational hypothesis). Moreover, it has a high heap turnover ratio which might suggest substantial GC workload [13]. However, only G1 was able to perform collections in such environment with positive outcome as, for instance, Parallel GC was able to perform 10 collections in approximately 130 milliseconds when excluding argument *–no-pre-iteration-gc*, which reported worse performance of Parallel GC compared to G1 GC due to G1's region-based heap architecture.

Although it might be concluded that G1 and Parallel GC are the main competitors for some test cases, there are also indicators that sometimes the best collector in terms of optimization is CMS GC, which is a rare case in our results. For example, in case of *xalan*, CMS is certainly the best choice, but with taking into consideration that it is deprecated, the Serial collector is the preferred choice for *xalan*, rather than G1 or Parallel GC. However, concerning an optimal amount of time spent, we consider G1 GC a better option in comparison with other collectors in this case. In contrast, with the exclusion of CMS, the best collector for *sunflow* is Parallel GC with the shortest execution time. It is important to mention that *sunflow* is one of the most allocation-intensive benchmarks, and might allocate up to 134 GB respectively.

The figures that demonstrate the behavior of garbage collectors within upcoming JDK 12 don't differ much from JDK 11. However, when taking a closer look, Parallel GC performed less operations in case of *pmd* in the shorter period than in JDK 11. Also, G1's total collection time was shorter in this case. An interesting difference might be seen as well as in CMS's and Serial's behavior when measuring the number of collections, which is similar to JDK 11, but the overall garbage collection time is almost doubly reduced for Serial, and remarkably increased when CMS was used to perform collection for *pmd*. As presented (Figure 6 and Figure 7), the overall time duration for G1 is significantly reduced since JDK 8. It is also clear to see that Parallel was a better option for *pmd* (Figure 8) until the release of Java 11 in which G1 has shown the better behavior than Parallel GC, although, within JDK 12, Parallel's execution time noticeably decreased. Similarly, with utilizing the algorithms on another benchmark, i.e., *tradebeans*, within all versions of Java, G1 performed in the best manner and it reduced total collection time since its first release.

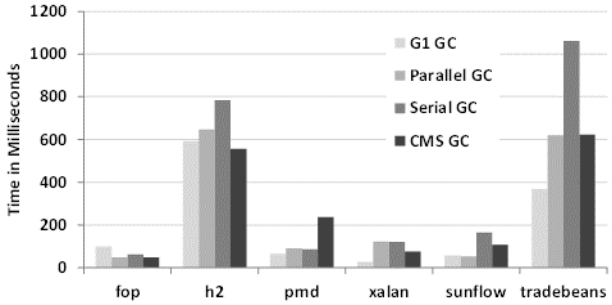

Figure 6. Comparison of durations (in milliseconds) of collections within JDK 12 for selected DaCapo benchmark applications

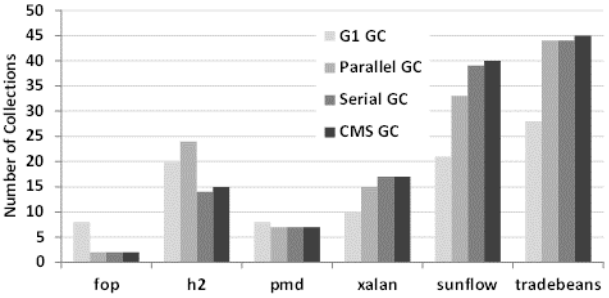

Figure 7. Comparison of number of collections within JDK 12 for selected DaCapo benchmark applications

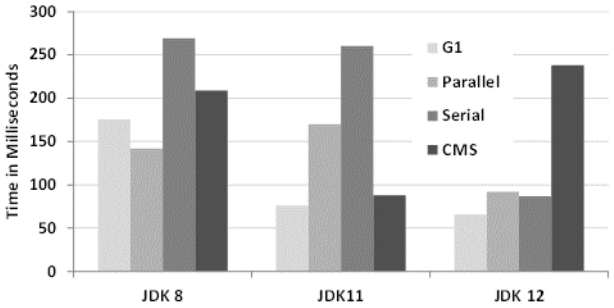

Figure 8. Total execution time for pmd benchmark

IV. DISCUSSION

Through Java's history, Garbage Collection Algorithms have been tediously reanalyzed for achieving an environment where GCs operate in an optimal manner. According to P. Lengauer, V. Bitto, H. Mössenböck and M. Weninger [12], the minor pause time of the G1 is only 71% of the pause time of the ParallelOld GC, e.g. the *h2* application's pause time is 300 ms with ParallelOld GC, and only 81ms with the G1 GC which is mostly due to the G1's ability to choose the regions which will be collected and, as a consequence, control pause times as well as number of regions in which memory will be released.

The performance of G1 and Parallel GC in JDK 8 and 11 has been tested on OptaPlanner benchmarks [15]. As Parallel GC is focused on throughput, whereas G1's main goal is low-latency, Parallel GC is still the better collector for OptaPlanner in terms of optimization according to the results. However, for almost every given data set, the average percentage of improvement of G1 in Java 11 is 16%, which can be supported with the newly introduced Parallel Full Garbage Collection with multiple threads.

Considering the fact that new experimental GC algorithms have been introduced within newer versions of Java, already existing collectors have also been compared to Shenandoah GC by running DaCapo benchmarks [11], and in 7 out of 11 test cases, G1's overall time duration was decreased or equal to Shenandoah GC. However, when measuring the performance of Shenandoah and other collectors, i.e., G1, Parallel and CMS GC, with a benchmark that stimulated a real customer application, Shenandoah had recognizably fewer GC pauses opposed to other algorithms.

V. CONCLUSION

Although there might be conditions, for instance, an application running with multiple or rather single thread, which might have an impact on algorithm performance, distinguishable changes might be seen in garbage collection algorithms' implementations. G1 has operated better or in an equal manner as Parallel GC in cases of *h2*, *pmd*, *xalan*, and *tradebeans* considering the overall duration of iterations in the latest Java release. However, CMS and Serial, have not introduced any convincing evidence that would prevent us from questioning its strongly held position over the past years, but they have not shown to be assuredly superior over G1 and Parallel GC. Therefore, with improved G1, it certainly represents a direction in which future GCs are heading to. We believe that the future experimental GCs will as well contribute to overall systems' optimizations. It will be worthy to explore the enhancements that will inevitably benefit those environments in which specified GC manages memory without any additional barriers which might decrement the productivity of an application.

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